

MODERN TRENDS IN IMPROVING BREAD QUALITY

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Purpose: The aim of this article is to identify the characteristics of bread production innovations being implemented at the current stage of the baking industry, taking into account environmental and healthy eating aspects. The article presents research results on the use of nanowater (plasma water) in the production of wheat-rye bread. The authors also presented the results of research on wheat and rye bread produced using nanowater and tap water.

Design/methodology/approach: The literature research and the critical analysis of both, the national and foreign subject literature have been used as the research methodology.

Findings: In response to the transformations occurring within the bakery industry and considering the growing demand in Poland for bread that meets consumer quality expectations, research was conducted to examine the impact of innovations in the technological process on the improvement of bread quality. Modern trends in improving the quality of bread focus on health, natural ingredients, traditional methods and the use of modern technologies such as the use of nanowater (plasma water) in the bread production process. These technologies are becoming increasingly noticeable among bread producers. The potential benefits of using nanowater in baking stem from its unique, ordered structure, which is thought to promote biological and chemical processes occurring in dough. In this article, the authors presented the features of innovation in bread production, such as: hydrocolloids in extending the freshness of bread, the use of gases (carbon dioxide, nitrogen, air) in bread production, supplementation of bread with microelements and calcium and magnesium ions, "zero waste" technology for waste minimization, the use of plasma water (nanowater) as a base for bread production.

Practical implications: Practical implications include presenting the use of nanowater in technological processes to improve bread quality, using the baking industry as an example. Introducing nanowater into bakeries offers potential technological and quality benefits (health-promoting properties, microbiological stability). This will be an important solution for future decisions by bakery owners regarding the use of nanowater in bakeries.

Originality/value: The article may constitute a recommendation for companies/entrepreneurs in the bakery industry in the area of improving the quality of bread.

Keywords: quality of bread, the essence of innovation in the use of nanowater in the technological process of bread production, classification of innovative features of bread production such as: (hydrocolloids, supplementation of bread with microelements and calcium and magnesium ions, "zero waste" technology), hierarchy of the impact of the use of nanowater in the technological process on improving the quality of bread.

Category of the paper: research paper.

Introduction

Bread is a fundamental component of the Polish diet. When consumed in a rational manner, it plays an essential regulatory role in the human digestive system and constitutes a significant source of daily energy intake (approximately 25-30%) (Dziwkosz, 2012). Beyond its nutritional value, bread may also provide pro-health benefits, and it is precisely this type of product that attracts contemporary consumers (Gambuś, Litwinek, 2011). As many as 98% of Poles report eating bread every day, which confirms its status as a key food product in Poland and justifies its prominent position in the scientific literature.

Current trends in improving bread quality concentrate on health, natural ingredients, traditional processing methods, and the use of modern technologies (Drozd, 2021). These technologies are increasingly recognized by bread manufacturers, who continue to invest in research and development to meet growing consumer expectations (Drozd, Wolniak, 2023). Modern baking is fully aligned with the broader movement toward technological innovation (Drozd, Wolniak, 2021). The innovations presented in this article pertain directly to the technological process of bread production. Novel baking methods contribute to continuous improvement in bread quality (Drozd, 2025).

Contemporary bakery production, like any modern economic sector, requires the elimination of waste through its reduction, reuse, recycling, and composting (Oest et al., 2022). For this reason, the article discusses the “zero-waste” technology, which enables the reintegration of returned or leftover bread into the production cycle. This approach aligns with the principles of a circular economy, in which resources are continuously reused without generating unnecessary waste.

2. Characteristics of Innovativeness in Bread Production

Among the novel approaches currently recognized in Poland for improving bread quality, the following are considered particularly significant:

1. The use of hydrocolloids to extend bread freshness.
2. The application of gases (CO₂, N₂, air) in bread production.
3. Bread supplementation with trace elements and calcium and magnesium ions.
4. “Zero-waste” technology – alcohol derived from bakery waste.
5. Plasma-treated water (nanowater, clustered water) used instead of standard tap water in bread production.

