ПОЛТАВСЬКИЙ УНІВЕРСИТЕТ ЕКОНОМІКИ І ТОРГІВЛІ

НАУКОВИЙ ВІСНИК

ПОЛТАВСЬКОГО УНІВЕРСИТЕТУ ЕКОНОМІКИ І ТОРГІВЛІ

Серія «Технічні науки»

Випуск 1, 2026

Видавничий дім
«Гельветика»
2026

Реєстрація суб'єкта у сфері друкованих медіа: Рішення Національної ради України з питань телебачення і радіомовлення № 1555 від 09.05.2024 року. Ідентифікатор медіа: R30-04059.

Суб'єкт у сфері друкованих медіа – Полтавський університет економіки і торгівлі (вул. Банка Івана, буд. 3, м. Полтава, 36003, can@puet.edu.ua, тел. (0532) 50-91-70; (0532) 50-02-22).

Періодичність – 3 рази на рік.

Затверджено відповідно до рішення вченої ради Полтавського університету економіки і торгівлі (від 29.04.2026 року протокол № 5)

Науковий вісник Полтавського університету економіки і торгівлі. Серія «Технічні науки» включено до переліку наукових фахових видань України в галузі технічних наук (категорія «Б») на підставі Наказу МОН України від 27 вересня 2021 року № 1017 (додаток 3)

Галузь науки: G – Інженерія, виробництво та будівництво.
Спеціальності: G13 – Харчові технології; G15 – Технології легкої промисловості; G2 – Технології захисту навколишнього середовища.

Збірник включений до міжнародних наукометричних баз даних: Index Copernicus, Google Scholar

Електронна сторінка видання: www.puet.poltava.ua/index.php/technical
DOI: 10.37734/2518-7171-2026-1

Статті у виданні перевірені на наявність плагіату за допомогою програмного забезпечення StrikePlagiarism.com від польської компанії Plagiat.pl.

ISSN 2518-7171 (print)

ЗМІСТ

ІННОВАЦІЙНІ ТЕХНОЛОГІЇ ХАРЧОВИХ ВИРОБНИЦТВ

НОВІ РЕСУРСО- ТА ЕНЕРГОЗБЕРІГАЮЧІ ТЕХНОЛОГІЇ ХАРЧОВИХ ВИРОБНИЦТВ І ТОРГІВЛІ

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ЯКІСТЬ І БЕЗПЕКА ПРОМИСЛОВИХ ТОВАРІВ, СТАНДАРТИЗАЦІЯ, МЕТРОЛОГІЯ, СЕРТИФІКАЦІЯ ТА УПРАВЛІННЯ ЯКІСТЮ

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UDC 664.642:664.641.12:582.635.4
DOI https://doi.org/10.37734/2518-7171-2026-1-2

STUDY OF THE INFLUENCE OF ADDITIVES OF NETTLE EXTRACTS ON THE PROCESSES OF FORMATION OF THE GLUTEN COMPLEX OF WHEAT DOUGH

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Abstract. *The aim of the article is a comprehensive study of the effect of additives of Urtica dioica L. extracts on the processes of gluten complex formation in wheat yeast dough to substantiate the feasibility of their use in the production technologies of functional bakery products with high nutritional value. The research was conducted on samples of wheat flour of the highest and first grades (GOST 46.004-99), as well as flour from dried leaves of dioecious nettle (Urtica dioica L.) harvested in 2025. The extraction was carried out at temperatures of 20, 30 and 40°C for 1-6 hours at a hydraulic ratio of 1:10. The degree of extraction was estimated by the mass fraction of solids in the solution. The rheological properties of gluten were studied by the indicators of extensibility, flowability and compressive strain (using the penetrometer AR-4/1). The sugar-forming capacity of the flour was determined by the amount of accumulated maltose, and the gas-forming capacity was determined using the Jago-Ostrowski device during 5 hours of fermentation. It was proved that the extracts of nettle have a complex technological effect on the gluten complex of wheat dough: the yield and rheological properties of gluten are increased, and the sugar and gas-forming capacity of flour is increased. These effects are due to the synergistic effect of the nettle protein complex, ascorbic acid and peroxidase enzyme, which inhibit proteolytic activity through the mechanism of oxidation of sulfhydryl groups with the formation of additional disulfide bonds. The results indicate the prospects of using aqueous, salt and water-alcohol extracts of nettle as natural improvers in the production of functional bakery products.*

Key words: *nettle (Urtica dioica L.), gluten complex, wheat dough, rheological properties, plant extracts, functional bakery products, gas formation, sugar formation, proteolysis, ascorbic acid.*

Formulation of the problem in general. Bread and bakery products remain the main element of the human diet, providing a significant share of the daily energy requirement. However, traditional technologies based on the use of refined wheat flour face serious criticism from nutritionists and the medical community. The high glycaemic index, deficiency of essential micronutrients, dietary fibre and inadequate amino acid composition of mass-produced bread are risk factors for metabolic disorders, obesity and type 2 diabetes.

