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THE IMPACT OF INNOVATION IN THE TECHNOLOGICAL PROCESS ON QUALITY. IMPROVEMENT: A CASE STUDY OF THE BAKERY INDUSTRY

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Purpose: The aim of the article is to present the impact of innovation in the technological process on the improvement of bread quality, using the bakery industry as an example.
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. The indicated survey research was carried out between 2020 and 2023, involving 51 bread producers from the Pomeranian Voivodeship, where 56 innovations implemented in the bread production technological process were identified. The analysis and evaluation of the research results were carried out in individual groups of innovations. The attempt undertaken in this article to determine the impact of the implemented innovations on improving the quality of bread indicates that the implemented innovations in the technological process had a noticeable impact on improving the quality of bread in all groups covered by the study, both for the producer and the consumer.
Practical implications: Practical implications include presenting the impact of innovation in the technological process on improving the quality of bread using the bakery industry as an example. This will be an important solution in making a number of decisions by managers and bakery owners in terms of strategic use of them.
Originality/value: The article may be a recommendation for manufacturing companies. The structure of the suggested management functions allows for manufacturing companies optimization, process control and manufacturing quality.
Keywords: bread quality, the essence of product innovations in the technological process, the classification of innovations within the technological process, the hierarchy of the impact of innovations in the technological process on the improvement of bread quality.
Category of the paper: research paper.

1. Introduction

Bread is a fundamental component of every Pole's diet. Within the structure of bakery products, bread accounts for approximately 70% (Ambroziak, 2002; Dziki et al., 2016). Bread and other bakery goods can contribute significantly- around 25–30% - to the body's daily energy requirements (Gambuś, Litwinek, 2011). The caloric value of bread is determined by its content of sugars, proteins, and fats. Bread, especially wholemeal varieties, alongside fruits and vegetables, is a primary source of dietary fiber. It also contains microelements and B-group vitamins (Dziwkosz, 2012). In this context, the issue of bread quality remains highly relevant.

Ensuring consumers have access to high-quality bread that simultaneously guarantees nutritional value and health safety should be a paramount concern for producers (Drozd, Wolniak, 2023). In recent years, a decline in the demand for bread has been observed; however, the share of all bakery products in overall food expenditures has decreased only slightly. The importance of other fresh bakery goods is steadily increasing (Drozd, 2021).

Following the economic system transformation, many new bakeries emerged. At the same time, factors such as significant price increases and changes in lifestyle have led to a partial reduction in bread consumption (Drozd, Wolniak, 2021). Intense competitive struggles have become a pressing issue for the modern bakery industry. The growing societal demands regarding bread quality have necessitated new solutions, with quality becoming a strategic objective.

In response to the transformations occurring within the bakery sector and considering the rising demand in Poland for bread of the quality expected by consumers, research was conducted between 2020 and 2023 to investigate the impact of innovations in the technological process on the improvement of bread quality. The survey involved a group of 51 bread producers from the Pomeranian Voivodeship, where a list of 56 innovations implemented in the bread technological process was compiled

2. The essence of product innovations in the technological process

The successful development of enterprises, both locally and globally, is conditioned by conscious and thoughtful implementation of innovations. It increasingly turns out that without their use, gaining a lasting competitive advantage has become practically impossible. Innovations are currently the most effective way to attain long-term market success. Nevertheless, to maintain adequate competitiveness, enterprises should strive to create new or enhance existing products and services, production processes, organizational structures, and marketing strategies (Wiśniewska, Grudowski, 2014; Żołnierski, 2006).

Starting from the methodology consistent with the Oslo Manual (Oslo, 2018), we can distinguish two main types of innovation:

- Innovations that lead to changes in a company's products (product innovations).
- Innovations that lead to changes in a company's business processes (business process innovations).

Product innovation includes activities aimed at a new or improved good or service that differs significantly from the enterprise's previous goods or services and that has been introduced to the market (Singh et al., 2022).

Business process innovation refers to a new or improved business process for one or more business functions that differs significantly from the company's previous business processes and that has been implemented for use by the enterprise.

For the purposes of the research, the technological process was treated as a functional whole within which product innovations are implemented.

According to the Oslo Manual, product innovations must provide a significant improvement in one or more characteristics or functional specifications. This includes the addition of new functions or improvements to existing functions or user utility. Relevant functional features in this context include quality, technical specifications, reliability, durability, cost-efficiency during use, affordability, convenience, usability, and user-friendliness.

Product innovations do not necessarily have to involve improvements in all functions and operational specifications. Enhancing or adding a new function may entail the loss of other features or a decrease in performance in certain aspects. Product innovations may be based on the use of new knowledge or technology, or they may rely on new applications or combinations of existing knowledge or technology.

In American literature, the production process is understood as the sum of all activities undertaken to produce a finished product within a manufacturing plant.

Within the production process, two fundamental areas can be distinguished: the technological process and auxiliary activities, which include transport, inspection, maintenance, and storage (Srivatsan et al., 2018).