Hydrocolloids represent one of the most effective groups of additives employed in the bakery industry to prolong bread freshness. These are high-molecular-weight compounds, either natural or modified, characterized by their ability to bind large quantities of water and to form colloidal systems (Ishaq et al., 2024). The most commonly used hydrocolloids in breadmaking include guar gum, xanthan gum, carboxymethylcellulose, pectins, alginates, carrageenan, and locust bean gum. Their application improves not only the structure of the dough but also significantly slows down bread staling processes, which directly contributes to longer shelf life and better consumer acceptance (Dłużewska, Krygier, 2007). The use of hydrocolloids influences the following parameters (Pirsa, Hafezi, 2023):

- water retention capacity within the crumb structure,
- delayed starch retrogradation, which is the primary cause of crumb firming during bread storage,
- crumb porosity and loaf volume, resulting in higher dough expansion and a more uniform pore distribution,
- stabilization of fat emulsions in the dough, leading to an even dispersion of fat and improved crumb softness.

It should also be emphasized that certain hydrocolloids possess prebiotic properties that support the development of beneficial intestinal microflora, thereby increasing the functional value of bakery products (Pilarska, Gawalek, 2016). A notable example is inulin, which not only improves bread texture and extends freshness but also exerts positive effects on consumer health.

Growing consumer interest in long-lasting products free from chemical preservatives has made hydrocolloids an attractive market alternative. Their natural origin and beneficial effects on bread structure and freshness contribute to their increasing use in the bakery sector (Guarda et al., 2004). The implementation of hydrocolloids aligns with the demands of the modern bakery market, where natural composition, functional performance, and high quality of the final product are of fundamental importance (Pahwa et al., 2016).

Technical gases such as carbon dioxide, nitrogen, and air play a significant role at various stages of bread production—from fermentation, through mixing and shaping, to packaging and storage of finished products. Their application aims to improve quality, shelf life, and product safety, while also enabling the introduction of modern, more efficient technologies in industrial baking (Chiotellis, Campbell, 2003). From the standpoint of innovativeness, dough aeration represents an advanced technological approach to modifying the structure of raw material without chemical additives. The process can be fully controlled, automated, and adjusted to specific formulation parameters. Gas injection takes place using specialized pressure mixers that allow simultaneous mixing, aeration, and cooling of the dough (Raad et al., 2025). This technology offers both ecological and economic advantages. It reduces the consumption of raw materials (e.g., flour, yeast, fat), decreases production losses, and extends product shelf life, all of which directly contribute to waste reduction (Grenier et al., 2021).

In accordance with market requirements and EU regulations, gases such as carbon dioxide and nitrogen are considered safe for use in the food industry, broadly approved, and not classified as food additives. Dough aeration is particularly useful in the production of toast bread, gluten-free bread, low-carbohydrate baked goods, and dietary products, where precise control of consistency, structure, and sensory characteristics is crucial (Verheyen et al., 2015). In toast bread, aeration contributes to a uniform fine crumb structure and greater elasticity, which improves toasting performance and prolongs freshness. In gluten-free products, which lack the natural gluten network responsible for retaining fermentation gases, dough aeration provides an innovative technological support for developing a porous structure. In dietary and low-carbohydrate bakery products, aeration enables an improvement in loaf volume and structural characteristics despite the reduced content of flour, gluten, or starch (Sroan et al., 2009).

Technical gases such as carbon dioxide, nitrogen, and air perform multidimensional functions in bread production—from supporting natural fermentation and improving texture, through controlling the atmosphere inside packaging, to enhancing the durability and safety of the final product. Their use constitutes not only an element of modern bakery technology but also a tool for ensuring quality, hygiene, and competitive advantage on the market (Kołozyn-Krajewska, 2019).