The current stage of development of the food industry (2021-2026) is characterised by a transition from the concept of food security (quantity) to the concept of "food for health" (quality). According to analytical data, the market for functional baking ingredients is showing steady growth, which is projected to reach more than USD 3 billion by 2034 [1]. The main drivers of this process are consumer demand for products with a clean label, high protein and fibre content, and reduced salt and sugar content.

The relevance of the topic is enhanced by the need to implement the principles of the circular economy. The bakery industry has a unique potential for valorising food industry by-products (fruit pomace, oilseed meals, coffee sludge, etc.), turning them into valuable functional additives. This solves environmental problems and reduces the cost of production while increasing its nutritional value [2].

Understanding the mechanisms of dough structure formation is key to the successful implementation of any additives. Yeast dough is a complex colloidal system whose rheological properties are determined by the interaction of gluten proteins (gliadin and glutenin), starch grains, lipids and water.

The introduction of any gluten-free additive inevitably leads to a gluten dilution effect. This reduces the ability of the dough to retain the carbon dioxide released by the yeast and can lead to a reduction in bread volume and poorer porosity.

However, current research shows that the mechanism of interaction is more complex. Hydrophilic additives (fibre, hydrocolloids) compete with gluten proteins for water, changing the kinetics of hydration and dough formation [3]. Polyphenolic compounds present in plant extracts can interact with thiol groups (-SH) and disulfide bonds (-S-S-) of proteins, acting as oxidants, thereby changing the rheology of the dough towards strengthening or thinning [4].

When selecting additives, it is important to consider their effect on the activity of yeast and lactic acid bacteria (in the case of sourdoughs), which is significantly dependent on the availability of available sugars, amine nitrogen and pH of the medium [5]. Additives can both stimulate fermentation (sources of simple sugars, vitamins) and inhibit it (presence of antimicrobial components, essential oils). For example, a study using moringa leaf powder showed the need for pretreatment of raw materials to inactivate yeast growth inhibitors [6].

In addition to macronutrients, modern science focuses on enriching bread with polyphenols to give it antioxidant properties. For example, research has shown that grape seed proanthocyanidins (GSP) have a unique ability to modify the structure of starch. In combination with malic acid, they increase the orderliness of starch molecules but reduce its crystallinity. This leads to the inhibition of the enzymeβ -amylase in the human body, which slows down the breakdown of starch to glucose. In vitro experiments have shown a reduction in glucose release of up to 5.43%, making this bread a product with a low glycaemic index [7].

From the above analysis, it can be concluded that it is important to search for new additives of natural origin from plant materials that can comprehensively affect the quality of bakery products.

Analysis of recent research and publications. Nettle (Urtica dioica) can serve as a promising raw material for the creation of natural additives. Studies conducted by the team of authors confirm the status of nettle as a source of high-value nutrients. Researchers have identified a wide range of phenolic acids (chlorogenic, ferulic, caffeic), flavonoids (rutin, quercetin, kaempferol) and amino acids. Particular attention is drawn to the high content of magnesium, calcium, iron and zinc in bioavailable forms. The antioxidant activity of nettle extracts, assessed by DPPH and FRAP methods, correlates with the polyphenol content and demonstrates high stability even during processing [8].

An important aspect is the variation in composition depending on the part of the plant. While the leaves are a source of chlorophylls, vitamins (A, C, K) and minerals, nettle seeds are characterised by a high content of fatty acids (linoleic andα -linolenic) and specific phenolic compounds that affect the texture of products [9].

Nettle root, in turn, contains unique lectins (UDAs) that exhibit antiviral and antifungal activity, opening up prospects for the creation of specialised products to support the immune system [10].

The team of authors proved that in the dried state, nettle leaves contain 25% to 34% crude protein. This is an extremely high figure for leafy greens. The nettle's amino acid profile is balanced, containing all essential amino acids, which allows to increase the biological value of wheat protein (which is limited by lysine) when combined [11].

The carbohydrate content is mainly represented by dietary fibre (fibre). According to studies, the total content of dietary fibre can reach 9-18%, with a significant proportion being insoluble fractions (cellulose, hemicellulose). These hydrophilic polysaccharides are the main agents that change the rheology of the dough, competing with gluten for water [11]. The ash content of nettle leaf powder is 15-17%, which is 25-30 times higher than that of high-grade wheat flour. This makes nettle one of the most powerful natural sources of minerals [12].

For gluten-free products, which often suffer from protein and mineral deficiencies, nettle becomes a valuable ingredient. Studies have been conducted on the effect of nettle flour on the properties of rice wafers. It was found that nettle proteins have a high foaming capacity (13.91%) and foam stability (93.66%), which allows improving the porosity structure of gluten-free products. The addition of nettle reduced the peak viscosity of the dough, which indicates a limitation of starch grain swelling, but ensured the stability of the structure during baking (breakdown viscosity). The resulting waffles were characterised by a significantly higher protein, ash and fibre content while maintaining acceptable sensory characteristics [13].