The technological process is by far the most important element of the production process. It is defined as an organized and systematic set of activities aimed at altering the properties (physical or chemical) of the objects of labor (Feld, 2000). This issue can also be described as intentionally carried out chemical and physical phenomena that are designed to lead to the creation of the desired product.

Everything begins with a set of raw materials that undergo a deliberate transformation, resulting in the emergence of the final product (Sharma, 2017).

The technological process is an organized set of purposeful activities carried out during production, starting from the withdrawal of input material from the warehouse, through all technological, transport, inspection, and storage operations (including natural processes),

up to and including the delivery of the finished product (Duda, 2000). In these activities, specific resources are used to transform inputs into outputs (Zgodavova et al., 2020).

Many enterprises harbor concerns about implementing and applying new solutions based on innovations in technological processes. However, the growing pressure to improve market competitiveness and to provide better customer service makes this, at present, the only viable path for a company's development (Hall, 2005).

3. The impact of innovations in the technological process on the improvement of bread quality

The classification of innovations in the technological process

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. The indicated survey research was carried out between 2020 and 2023, involving 51 bread producers from the Pomeranian Voivodeship, where 56 innovations implemented in the bread production technological process were identified.

The innovations were systematized and divided into technological lines and machines.

Subsequently, the 22 technological lines (see Table 1) were classified into lines for the production of bread, bakery goods, frozen dough, and lines incorporating the use of robots.

The machines, totaling 34 units (see Table 2), were categorized into specific groups, including: silos, mixers with bowls, proofing chambers (dough proofers), thermal oil and electric ovens, and X-ray detectors.

Table 1.
Type of Innovation – Technological Lines

TYPE OF INNOVATION – TECHNOLOGICAL LINES
I. LINES FOR BREAD PRODUCTION
1. Industrial eco-friendly automated line
2. Cyclothermal automatic line
3. Automated line with overhead intermediate proofing
4. Automated line - producer no. 1
5. Automated line - producer no. 2
6. Automated line - producer no. 3
7. Automated line for the preparation and baking of bread with extended shelf life
8. Automated line with static intermediate proofing
II. LINES FOR BAKERY PRODUCT PRODUCTION
9. Eco-friendly automated line
10. Automated line - producer no. 1
11. Automated line - producer no. 2
12. Automated line - producer no. 3
13. Modified automatic line

Cont. table 1.

III. LINES FOR FROZEN DOUGH PRODUCTION
14. Automated line for frozen dough production - producer no. 1
15. Automated line for frozen dough production - producer no. 2
16. Designed automated line for frozen dough production
17. Automatic line for bread production from frozen dough
IV. TECHNOLOGICAL LINES WITH ROBOTS
18. Robotic system for loading and unloading bread from bakery ovens - producer no. 1
19. Robotic system for loading and unloading bread from bakery ovens - producer no. 2
20. System for palletizing and depalletizing with the participation of a multi-tasking robot
21. Robotic system equipped with advanced machine learning functions with innovative software supporting production processes
22. Transport system for handling specific machines by a robot

Sources: Studies based on data received from the bakery.

Table 2.

Type of Innovation – Machines

TYPE OF INNOVATION – MACHINES
I. SILOS
1. External silos made of acid-resistant steel for storing non-standardized flour, with automated delivery of the raw material to production
2. Monolithic silos made of stainless steel with automated flour delivery to production
3. External silos with automated flour delivery to production
4. Automated internal silos made of fiberglass
5. Automated internal silos made of fiberglass
6. Automated internal silos made of fiberglass
7. Automated flexible internal silos made of antistatic fabrics
8. Automated internal silos made of aluminum alloy
II. MIXERS WITH BOWLS
9. Automated set of spiral mixers with movable bowls
10. Automated set of spiral mixers with movable bowls
11. Automated set of spiral mixers with bottom discharge bowls
12. Automated set of spiral mixers with fixed bowls
13. Mixers with bottom discharge bowls
14. Spiral mixers with bowls on mobile carts
III. DOUGH PIECE PROOFING CHAMBERS *(PROOFING CHAMBERS)*
15. Set of proofing chambers
16. Set of proofing chambers
17. Set of freezing-proofing chambers
18. Set of proofing chambers
19. Through-flow proofing chambers
20. Chambers for delayed baking
IV. THERMO-OIL AND ELECTRIC OVENS
21. Automated thermo-oil ovens
22. Automated rack-type thermo-oil ovens
23. Automated batch-type thermo-oil ovens
24. Automated tunnel-type cyclothermal ovens
25. Automated rotary thermo-oil ovens
26. Thermo-oil ovens with an automatic dough loading system
27. Trolley-type thermo-oil ovens
28. Automated electric ovens
29. Automated modular bakery ovens
V. X-RAY DETECTORS
30. Industrial X-ray detector
31. X-PERT X-ray detector
32. EAGLE X-ray detector
33. NEXT GUARD X-ray detector
34. DMX X-ray detector

Sources: Studies based on data received from the bakery.