Enriching bread with trace elements and with calcium and magnesium ions represents one of the key directions in the development of functional foods aimed at improving the nutritional value of everyday food products. Bread, as one of the most frequently consumed items in the human diet, can serve as an effective carrier of physiologically important minerals, particularly in the context of widespread deficiencies of calcium, magnesium, zinc, iron, or selenium observed in the population (Kowalski et al., 2022). Supplementation of bread in this respect constitutes an efficient pro-health strategy that combines technological considerations with dietary prevention.

From a technological standpoint, the supplementation of bread with microelements may be implemented at the dough-mixing stage or by applying premixes added directly to the flour. One of the major challenges in this process is maintaining technological performance and sensory acceptability, as certain mineral salts may affect dough colour, its ability to rise, loaf volume, and flavour (Pojić et al., 2015). High calcium content may also lead to a firmer crumb structure. Iron, in turn, may react with polyphenols, causing dough greying or the appearance of a metallic aftertaste. Because of these factors, careful formulation development is required, including testing the stability and uniform distribution of minerals in the dough.

Producers of bread enriched with microelements and calcium and magnesium ions are additionally obliged to provide accurate labelling of mineral content and to clearly state their nutritional function (Ziobro et al., 2023).

The market demonstrates growing interest in functional bakery goods, including products enriched with calcium, magnesium, and trace elements. Supplementation of bread with these minerals constitutes an effective means of improving dietary quality and responding to societal needs associated with nutritional deficiencies. It represents a practical and scalable solution that can be successfully implemented both in large industrial bakeries and in smaller local establishments. Provided that appropriate technological and legal standards are maintained, mineral-enriched bread may become an important element of nutritional prophylaxis promoting a healthy lifestyle (Wolniak, Drozd, 2025).

In the context of reducing food waste, increasing attention is devoted to the “zero-waste” concept, which assumes maximal use of raw materials and the minimization of waste (Drozd, Wolniak, 2023). One of the innovative pathways for implementing this idea in the bakery sector is the processing of production waste and unsold bread into ethyl alcohol (Castello, 2019). Bakeries generate substantial quantities of waste—defective finished products, dough residues, and returned bread from retail networks. These materials may serve as a substrate for alcoholic fermentation (Yung et al., 2023). Owing to their high content of starch, sugars, and proteins, bread products create an excellent medium for microorganisms responsible for fermentation. From a technological standpoint, the production of alcohol from bread does not differ fundamentally from classical fermentation methods employed in the spirits industry (Nierzwicki, 2010).

The environmental dimension is equally important. Bread, as an organic waste material, decomposes rapidly and releases methane and other greenhouse gases during storage. Converting it into alcohol reduces the carbon footprint and decreases the volume of biodegradable waste destined for landfill sites. Alcohol production from bakery waste provides ecological, economic, and social benefits and is emerging as a realistic solution for the future of the bakery industry.

The application of plasma-treated water (nanowater, clustered water) in breadmaking represents an innovative approach aimed at improving bread quality and enhancing microbiological safety (Drozd, 2021). Water activated using low-temperature plasma is gaining recognition as a functional substitute for standard tap water commonly used in bakery operations. The presence of reactive oxygen and nitrogen species generated through plasma–water interactions imparts antibacterial, antioxidative, and physicochemical-modifying properties to plasma-treated water (Ulutürk, Gül, 2025).

A key advantage of using plasma-treated water in bread production is the improvement of microbiological safety in both the dough and the final product. Plasma-treated water also influences gluten structure and activity, contributing to improved rheological characteristics and superior parameters of the baked loaf (Ershidat et al., 2024). With respect to fermentation processes, plasma-treated water may function as a mild regulator of yeast activity, which in practice enables a reduction in processing time without compromising the quality of the final product. In terms of storage stability, bread produced with plasma-treated water demonstrates

greater resistance to mould growth and slower crumb staling. Extending product shelf life without chemical preservatives represents a significant advantage from both commercial and nutritional perspectives.