Pasta is an ideal product for fortification. Research by a team of scientists has shown that adding 5% lyophilised nettle to durum wheat pasta increases the calcium content by 5.8 times. The most important result was a reduction in the glycaemic index (GI). The paste with 3% nettle showed the lowest calculated GI (49.31%). The mechanism of this effect is based on the formation of a physical barrier of fibre and nettle proteins around the starch granules, which slows down their hydrolysis by digestive enzymes. This makes this paste a recommended product for dietary nutrition in diabetes mellitus [14].

Studies have also been conducted on the use of nettle supplements in confectionery. For example, when studying nettle supplements in biscuits and muffins, differentiation in the use of different parts of the plant was observed. The researchers compared the effect of nettle seeds and nettle seed extract on the texture of biscuits. The biscuits with the seeds were softer and less brittle than the control, which is explained by the high content of lipids in the seeds, which act as dough plasticisers. Instead, nettle extract gave the products a more intense reddish hue (probably due to the oxidation of phenols). Sensory analysis showed a preference for products with seeds [15].

Adding nettle flour to wheat dough significantly changes its structural and mechanical properties. Studies by Ukrainian scientists using the Brabander pharynograph have shown that replacing part of wheat flour with nettle flour (2-6%) leads to an increase in the water absorption capacity of the dough. This phenomenon is explained by the high content of hydrophilic polysaccharides (fibre) in nettle, which compete with gluten for water. Increasing the proportion of nettle also prolongs the time of dough formation and affects its stability [16].

Interestingly, low dosages (2%) increase the volume of bread, while higher concentrations (4-6%) lead to a decrease in specific volume due to the effect of gluten dilution and mechanical destruction of the protein backbone by fibre particles. This correlates with the findings of foreign researchers who also noted a change in the colour of the crumb to a darker or greenish colour due to the presence of chlorophylls and Maillard reaction products [17].

Given the above review, it can be noted that nettle supplements are a promising source of proteins, minerals and antioxidants. The search for ways to produce these additives from different parts of the plant and technologies for their introduction into bakery products remains relevant.

Formation of the objectives of the article. The aim of the article is to comprehensively study the effect of additives of nettle extracts on the processes of gluten complex formation in wheat yeast dough for the development of functional products with increased nutritional value. The objects of the study were wheat flour of the highest and first grades (GSTU 46.004-99 "Wheat flour. Technical conditions"), dioecious nettle leaves (Urtica dioica L.) harvested in 2025, and flour from dried nettle leaves. The nettle flour was obtained by grinding on a tissue microchopper PT-1 at a speed of 4000 rpm to a particle size of less than 200 µm. To analyse the rheological properties of gluten, an AR-4/1 penetrometer was used to determine the compressive strain (H_{comp}). The extensibility and floatability of the gluten ball were measured according to standard methods [18]. The sugar-forming capacity of the flour was estimated by the amount of accumulated maltose. The gas-forming ability of the dough was monitored using a Jago-Ostrowski device for 5 hours of fermentation. Test baking was carried out according to GOST 9404-60, evaluating the specific volume, porosity, and organoleptic profiles of the products [18].

Summary of the main research material. The way of introducing biologically active substances from nettle in the form of extracts was chosen for the enrichment of flour products. This was justified by the fact that the extract (aqueous, alcoholic, etc.) provides a more controlled dosage of polyphenols and other BAS, better uniformity of their distribution in the dough and minimal impact on the gluten backbone compared to the addition of coarsely chopped vegetable raw materials with fibre, which is important for preserving the rheological and sensory characteristics of bread and dough products [19].

In order to obtain nettle extract, dried leaves of this plant were chosen as plant material for the study. To ensure the most complete extraction of soluble compounds from this type of raw material, the following extractants were used: weak solutions of sodium chloride (1% solution), ethyl alcohol solutions of various concentrations (1%, 5% and 10%), and distilled water. In parallel, extraction with drinking water was carried out, which was taken as a comparison standard.

The maximum concentration of the saline solution was justified by the effect of table salt on organoleptic characteristics, and the concentration of ethyl alcohol was justified by the requirement of guaranteed absence of alcohol in the finished product. Using stronger solutions (e.g., replacing 20%), approximately 25% of the added amount of alcohol will remain in the centre of a large product after baking due to its retention by the capillary-porous structure of the crumb. It has been experimentally established that when using low-concentration alcohol solutions, the final ethanol content in bread is reduced to analytical traces. This confirms the need to strictly limit the initial concentration of the solution (within 5-10%) to achieve the target residual minimum [20].

The extraction of plant material was carried out at temperatures of 20, 30, and 40°C with continuous stirring. The duration of the extraction process was from 1 to 6 hours with sampling at 1 hour intervals. The ratio of raw material to extractant was 1:10. The degree of extraction was estimated by the mass fraction of solids in the solution.