The description of the individual groups of innovations implemented in the technological process, along with their expected impact on the improvement of bread quality, was developed based on: domestic and foreign literature, information provided by bread producers in questionnaire surveys, participant observations conducted in bakeries.

Innovations in the technological process are primarily aimed at introducing changes in the methods of product manufacturing (Andersson et al., 2020). Meanwhile, bread quality is the result of a range of factors shaping the production process, including the machinery used (Ribeiro, Collins, 2007).

4. Determining the expected impact of innovations on the improvement of bread quality in bakeries

The innovations implemented in the technological process across the 51 surveyed bakeries share common features that contribute to the improvement of bread quality, in particular:

1. The machines installed in the technological lines were made of high-quality, smooth materials, easy to keep clean, which helps protect the working environment by reducing dust pollution in production areas (Drozd, 2019; Carla et al., 2024). The hermetic sealing of technical equipment, in turn, limits the dispersion of flour dust. This dust, when combined with high humidity and air temperature, creates favorable conditions for the development of microorganisms (such as mold spores) and pests such as cockroaches, weevils, and mites (Drozd, 2020; Cauvain, 2017). To produce high-quality bread, it must be manufactured under conditions that meet applicable hygiene standards, to which specialized technical equipment designed for the bakery industry significantly contributes. Production safety thus translates directly into the health safety of bread (Cappelli et al., 2021).
2. Specialized technical equipment is designed to prevent the deterioration of raw material quality during the technological process, mainly by ensuring strict adherence to technological parameters. This approach protects, among other things, the nutritional value of bread (Cauvain, Clark, 2019). Technological parameters that affect bread quality include fermentation time, dough yield and the degree of souring during the various production phases, dough mixing time and intensity, proofing time of dough pieces, as well as baking temperature and time (Cacak-Pietrzak, Rakocka, 2022). New bread production technologies enable the shortening of production phases or even entire processes, while simultaneously improving product quality (Oest et al., 2020). This is associated with changing bread yield standards, which are influenced, among other factors, by the production technology conditions of the bakery where the measurement is taken (Sassanelli et al., 2021). The standards for average bread yield

must allow for the achievement of optimal bread quality within the existing technical conditions of the bakery (Drozd, 2019).

3. The broad and diverse range of recipes currently available in Poland has greater application potential in automated and robotized bakeries. With the use of appropriate technology, the proper composition of raw materials, i.e., the recipe, should ensure the intended nutritional value (Drozd et al., 2022).
4. Automation and robotization primarily ensure the repeatability and accuracy of individual production phases, which significantly affect bread quality (Hawryluk, 2019).
5. The quality of bread and the repeatability of its technological parameters are determined primarily by the knowledge and qualifications of employees, as well as by the high quality of machines and equipment (Drozd, 2019; Van der Spiegel et al., 2005). Innovations introduced into the technological process necessitate the employment of workers with appropriate qualifications to operate technological lines, robots, and machines.
6. In professional literature, the selection and stability of optimal process parameters are recognized as key factors shaping bread quality (Kamel, Stauffer, 2003). This task falls mainly to the management staff overseeing the technological process, particularly technologists.

The first group of innovations implemented in bakeries concerned technological lines.

Specialized bread production lines are currently equipped with various machines, particularly dividers or scales integrated with dividers, rounders, molders, dough piece separators, and belt conveyors. The rounder installed in the technological line gives the dough pieces a smooth surface, which, when sprayed with water, affects the bread crust. A specific microclimate is created in the dough proofing chamber, allowing the dough to "relax" and stabilize its structure. The molder gives the loaves their proper shape. The ideal synchronization of the line's operations ensures that the bread baking process occurs precisely within the specified time frame (Bejaei et al., 2021; Constantinescu, 2021).

Modern automated lines also make it possible to produce health-promoting loaves containing sourdough additives, which enhance both the flavor and aroma, as well as loaves with extended shelf life. A popular bread production line in Poland is the ICP Bread Line, which features an overhead intermediate proofer. The arrangement of machines within this line can be adapted to the spatial conditions of the bakery. Automated bread production lines, in particular, guarantee the baking of highly consistent doughs, resulting in loaves with perfect shape and that meet strict technological parameters (Drozd, 2019; Dan et al., 2018).

Producers from the Pomeranian Voivodeship have invested in specialized automated technological lines for bread production, sourced both from the Polish and international markets.

The bread production lines installed in the Pomeranian Voivodeship are high-quality specialized technical devices that enable the manufacture of a wide range of top-quality bakery products. The quality of bread is greatly influenced primarily by the gentle "handling" of the dough without damaging its structure. The dough is highly consistent, has an ideal shape, and meets strict baking parameters.

Automated lines have a modular design and mainly consist of a dough divider, molder, rounder, and intermediate proofer. Additionally, automation and production efficiency are supported (depending on the type of line) by other machines such as bowl tippers, funnels, weight controllers, conveyors (various solutions), and greasing devices. Automated bread production lines guarantee excellent results in the production of many types of bakery products, both in terms of recipes and product shape. Automation allows for the fine-tuning of line parameters by stimulating specific technological processes in bread production and optimizing changeovers in the longer term (Kotsianis et al., 2022).