Plasma-treated water constitutes an innovative and multifaceted tool in contemporary baking. Its application allows for the enhancement of bread quality, improved microbiological stability, reduction of chemical additives, and extension of product shelf life. As an environmentally compatible technology that is relatively easy to implement, it may play an important role in the transformation of the bakery sector toward more natural production practices aligned with the expectations of modern consumers.

3. Results of the Study on Wheat–Rye Bread Produced with Nanowater

The authors of the article were engaged in cooperation with one of the bakeries participating in a research project focused on implementing an innovative technology for producing plasma-treated water (nanowater, de-clustered water) as the base component of bakery products. The bakery owner, collaborating with the authors, commissioned a specialized laboratory to analyze wheat–rye bread from their own bakery-already producing bread using nanowater - and from two other bakeries producing bread with standard tap water. These analyses constituted the final stage of the project in the participating bakery, during which an innovative technology for obtaining plasma-treated water as a base for bakery products had been developed.

In 2025, the study of wheat–rye bread covered the following parameters:

- determination of salt content, total sugars in dry matter, and fat content,
- determination of acidity and moisture,
- determination of baking yield and loaf volume,
- evaluation of bread suitability for consumption using sensory analysis.

Additionally, the study examined yeast survival in bread dough prepared with nanowater and with standard tap water during storage, after freezing, and after thawing.

The conducted tests demonstrated that wheat–rye bread made with nanowater was characterized by lower salt content (determined using the Mohr method), higher acidity, higher total sugar content in dry matter (according to the Luff-Schoorl method), higher fat content, lower moisture content, and greater loaf volume¹.

¹ The laboratory report contained percentage changes of the analyzed parameters in relation to the bread produced by the examined bakery using standard tap water. However, the authors of the article did not obtain permission from the report owner (and the bakery owner) to publish these data.

The parameters obtained for bread produced with nanowater—such as lower salt content, higher acidity, lower moisture, and greater loaf volume—are highly advantageous from the consumer's perspective and indicate an improvement in bread quality achieved solely by replacing tap water with nanowater. The presence of sugars and fats in bread is commonly regarded as less desirable. However, the sugar content in bread depends both on the initial sugar level in the flour and on the amount of sugar added during baking. The study included wheat–rye breads with different flour compositions, which may partially distort the final result. Moreover, the sugars present in bread can serve as an easily accessible energy source within a high-carbohydrate diet. Fat content in bread, in turn, results from the addition of oil-bearing plant ingredients or fats such as oils or butter. This does not automatically imply that bread containing fat is of lower nutritional value. Fat contributes to crumb tenderness, improved aroma, enhanced absorption of fat-soluble vitamins, longer freshness, and better moisture retention.

The scoring evaluation, which combined organoleptic assessment with points assigned for physicochemical indicators, demonstrated that bread produced with nanowater was the only sample to achieve the highest total score of 40 points. This is the maximum attainable rating. The presence of nanowater clearly enhances sensory quality.

Additional tests concerned yeast survival in dough subjected to storage, freezing, and thawing. Yeast viability was assessed at four time points: 0 h, 12 h, 24 h, and 48 h. In dough prepared using clustered water, yeast maintained higher viability over a longer period, particularly at 24 and 48 hours after thawing. In the sample prepared with tap water, a gradual decline in yeast activity was observed, suggesting a faster rate of cell death under refrigerated conditions or lower resistance to the stress associated with freezing and thawing. These findings indicate that clustered water may enhance yeast survival in dough after thawing, which represents an important technological advantage in industrial baking. It enables not only an extension of dough usability for further processing but may also translate into improved baking performance and more stable final product quality, especially in delayed or frozen production systems (Cacak-Pietrzak, Rakocka, 2022).