According to the results of the study, it was found that when using different types of extractants, the maximum dry matter yield was observed at a temperature of 40°C for two hours. The kinetics of the nettle extraction processes with drinking water, distilled water, sodium chloride solution, and ethanol solutions are shown in Figure 1.

The analysis of the data obtained shows that almost complete equalisation of the concentrations of substances extracted from this type of plant material is achieved after 3 hours of infusion of dry nettle at 40°C.

After 6 hours of extraction, the dry matter content of the infusion was for extraction with drinking water – 0.89± 0.02%, distilled water – 1.23± 0.01%, 1% sodium chloride solution – 1.42± 0.01%, 1% ethanol solution – 1.35± 0.01%, 5% ethanol solution – 1.46± 0.02%, 10% ethanol solution – 1.95± 0.02%. In comparison with the concentration after 3 hours of extraction, it increased by 2.2...4.1%.

Thus, the maximum transfer of extractive substances to the infusion is observed when using a 10% ethanol solution as an extractant. The dry matter content in this variant exceeds that of drinking water by 54.35± 0.02%. The use of a 1% solution of sodium chloride provides an increase in the yield of extractive substances by 37.32 0.01% relative to drinking water, while the use of distilled water increases the dry matter content of the infusion by 27.64± 0.01%.

Thus, to intensify and increase the completeness of dry matter extraction from dry plant material, it is necessary to select extraction conditions individually. From a practical point of view, it is advisable to use a 1% sodium chloride solution or a 10%

ethanol solution as an extractant for the preparation of aqueous infusions and to carry out the extraction for 3 hours.

The probable mechanism for increasing the extraction efficiency when using weak salt solutions is a violation of the osmotic pressure at the interface above the surface of nettle particles and cells, which causes the destruction of cellular structures and contributes to a more complete extraction of extractive substances. The use of ethyl alcohol solutions, in turn, allows for additional extraction of protein fractions from dried raw materials, which is associated with the solubilising properties of water-alcohol systems for proteins of plant origin.

When dough is kneaded, the water-insoluble protein fractions of flour, such as gliadin and glutenin, form a cohesive, elastic, plastic, stretchable mass – gluten.

In wheat dough, swollen, water-insoluble proteins form a continuous sponge-like mesh base (a kind of "frame" or "backbone") that largely determines the physical properties of the dough and, therefore, the strength of the flour. Therefore, the gluten content of wheat flour and its properties, primarily physical, can be considered one of the essential indicators of flour strength.

The content of crude gluten was determined in flour mixed with water, water, salt and alcohol extracts of nettle. The results of the study are shown in Figure 2. As can be seen from the results, the use of nettle extracts increased the gluten yield.

The analysis of possible factors of gluten yield increase shows the following. During the extraction of nettle, some water-soluble proteins, water-soluble pentosans (they are part of the plant cell walls), minerals, etc. are transferred to water.

As mentioned above, proteins are the main component of gluten. The connection between flour and extract proteins can be made through the formation of hydrogen bonds between protein molecules, through the interaction (association) of hydrophobic parts of protein molecules, or through the formation of disulfide bridges (-S-S bonds). In other words, the addition of extract proteins to flour proteins causes an increase in gluten yield.

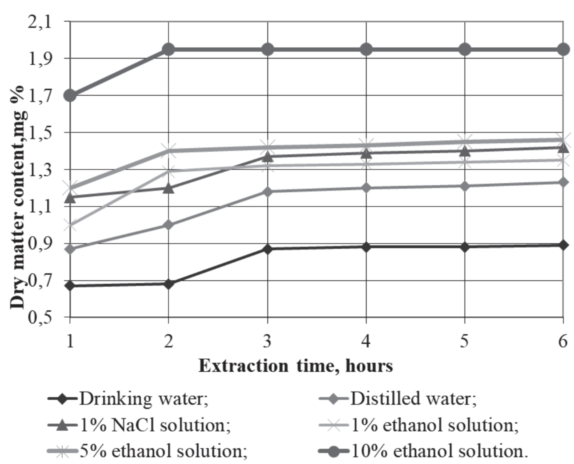

Fig. 1. Kinetics of extraction of dry matter from nettle leaves

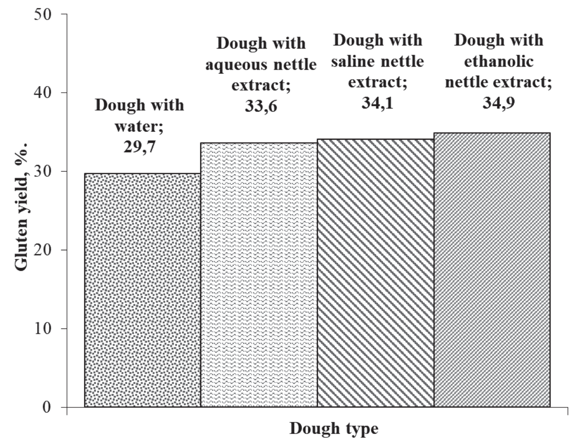

Fig. 2 Gluten yield when using nettle extracts

The extract may also contain water-soluble pentosans, which can be considered as mechanical impurities that are not completely separable from gluten. Their content in flour and thus in gluten is low, but they have a high water-absorbing capacity and can therefore also affect the gluten yield.