Only specialized lines are used for the production of frozen dough. Frozen dough is intended for baking rolls and bread directly at the point of sale. Most large distribution chains, restaurateurs, and even convenience stores at petrol stations are moving toward the final baking of bread at the point of sale. Two delayed baking technologies are employed: one involves shock-freezing raw dough pieces and storing them frozen, while the other involves shock-freezing partially baked dough pieces, which are then finished baking later (Słowik, Staszewska, 2002).

During the dough freezing process, the development of microorganisms is inhibited; however, this requires precise cooling to produce high-quality dough that meets established bakery standards. Frozen bread does not contain preservatives or artificial colorings but is generally devoid of natural sourdough (Ocieczek et al., 2016). Despite its advantages and disadvantages, bread made from frozen dough enjoys steady demand because it provides consumers with the key attribute of freshness, identified with external appearance-crumb structure, aroma, and crust. Among the specialized lines for frozen dough production, a custom-designed line was also installed in the Pomeranian Voivodeship.

An inseparable element of every robotized technological line is the inclusion of components related to occupational safety and hygiene, in the form of so-called technological fencing (Drozd, Wolniak, 2023; Kaczmarek, Panasiuk, 2015). The primary purpose of this enclosure is to properly secure the entire robotized technological line against accidental or unauthorized access by external persons, as well as to prevent cross-contamination (Gawęcki, Roszkowski, 2010).

Cross-contamination by pathogenic agents significantly impacts food safety and public health levels and is among the most common causes of food poisoning (Adams, Moss, 2008). Robots intended for contact with food must meet high standards of occupational safety and hygiene. For example, mandatory equipment includes grippers with "soft fingers", stainless

steel connectors, emergency stop switches, and vision systems-all of which also influence the health safety of food products (Mortimore, Wallace, 2013).

The benefits of implementing robots in technological processes also extend to the reliability of machines within robotized systems, due to their increasingly faster operating speeds. This, in turn, helps ensure the timely delivery of fresh bread to the retail network (Drozd, 2019).

In Europe, the following advantages of robotization are recognized: greater flexibility of manufacturing processes, improvement of the standard and quality of food products, and enhancement of workplace safety (Cséfalvayb, Gkotsis, 2018). Robotization does not require fundamental changes to the production process but rather modifies tasks that represent "bottlenecks" within the technological process (Kaczmarek, Panasiuk, 2014).

In the bakeries of the Pomeranian Voivodeship, robots have been applied in the technological process for tasks such as loading and unloading dough from bakery ovens, palletizing and depalletizing with the use of multifunctional robots, transport to service specific machines, and controlling specific production phases (Drozd, 2019, 2020). Each implemented robotized system requires an individualized approach to the design of work and operation (Nasruddin et al., 2013).

The second group of innovations implemented in the bread technological process consisted of machines, which were assigned to specific categories. Silos are intended for the storage of the basic raw material, which is flour. Flour is delivered directly into the silos from specialized transport vehicles. Modern silos are equipped with a control system featuring scales and tensometric sensors. Thanks to the operation of such a system, a bakery has full control over flour delivery and consumption throughout the entire production cycle.

The installation of sifting systems, screens, and the hermetic sealing of storage tanks ensures high quality and cleanliness of the raw material, eliminating the presence of foreign bodies. Regular aeration of the flour (the so-called "massaging" process) creates excellent conditions for its maturation (Drozd, Wolniak, 2023). Bakeries have also invested in silos made from acid-resistant steel, intended primarily for the storage of non-standardized flour without chemical additives and enhancers. Depending on the spatial conditions, either external or internal silos are installed. Bread producers aim, whenever possible, to purchase internal silos, which, in their opinion, offer more favorable flour storage parameters (Lubczyńska, 2002). External silos, however, are exposed to changing weather conditions. The introduction of modern silo systems significantly contributes to the improvement of bread quality, mainly through the optimal aeration and loosening of flour.

Mixers with bowls represent the next group of machines within the bread technological process. After sifting, the flour is combined with other ingredients such as yeast or natural sourdough, salt, sugar, enhancers, and water, which is gradually added. Automated mixers are connected to high-precision weighing hoppers and a control computer, ensuring the consistency of raw materials and the precise execution of recipes. The water added also has a strictly controlled temperature. These procedures ensure the even combination of all dough ingredients

during the mixing, creaming, kneading, and folding stages, within a specified timeframe. Through automated control processes, excellent dough consistency and a reduction in mixing time are achieved, both of which positively impact bread quality (Sassanelli et al., 2021).

It is worth emphasizing that in modern mixers with bowls, together with auxiliary devices, the following solutions are used: variable mixing speeds to eliminate dough overheating, an optimized mixing process guaranteeing good aeration, the ability to accelerate dough development through intensive high-speed mixing with reduced yeast quantities, laser measurement of dough temperature, and the fulfillment of stringent hygiene and occupational safety standards. Manufacturers of bakery equipment also offer the integration of a linear transport system, which guarantees a high level of automation. This system enables the simultaneous management of dosing, mixing, and bowl emptying processes, allowing multiple recipes to be executed at once in different mixers (Drozd, 2020).