The innovative application of nanowater in bread production represents a technologically advanced attempt to modify how dough hydrates, ferments, and develops its structural properties. Plasma-activated water contains reactive oxygen and nitrogen species that influence gluten network formation, yeast metabolism, and microbiological stability. In the analysed study, bread produced with nanowater exhibited lower moisture, higher acidity, increased loaf volume, and superior sensory evaluation. These outcomes suggest that altering the physicochemical characteristics of process water can improve dough rheology and extend freshness without relying on chemical preservatives. The concept fits into broader technological trends that favour process-based improvements over additive-driven interventions and aligns with the search for more natural and technologically efficient methods of quality enhancement.

However, the evidence also shows that the advantages of nanowater are not uniform across all parameters. The observed rise in sugar and fat content indicates complex interactions between water structure and ingredient composition, which require further controlled experimentation. Differences in flour blends, fermentation kinetics, and production conditions may partly account for these variations, underscoring the need for systematic studies before drawing generalised conclusions. The improved yeast survival after freezing and thawing is promising for industrial deferred-baking systems, yet it also points to biological mechanisms that remain insufficiently understood. Consequently, although nanowater has notable potential as an innovative tool in bakery technology, its broad implementation should be preceded by comprehensive validation across diverse production contexts to confirm the stability, reproducibility, and technological reliability of the observed effects.

4. Conclusions

The innovative solutions presented for the bakery sector demonstrate a wide range of benefits, particularly increased efficiency, improved bread quality through the development of products with enhanced sensory and nutritional characteristics, optimal resource utilization, and environmental protection. Modern technologies rely on the latest scientific and technical achievements; however, they are not yet widely implemented in bakery practice. Research on nanowater, for example, suggests potential advantages such as improved rheological properties and greater stability, yet convincing evidence of its effectiveness in bread production remains insufficient. The empirical results and physicochemical assessments presented in this article likewise did not confirm the superiority of nanowater over tap water in every respect. As with all emerging technologies, bread production based on nanowater requires further systematic investigation.

The conclusions drawn from the study of wheat–rye bread produced with nanowater may be summarised as follows:

1. Sensory value: Bread made with nanowater was the only sample to achieve the maximum possible score, obtaining first-class quality.
2. Health-related properties: Reduced salt content improves the pro-health value of the product by lowering the risk of hypertension and kidney disease. Higher acidity has a positive effect on digestion, intestinal microbiota, and bread shelf life.
3. Nutritional aspects: Higher fat and sugar content increases caloric value but also enhances flavour and energy availability. Lower moisture contributes to extended durability and freshness.
4. Texture and loaf volume: Increased loaf volume improves crumb softness, elasticity, and visual appeal.

In relation to the remaining technological innovations, the following benefits for both consumers and producers may be identified:

1. Hydrocolloids play a key role in extending bread freshness without chemical preservatives by delaying staling, a process associated primarily with starch retrogradation and water loss. They increase dough viscosity and stabilize structure, which translates into improved texture of the finished product. Hydrocolloids also enhance crumb softness and elasticity, perceived sensorially as prolonged freshness. Some hydrocolloids exhibit prebiotic properties beneficial for intestinal microflora.
2. The use of gases in breadmaking influences dough aeration. Carbon dioxide affects flavour and aroma, whereas nitrogen, as an inert gas, is used in packaging to extend freshness and protect against oxidation and mould growth. From an innovation perspective, dough gasification represents an advanced technological strategy for modifying raw material structure without chemical additives.
3. Supplementation with microelements and calcium and magnesium ions can serve as an effective method of enriching the diet with essential nutrients and preventing population-level deficiencies. This approach, however, involves several technological challenges, including the selection of appropriate mineral salts. When correct technological and legal standards are maintained, enriched bread can become a meaningful component of dietary prevention promoting healthy lifestyles.
4. The “zero-waste” technology in bakery production aims at eliminating waste generation, optimizing resource use, and implementing circular economy principles. The example presented in this article—alcohol production from bread waste—combines ecological, economic, and social benefits and represents a realistic and promising solution for the future of the bakery industry.

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