The highest gluten yields were observed when using salt and alcohol extracts. This is because salt promotes faster hydration of gluten proteins, and the alcohol extract additionally contains alcohol-soluble proteins extracted from nettle. That is, when kneading dough with nettle extracts, the gluten yield increases, and, therefore, the dough kneaded with the extracts should be better.

As can be seen from Figure 2, the use of nettle extracts can increase the total gluten yield by 11.6...14.9%, which can be noted as a positive effect. Therefore, it can be expected that the dough mixed with the extracts should be better. Next, we analysed the change in gluten extensibility during the proofing process (Figure 3).

The graphs show that at the beginning, the gluten extensibility of the dough kneaded with water (the first case) and salt extract (the second case) was the same (14± 0.1 cm), while the water extract (the third case) was 2.5± 0.1 cm higher. In the alcohol extract (fourth case), it was 16± 0.2 cm. After an hour of curing, the extensibility in the first case increased sharply from 14± 0.1 cm to 31± 0.2 cm. In the second case, the elongation increased from 14± 0.1cm to 20± 0.1cm, in the third and fourth cases, the elongation value remained practically unchanged – from 16± 0.1cm to 17± 0.2cm and from 16± 0.2cm to 18± 0.1cm, respectively. After two hours of resting, the extensibility in the first case began to decrease (from 31± 0.1 cm to 28± 0.2 cm), the gluten became more liquid and tearable, and the tensile strength and elasticity decreased sharply. In the second and fourth cases, the gluten extensibility increased slightly, and in the third case, there was a sharp increase.

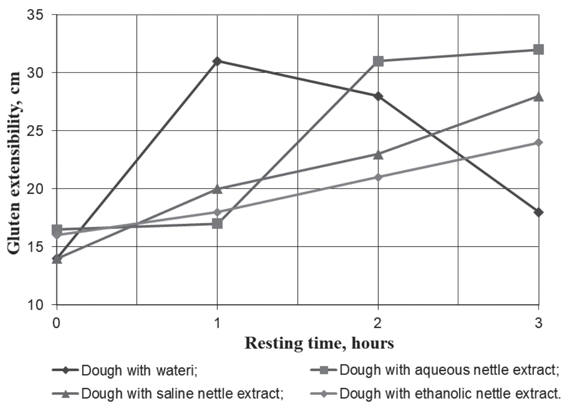

Fig. 3. Determination of the change in gluten extensibility during proofing.

After three hours of proofing, the gluten elongation in the first case decreased sharply and amounted to 18± 0.1 cm, the elongation in the second and fourth cases also increased slightly (28± 0.1 cm and 24± 0.2 cm), and in the third case it remained practically unchanged and amounted to 31± 0.1 cm.

These graphs show that gluten from dough mixed with extracts is better in rheological parameters than gluten from dough mixed with water. To analyses and understand the results obtained, it is necessary to consider the processes that occur in gluten during proofing.

As established by a study [21], flour contains a proteinase that hydrolytically breaks down proteins by their peptide bonds. The study of proteinases revealed their effect on the physical properties of gluten. The action of the proteinase caused gluten liquefaction and a decrease in elasticity. Proteinases of this type are characterised by their ability to be activated by compounds containing the sulfhydryl group -SH- (cysteine, glutathione). Also characteristic of this type of proteinase is the ability to inactivate oxidising compounds ($H_{(2)}O_2$, oxygen, etc.). The ability of flour proteinases to be activated by reducing agents and inactivated by oxidising agents is associated with the presence of -SH groups in the structure of protein molecules of these enzymes. The conversion of these groups into disulfide bonds – bridges, during oxidation inactivates the enzyme.

The proteolysis activator found in grains, flour and yeast, and therefore in dough, is glutathione. It is a tripeptide that contains a cysteine residue containing a -SH group. In its oxidised state, glutathione is no longer able to activate proteolysis. The proteolysis-activating effect of glutathione is reduced to the reduction of -SH groups that were in the inactive proteinase in the form of -S-S bonds. The action of proteolysis inhibitors – oxidants can be considered as oxidation of -SH groups in both the proteinase enzyme and its activator (glutathione).

The direct effect of -SH-containing reducing agents and oxidising reagents on the protein substances of flour and dough is now generally recognised. The composition and structure of the protein substance of grain and flour contains the amino acid residues cysteine and cystine, and therefore groups of -SH and -S-S bonds. The role of disulfide bridging bonds is particularly significant in the tertiary and quaternary structure of protein matter. The formation of disulfide bonds strengthens the intramolecular structure of the protein, making it denser and more solid. Breaking of disulfide bonds causes a weakening of the structure of the protein molecule, making it more "mobile".