Dough piece proofing chambers (proofing chambers) are responsible for the resting phase of dough pieces, which significantly affects their proper rising. This production phase requires the appropriate temperature, air humidity, and proofing time. Modern proofing chambers allow for the implementation of various initial fermentation times for the dough. Inside the chamber, ideal conditions are maintained for yeast activity, ensuring that the fermentation process proceeds in a stable and repeatable manner. Furthermore, modern proofing chambers allow precise control of air humidity and temperature, with the ability to adjust conditions individually for each type of dough. Proper dough rising fundamentally influences the structure and flavor of the final product (Martinez-Monzo et al., 2022).

In the Pomeranian Voivodeship, a chamber for delayed baking has also been installed. It allows dough to be stored under optimal temperature and humidity conditions for a specified period. Thanks to this, production can be planned in advance, using ready dough for baking at the appropriate moment. Delayed baking chambers eliminate the risk of excessive or insufficient dough rising, which affects its structure, flavor, and even shelf life (Maśliński, 2008).

The functionality and reliability of bakery ovens are of great importance for maintaining a stable baking temperature, depending on the type of dough being baked (Niziński, Michalski, 2007). According to bakers, the optimal baking temperature primarily determines characteristics such as the shape, color, elasticity, aroma, flavor, and crust of the bread. Modern thermo-oil ovens are made entirely of acid-resistant steel and are designed for intensive use. They are equipped with control systems linked to computers that continuously monitor the proper operation of the devices. The construction of thermo-oil ovens ensures even temperature distribution across the heating plates, guaranteeing uniform and repeatable baking (Drozd, 2019).

In one of the bakeries, a rotary oven was installed, which is considered one of the most energy-efficient models and significantly impacts the quality of the bake (Karaszewski, 2005). The baking parameters of the dough are specific to each oven model and must, therefore,

be determined empirically for each individual unit (Ambroziak, 2002). In the Pomeranian Voivodeship, a set of automated electric ovens was also installed. This system consists of six independent baking chambers of various capacities. Each chamber is equipped with its own steaming system and control panel. The advantage of this solution is the ability to simultaneously bake a variety of pastry assortments.

In bakeries within the Pomeranian Voivodeship, a cyclothermal tunnel oven and a thermo-oil rack oven were also installed. Cyclothermal tunnel ovens are intended for the mass production of specific products and operate based on the circulation of hot air through recirculation channels, providing these ovens with a high thermal capacity (Banooni et al., 2023). Thermo-oil rack ovens are versatile and combine the advantages of rotary ovens with classic deck ovens. Gentle heat radiation, the application of air convection, and an appropriate steaming system all contribute to the continuous improvement of baking quality (Cappelli, Cini, 2021).

The operating principle of the detector is based on X-ray structural analysis. Thanks to the diffraction scattering of radiation generated by sources of ionizing radiation, a projection of the object's internal structure is produced and monitored on a screen. The X-ray detector is capable of inspecting both unpackaged bread and bread packaged in metallized foil, while simultaneously performing weight measurements (Mathanker, Weckle, 2020).

Above all, the X-ray detector enables the detection of high-density foreign bodies and contaminants such as metals, glass, stones, bones, rubber, and plastics, and it rejects contaminated bread. Additionally, certain types of X-ray detectors can identify product defects such as breakage or deformation, as well as assess bread weight, degree of filling, and shape (Gawęcki, Roszkowski, 2010). In the Pomeranian Voivodeship, high-quality X-ray detectors were also installed. The integration of X-ray detectors into technological lines contributes to food safety, improves the shape and volume of the bread, and enhances hygienic and sanitary conditions. According to the World Health Organization, the irradiation of food does not affect its safety or nutritional value (Cafarelli et al., 2022).

5. Summary

The functionality of modern, automated technological machine lines, implemented in the bakeries during the study period, differs significantly from technological processes controlled manually by humans. Modern machines within technological lines now fulfill tasks that were previously performed by employees and, moreover, contribute to the improvement of bread quality. Nevertheless, appropriate qualifications are necessary to operate modern machinery.

The research procedure was conducted with the aim of determining the expected impact of the innovations implemented in the technological process on the improvement of bread quality.

The analysis and evaluation of the research results were carried out within the individual groups of innovations. Among the automated technological lines for the production of bread and bakery products, in terms of improving bread quality, all three groups of factors related to the technological process should be highlighted, particularly: the repeatability and precision of individual production phases; the ability to apply appropriate raw material compositions to ensure the intended nutritional value; the ideal synchronization of the line's operation, ensuring that the baking process takes place precisely at the scheduled time; the possibility of optimizing process parameters; the elimination of human errors; the monitoring and control of technological process parameters; the protection of raw material quality through compliance with strict technological parameters; and ensuring a sufficient supply of fresh bread to the market, identified by its external characteristics such as crumb structure, aroma, and crust quality.

Specialized lines for frozen dough production, designed for baking rolls and bread at the point of sale, provide consumers with high-quality products (provided precise freezing is maintained), free of preservatives and colorants while guaranteeing freshness. In terms of bread quality, freshness is the most valued attribute by consumers. The benefits of implementing robots are primarily observed in ensuring hygienic and sanitary conditions as well as the reliability of machinery, in addition to modifying tasks that previously represented "bottlenecks" within the technological process. Moreover, the entire operational area of a robot is secured through technological barriers, which also prevent cross-contamination.

The impact of innovative machine groups, primarily automated, on the improvement of bread quality manifests itself in terms of technological and raw material factors, namely:

- Silos – providing appropriate storage conditions for the primary raw material, flour; introducing a sifting and aeration system; and ensuring direct connection to the technological machine line.
- Mixers with bowls – achieving the even incorporation of all dough ingredients within a specified time and obtaining excellent dough consistency.
- Dough piece proofing chambers – ensuring appropriate temperature, air humidity, and proofing time for the dough pieces, conditions that modern chambers can precisely deliver.
- Bakery ovens – maintaining the designated baking temperature at a stable level depending on the type of dough being baked.
- X-ray detectors – intended for the detection of foreign bodies and the rejection of contaminated bread. Some types of detectors, also installed in the Pomeranian Voivodeship, are capable of detecting product defects such as breakage or deformation.

Regardless of the specific actions undertaken to improve bread quality through the implemented innovations, it should be noted that all modern technical devices installed within the technological lines are made from high-quality smooth materials that are easy to clean and are hermetically sealed. This contributes to the reduction of dust and flour particle contamination, thereby improving hygienic and sanitary conditions in bakeries.

The attempt undertaken in this article to determine the impact of implemented innovations on the improvement of bread quality indicates that the technological innovations introduced have had a noticeable and positive effect on the enhancement of bread quality across all groups covered by the study, benefiting both producers and consumers.

References

1. Adams, M.R., Moss, M.O. (2008). *Food Microbiology-Third Edition.* Cambridge: The Royal Society of Chemistry, pp. 112-121.
2. Ambroziak, Z. (2002). Jakość pieczywa. In: *Piekarstwo – receptury, normy, porady i przepisy prawne* (pp. 109-113). Warszawa: Zakład Badawczy przemysłu Piekarskiego.
3. Andersson, R., Hamalainen, M., Aman, P. (2004). Predictive modelling of the bread-making performance and dough properties of wheat. *Journal of Cereal Science, Vol. 20,* pp. 129-138.
4. Banooni, S., Hosseinalipour, S.M., Mujumdar, A.S., Taherkhani, P., Bahiraei, M. (2023). Baking of flat bread in an impingement oven: modeling and optimization. *Journal of Drying Technology, Vol. 27(1),* pp. 103-112.
5. Bejaei, F., Seyedlou, S., Nalbandi, H., Ghassemzadeh, H.R. (2021). Developing the new industrial flatbread baking system using numerical technique to increase the product quality. *Journal of Food Process Engineering, Vol. 44, Iss. 11,* pp. 34-38.
6. Cacak-Pietrzak, G., Rakocka, A. (2022). Deferred Bread Baking Technology. *Journal of Grain and milling review, Vol. 1,* pp. 12-17.
7. Cafarelli, B., Spada, A., Laverse, J. (2024). X-ray microtomography and statistical analysis: Tools to quantitatively classify bread microstructure. *Journal of Food Engineering*, *Vol. 124*, pp. 64-71.
8. Cappelli, A., Cini, E. (2021). Challenges and opportunities in wheat flour, pasta, bread, and bakery product production chains: A systematic review of innovations and improvement strategies to increase sustainability, productivity, and product quality. *MDPI - Publisher of Open Access Journals, Vol. 13*, *Iss. 5*, pp. 26-38.
9. Cappelli, A., Lupori, L., Cini E. (2021). Baking technology: A systematic review of machines and plants and their effect on final products, including improvement strategies. *Elsevier Journal Finder*, *Trends in Food Science & Technology*, *Vol. 115*, pp. 275-284.