The formation and breaking of disulfide bonds has a similar effect on larger supramolecular formations, i.e. aggregates of a number of protein molecules. As a result of the hydrolytic action of enzymes in the dough, the substances they act on are disaggregated and broken down. As a result, the amount of substances that can pass into the liquid phase of the dough increases, which leads to a deterioration in its physical properties.

Returning to the results of the study, some water-insoluble proteins, which usually swell in water to a limited extent, can swell unlimitedly under the action of proteinases and, as a result, peptidise and become a viscous colloidal solution.

In the case under study, an increase in protein swelling should lead to an increase in gluten extensibility, which is observed in the corresponding graphs. However, in weak gluten, swelling processes are faster and are accompanied by hydrolytic degradation, disaggregation and peptidation. These processes are observed in the first case. During the first hour of proofing, an intensive swelling process took place, which resulted in a sharp increase in gluten extensibility. Then the process of proteolysis began to prevail, and as a result of protein disaggregation and peptidation, gluten lost its elasticity and resilience, and became poorly stretchable and tearable.

In the second, third and fourth cases, the swelling process also occurred (according to the literature, vegetable raw materials have proteolytic activity), but there was a "limited" swelling, i.e. the gluten retained its elasticity and elasticity and did not turn into a colloidal solution.

In the second and third cases, the swelling process was slower and proteolysis was insignificant compared to the first case.

In this way, the use of nettle extracts led to an improvement in the physical properties of gluten and, consequently, of the dough. To consider the reasons for this improvement, it is necessary to recall the composition of nettle described above.

The improvement in gluten properties could be due to the action of nettle proteins that have been transferred to the extracts. In addition, the improvement was due to the high content of ascorbic acid in nettle, which is a bread quality enhancer [22]. Based on research conducted by many scientists, the mechanism of ascorbic acid's improving effect can be presented as follows [23].

Flour has a redox enzyme system that includes ascorbic acid oxidase (ascorbate oxidase) and dehydroascorbic acid reductase (dehydroascorbate reductase). Ascorbic acid is subject to the combined action of the above enzymes.

At the first stage, ascorbate oxidase catalyses the oxidation of ascorbic acid to convert it to dehydro-L-ascorbic acid. The resulting dehydro-L-ascorbic acid is the oxidant with which the improving effect is associated.

In the second stage, the enzyme dehydroascorbate reductase, in the presence of the components of the flour protein-proteinase complex in the dough (referred to as R-SH), catalyses the reduction of dehydro-L-ascorbic acid to ascorbic acid. At the same time, 2 R-SH are converted into R-S-S-R, resulting in oxidative inactivation of the proteinase itself and its activator (glutathione) and strengthening of the protein structure by "cross-linking" with disulfide bridge bonds. This improves the physical properties of the dough.

The available experimental data [24] indicate that the formation of a compact and strong structure of wheat grain proteins with improved physical and mechanical properties is due to the activity of peroxidase, an enzyme contained in nettle. Obviously, the factors described above (nettle protein complex, ascorbic acid, peroxidase) caused the improvement of gluten physical properties during the proofing process.

The study found that nettle extracts improve the rheological properties of gluten, and thus the dough.

Gluten spreadability was determined to determine the effect of nettle extracts on the baking properties of flour. The lower the floatability of the gluten ball, the stronger the gluten and the better its baking properties. The results are shown in Figure 4.

As can be seen from Figure 4, the floatability of gluten from dough with extracts is lower than that of gluten from dough with water. Thus, the use of nettle extracts for dough kneading gave a positive result, i.e. led to an improvement in gluten quality.

The reasons for the quality improvement are similar to those described above. The smallest average contour diameter in the gluten obtained from dough with alcohol and salt extracts is 13.4...14.0% smaller compared to the control. That is, the results of this experiment confirm the results of the previous ones.

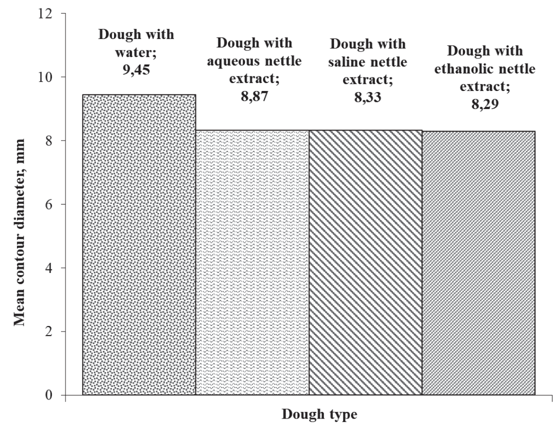

Fig. 4. Gluten balls spreading out

Next, the study was carried out using a penetrometer of the AR-4/1 brand. With the help of this device, the strength of gluten is judged by the compression deformation. This is quantified in penetrometer units (units), which corresponds to a certain gluten height when compressed ($H_{comp)}$. The higher the H_{comp}, the stronger the gluten. Figure 5 shows the results of the experiment.

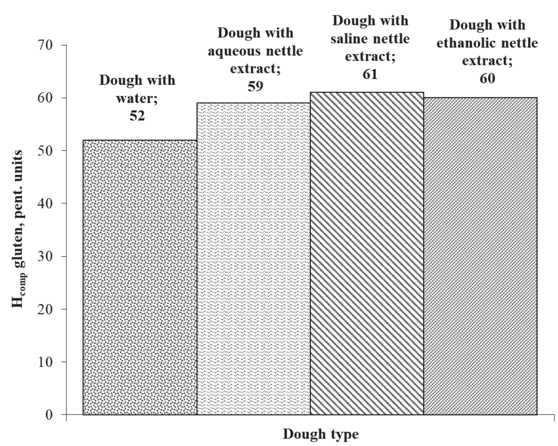

Fig. 5. Determination of gluten quality using a penetrometer.

As can be seen from the results of the study, the use of nettle extracts led to an increase in the H_{comp} of gluten by 11.9...14.8%. And the higher this value, the stronger the gluten. Thus, the use of nettle extracts leads to an increase in flour strength. The best result was obtained when using salt and alcohol extracts. The data of this study confirm the data of previous studies.

It is known from the literature that additives from plant materials improve the sugar-forming capacity of flour [26]. This indicator describes the ability of flour to provide yeast with sufficient sugar and form a reserve of residual sugars necessary for good quality bread. The results of the study to determine the sugar-forming capacity of flour are shown in Figure 6.

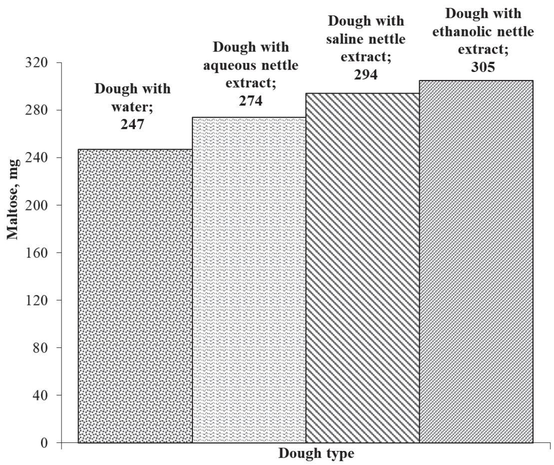

Fig. 6. Determination of the sugar-forming capacity of flour

The results show that nettle extracts increase the sugar-forming capacity of flour. This may be due to the amylolytic enzymes of nettle that have passed into solution.

Thus, the fermentation process should be more intensive, which should affect the gas formation process, and this, in turn, should affect the quality of the finished product. Thus, it can be seen that nettle additives increase the amount of maltose by 9.9...19.0% compared to the control.

Gas formation in the dough during its fermentation is one of the most important output parameters determined by the conditions of a number of technological stages of the process of producing yeast dough products and on which the quality of the finished products depends. The paper investigates the formation of carbon dioxide during the fermentation of dough produced using the above recipe. A typical picture of the fermentation of unleavened dough made from high-grade flour is shown in the figure. 7. Fermentation without additives is characterised by a slow release of CO_2 during the second hour of fermentation and an increase during the third hour. The peak of the largest amount of CO2 release occurs at 300 minutes.

From the beginning of fermentation, the use of nettle extracts not only increases the intensity of CO_2 release, but also moves the maximum CO_2 release to the left, which indicates a reduction in fermentation time. The best results were obtained when using alcohol and salt extracts of nettle. Thus, when using the salt extract, the amount of CO_2 increased by 5.29± 0.01% compared to the control, and when using the ethanol extract by 12.84± 0.02%. This can be explained by 2 factors: firstly, the extracts have been found to affect the sugar-forming capacity of flour, and secondly, due to their rich mineral composition, they can stimulate the activity of yeast cells, which requires a separate study.

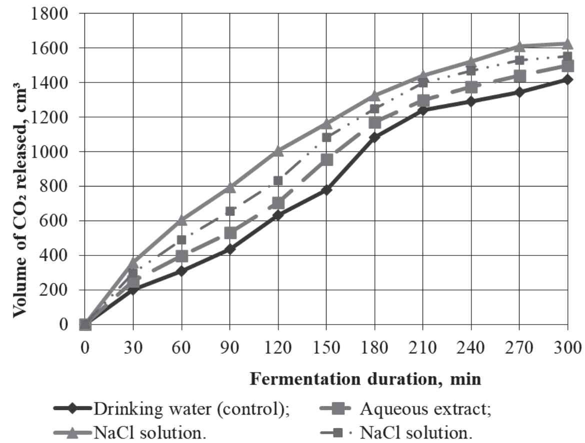

Fig. 7. Carbon dioxide formation during dough fermentation with nettle extracts

Conclusions from these problems and prospects for further research in this area. Based on the results of a comprehensive study of the effect of dioecious nettle (Urtica dioica L.) extracts on the formation of the gluten complex of wheat dough, the following was found.