10. Carla, A., Geraldes, S., Fabiane, K., Almeida, P. (2024). Improving the Production Process of a Baker. *Elsevier Journal - Flexible Automation and Intelligent Manufacturing: Establishing Bridges for More Sustainable Manufacturing Systems, Vol. 2*, pp. 128-135.
11. Cauvain, S.P. (2017). Baking problems solved- 2nd Edition. *Elsevier Journal - Woodhead Publishing Series in Food Science, Technology and Nutrition*, *Vol. 17,* pp. 56-69.
12. Cauvain, S.P., Clark, R.H. (2019). *Baking technology and nutrition*: *Towards a healthier world*. New Jersey (USA): John Wiley&Sons Ltf, pp. 56-71.
13. Constantinescu, C.G. (2021). *Study on influence of baking parameters on bread quality*. Publishing Series in Modern Technologies in the Food Industry, pp. 15-18.
14. Cséfalvayb, Z., Gkotsis, P. (2018). *Robotisation race in Europe: The Robotisation Chain Approach*. Oxford (UK): Economics of Innovation and New Technology, pp. 15-18.
15. Dan, Pop, A., Rus, G., Drenta, R.F. (2018). *Modeling and simulation of technological factors in bakery industry*. Slovakia: Springer. Advances in Manufacturing Engineering and Materials, pp. 531-538.
16. Drozd, R. (2019). Reliability of production machines in the bakery industry – theoretical and practical issues. *ABID, Vol. 3*, pp. 208-214.
17. Drozd, R. (2019). The influence of robotization on the reliability of the production process in the bakery industry. *ABID, Vol. 3*, pp. 223-230.
18. Drozd, R. (2020).The role of robotisation in improving bakery product quality. *ABID, Vol. 4,* pp. 261-267.
19. Drozd, R. (2021). Concept of managing quality in baking industry. In: Vector Representation. *Scientific papers of Silesian University of Technology. Organization and Management Series, No. 151*, pp. 157-172.
20. Drozd, R. (2021). Health safety of bread in small bakeries. *Scientific papers of Silesian University of Technology. Organization and Management Series, No. 157*, pp. 83-96.
21. Drozd, R., Wolniak, R. (2021). Systematic Assessment of Product Quality. *Journal of Open Innovation: Technology, Market and Complexity, Vol. 7*, pp. 1-12.
22. Drozd, R., Wolniak, R. (2023).Implementing the quality assurance system and assuring health safety in the light of increasing bread quality. *Scientific papers of Silesian University of Technology. Organization and Management Series, No. 176*, pp. 83-96.
23. Drozd, R., Wolniak, R., Piwnik, J. (2022). Systemic analysis of a manufacturing process based on a small scale bakery. *Publishing House Springer, Quality & Quantity Vol. 57(2),* pp. 1421-1437.
24. Duda, J. (2000). *Modelowanie procesu decyzyjnego w zautomatyzowanym projektowaniu procesu technologicznego*. Kraków: Politechnika Krakowska, pp. 1-9.
25. Dziki, D., Sidstała, M., Laskowski, J. (2016). Ocena właściwości fizycznych pieczywa. *Acta Agrophysica, No. 18(2),* pp. 235-239.
26. Dziwkosz, A. (2012). Pozycja pieczywa w diecie. *Przegląd Piekarski i Cukierniczy*, *No. 10,* pp. 16-17.

27. Dziwolak, W. (2015). Zarządzanie alergenami w produkcji środków spożywczych. *Problemy Jakości, No. 4*, pp. 24-28.
28. Feld, M. (2000). *Podstawy projektowania procesów technologicznych*. Warszawa: WNT, pp. 75-80.
29. Gambuś, H., Litwinek, D. (2011). *Pieczywo – dlaczego warto jeść i jakie wybierać*. Kraków: Uniwersytet Rolniczy w Krakowie, Wydział Technologii Żywności, pp. 23-29.
30. Gawęcki, J., Roszkowski, W. (2010). *Żywienie człowieka z zdrowie publiczne, cz. III*. Warszawa: PWN, pp. 34-39.
31. Haff, R.P., Toyofuku, N. (2018). X-ray detection of defects and contaminants in the food industry. *Journal of Sensing and Instrumentation for Food Quality and Safety, Vol. 2,* pp. 262-273.
32. Hall, B. (2005). Innovation and Diffusion, In: J. Fagerberg, D. Mowery, R.R. Nelson (Ed.), *The Oxford Handbook of Innovation,* pp. 101-104.
33. Hawryluk, P. (2019). Automatyzacja i robotyzacja procesów produkcji – trudność czy konieczność. *Przegląd Transport Przemysłowy i Maszyny Rolnicze, Vol. 1*, pp. 170-172.
34. Kaczmarek, W., Panasiuk, J. (2014). Rynek robotyki - trendy i przegląd nowych rozwiązań. *Control Engineering Polska, Vol. 5(109)*, pp. 80-88.
35. Kaczmarek, W., Panasiuk, J. (2015). Roboty w typowych procesach i aplikacjach. *Automatyka, Vol. 6*, pp. 115-117.
36. Kamel, B.S., Stauffer, C.E. (2003). *Advances in baking process technology*. USA: Springer Science Business Media B.V., Technical Foods Consultant, pp. 143-156.
37. Karaszewski, R. (2005). *Zarządzanie jakością. Koncepcje, metody i narzędzia stosowane przez liderów światowego biznesu*. Toruń: Wydawnictwo Dom Organizatora, pp. 106-109.
38. Kotsianis, I.S., Giannou, V., Tzia, C. (2022). Production and packaging of bakery products using MAP technology. *Elsevier Journal - Trends in Food Science & Technology, Vol. 13. Iss. 9-10*, pp. 319-324.
39. Lubczyńska, H. (2002). Surowce piekarskie, In: *Piekarstwo - receptury, normy, porady i przepisy prawne. Zakład Badawczy Przemysłu Piekarskiego, Handlowo-Usługowa Spółdzielnia „Samopomoc Chłopska”*, pp. 97-107.
40. Martinez-Monzo, J., Garcia-Segovia, P., Albors-Garrigos, J. (2022). Trends and innovations in bread, bakery, and pastry. *Journal of Culinary Science & Technology, Vol. 11, Iss. 1*, pp. 56-65.
41. Maśliński, K. (2008). *Użytkowanie maszyn i urządzeń do wytwarzania i obróbki produktów piekarskich*. Radom: Instytut Technologii Eksploatacji - Państwowy Instytut Badawczy, pp. 34-38.
42. Mathanker, S.K., Weckle, P.R. (2020) X-ray applications in food and agriculture: A review. *American Society of Agricultural and Biological Engineers*, *Michigan, Transactions of the ASABE, Vol. 56(3),* pp. 1227-1239.