The optimal conditions for extraction are a temperature of 40°C and a duration of 3 hours at a hydraulic module of 1:10. The maximum dry matter yield is provided by a 10% solution of ethyl alcohol (1.95±0.02%), which exceeds the value for drinking water by 54.35± 0.02%. The use of a 1% sodium chloride solution increases extraction by 37.32± 0.01% compared to the control, which is due to a violation of osmotic pressure on the surface of the cellular structures of plant material.

The use of nettle extracts in dough kneading leads to an increase in the yield of crude gluten by 11.6...14.9%. This effect is explained by the incorporation of plant proteins into the gluten backbone through the formation of hydrogen bonds and disulfide bridges, as well as the participation of water-soluble pentosans with their high water absorption capacity.

The rheological properties of gluten are improved: the spreadability of the ball decreases by 13.4...14.0%, and the compressive strain H_{comp} increases by 11.9...14.8% compared to the control. The stabilisation of gluten during the proofing process is explained by the inhibition of proteolytic activity due to the action of ascorbic acid and nettle peroxidase through the mechanism of oxidation of sulfhydryl groups with the formation of additional disulfide bonds.

The use of the extracts increases the sugar-forming capacity of flour by 9.9...19.0% and the intensity of gas formation during dough fermentation: the salt extract increases the release of CO_2 by 5.29± 0.01%, the alcohol extract - by 12.84± 0.02%, with a shift in the maximum gas formation towards a shorter fermentation duration.

A promising direction is to study the phenolic profile of the obtained extracts by HPLC-MS and determine their antioxidant activity (DPPH, FRAP) in order to establish a correlation between the polyphenol content and technological effects. It is important to study the effect of nettle extracts on the probiotic activity of sourdough starter cultures and microbiological parameters of finished products. A separate study is needed to determine the optimal dosage of extracts in finished formulations, evaluate the organoleptic and physicochemical characteristics of bread, and analyses changes in the nutritional value and glycaemic index of finished products using in vitro methods. It is also promising to study the synergistic effect of nettle extracts in combination with other natural improvers in the technologies of functional bakery products.

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***Анотація.** Метою статті є комплексне дослідження впливу добавок екстрактів кропиви дводомної (Urtica dioica L.) на процеси формування клейковинного комплексу пшеничного дріжджового тіста для обґрунтування доцільності їх застосування у технологіях виробництва функціональних хлібобулочних виробів із підвищеною харчовою цінністю. Дослідження проводились на зразках пшеничного борошна вищого та першого сортів (ГСТУ 46.004-99), а також борошна з висушеного листя кропиви дводомної (Urtica dioica L.) урожаю 2025 року. Екстракцію здійснювали при температурах 20, 30 та 40°С протягом 1-6 годин при гідромодулі 1:10. Ступінь процесу екстракції оцінювали за масовою часткою сухих речовин у розчині. Реологічні властивості клейковини досліджувались за показниками розтяжності, розпливаємості та деформації стискання (за допомогою пенетрометра АР-4/1). Цукроутворюючу здатність борошна визначали за кількістю накопиченої мальтози, газоутворюючу здатність – за допомогою приладу Яго-Островського протягом 5 годин ферментації. Доведено, що екстракти кропиви дводомної справляють комплексний технологічний ефект на клейковинний комплекс пшеничного тіста: підвищується вихід і зміцнюються реологічні властивості клейковини, збільшується цукро- та газоутворююча здатність борошна. Зазначені ефекти зумовлені синергетичною дією білкового комплексу кропиви, аскорбінової кислоти та ферменту пероксидази, які інгібують протеолітичну активність через механізм окислення сульфгідрильних груп з утворенням додаткових дисульфідних зв'язків. Результати свідчать про перспективність застосування водних, сольових та водно-спиртових екстрактів кропиви як натуральних поліпшувачів у виробництві функціональних хлібобулочних виробів.*

***Ключові слова:** кропива дводомна (Urtica dioica L.), клейковинний комплекс, пшеничне тісто, реологічні властивості, рослинні екстракти, функціональні хлібобулочні вироби, газоутворення, цукроутворення, протеоліз, аскорбінова кислота.*

Дата першого надходження статті до видання: 18.03.2026
Дата прийняття статті до друку після рецензування: 10.04.2026
Дата публікації (оприлюднення) статті: 18.05.2026

НАУКОВИЙ ВІСНИК ПОЛТАВСЬКОГО УНІВЕРСИТЕТУ ЕКОНОМІКИ І ТОРГІВЛІ

Серія «Технічні науки»

Випуск 1, 2026

Українською та англійською мовами

Відповідальний редактор: *І. Чудеснова*
Технічний редактор: *Н. Кузнєцова*

Дата розміщення онлайн: 18.05.2026. Дата друку: 25.05.2026.
Формат 60×84/8. Гарнітура Times New Roman.
Папір офсет. Цифровий друк. Ум. друк. арк. 9,53. Замовлення № 0526/426.
Наклад 100 прим.

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ДК № 7623 від 22.06.2022 р.