43. Mortimore, S., Wallace, C. (2013). *HACCP. A practical approach. Third Edition*. London: Springer, pp. 124-131.
44. Nasruddin, H., Afrfah, H., Pazil, M.D., Idris, N., Fazilah, R.N. (2013). A goal programming model for bakery production. *Journal of Advances in enyironmental biology, Vol. 7, No. 1,* pp. 187-190.
45. Niziński, S., Michalski, R. (ed.) (2007). *Utrzymanie pojazdów i maszyn*. Radom: ITE-PIB, pp. 102-108.
46. Ocieczek, A., Pukszta, T., Nebel, J. (2016). Wpływ zamrażalniczego przechowywania na wybrane cechy jakościowe pieczywa. *Organ Naczelnej Organizacji Technicznej, Vol. 5. No. 12*, pp. 6-11.
47. Oest, M., Bindrich, U., Vob, A., Kaiser, H.R. (2020). Bread Defects: Analysis of composition and further influence factors as determinants of dry-baking. *Journal MDPI, Food Quality and Safety, Vol. 9,* pp. 112-120.
48. Podręcznik Oslo 2018. *Zalecenia dotyczące pozyskiwania, prezentowania i wykorzystywania danych z zakresu innowacji*. Retrieved from: https://stat.gov.pl/files/gfx/portalinformacyjny/pl/defaultaktualnosci/5496/18/1/1/podrecznik_oslo_2018_internet.pdf, 25.04.2025.
49. Ribeiro, R., Collins, H. (2007). The Bread-making machine: Tacit knowledge and two types of action. *Elsevier Journal, Sage Journals Home*, *Vol. 28, Iss. 9*, pp. 23-29.
50. Sassanelli, C., Da, Costa., Feraandes, S., Terzi, S. (2021). Enhancing knowledge management in the PSS detailed design: a case study in a food and bakery machinery company. *Elsevier Journal, Sage Journals Home*, *Vol. 29, Iss. 4,* pp. 1-14.
51. Sharma, K.L.S. (2017). In overview of industrial process automation - Second Edition. *Elsevier Journal*, *Vol. 23*, pp. 45-48.
52. Singh, S., Prakash, Ch., Ramakrishna, S. (2022). Innovative Processes and Materials in Additive Manufacturing. *Elsevier Journal*, *Vol. 19*, pp. 4-6.
53. Słowik, E., Staszewska, E. (2002). Odroczony wypiek pieczywa, In: M.L. Janik M.L. (Eds.), *Piekarstwo - przepisy, normy, porady prawne* (pp. 145-149). Warszawa: Zakład Badawczy Przemysłu Piekarskiego i Handlowo Usługowa Spółdzielnia "Samopomoc Chłopska".
54. Srivatsan, T.S., Manigandan, K., Sudarshan, T.S. (2018). Use of Conventional Manufacturing Techniques for Material. In: T.S. Sudarshan, T.S. Manigandan (Eds.), *Manufacturing Techniques for Materials: Engineering and Engineered.* USA, pp. 436-437.
55. Van der Spiegel, M., Luning, P.A., De Boer, W.J., Ziggers, G.W., Jongen, W.M. (2005). How to improve food quality management in the bakery sector. *Journal of Life Sciences, Vol. 2, No. 53*, pp. 131-150.
56. Wiśniewska, M.Z., Grudowski, P. (2014). *Zarzadzanie jakością i innowacyjność w świetle doświadczeń organizacji Pomorza.* Gdańsk: InnoBaltica, pp. 23-27.

57. Zgodavova, K., Bober, P., Majstorovic, V., Monkova, K., Santos, G., Juhaszova, D. (2020). Innovative methods for small mixed batches production system improvement: The Case of a Bakery Machine Manufacturer. *MDPI - Publisher of Open Access, Actual Trends of Logistics and Industrial Engineering, Vol. 12(15)*, pp. 62-66.
58. Żołnierski, A. (2006). *Innowacyjność - metody wspierania, programy badawcze*. Warszawa Polska Agencja Rozwoju Przedsiębiorczości, Wydanie I, pp. 32-35.