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MODELING THE DETERMINANTS OF BREAD QUALITY IN THE TECHNOLOGICAL PROCESS

The aim of the article is to present the determinants of bread quality within the technological process, along with a model illustrating their interrelations. Based on a review of the literature as well as the authors' own research conducted in bakeries, individual determinants of bread quality in the technological process were characterized and categorized into three primary groups: raw material factors, technological factors, and organizational-technical factors. All identified determinants constitute a functional whole, forming the basis for the development of a functional model of bread quality determinants in the technological process. This model serves as a theoretical tool for research purposes. Using the results of studies carried out in bakeries located in the Pomeranian Voivodeship, a model was also developed to demonstrate the impact of implemented innovations in the technological process on the remaining determinants of bread quality.

Keywords: technological process, quality determinants in the bread technological process, improvement of bread quality.

1. INTRODUCTION

Bread in Poland is a fundamental component of the daily diet. When approached rationally, it can play an invaluable role in regulating the human digestive system and provide a significant portion of the body's daily energy requirements (approximately 25-30%). In addition to its nutritional function, bread can also serve pro-health purposes, and it is precisely such products that are of interest to today's consumers (Drozd, Wolniak, 2023).

Driven by the popularity of a healthy lifestyle, consumer interest is increasing in wholegrain breads, breads with added seeds, products with reduced salt content, high-protein breads, and those with specialized compositions (Galanakis, 2020).

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Ensuring the availability of high-quality bread that guarantees both nutritional value and health safety should be a priority for producers (Van der Spiegel et al., 2005).

Consumer awareness continues to grow. People are increasingly attaching importance to the health-promoting qualities of food, including bread. Changes in dietary habits, consumer behaviors, and purchasing models have led modern customers to show interest in bread products that meet specific dietary needs (Lubczyńska, 2002), such as:

- with increased fiber content;
- high-protein varieties intended for people with diabetes;
- starch-based (gluten-free) products;
- low-sodium options, e.g., for individuals with obesity, hypertension, or certain heart and kidney conditions.

In the technological process, it is crucial to identify the stages at which the quality of the product is vulnerable to change. Can these changes be eliminated, or are there preventive measures necessary to ensure the production of safe food? What factors influence the quality of the product? (Luning, 2005).

The subject literature-both international and Polish-does not provide unequivocal opinions regarding the specific factors that influence product quality in the technological process. Based on the literature (which will be cited in the characterization of individual factors) and the authors' own observations resulting from interactions with bakery enterprises, three primary groups of factors shaping bread quality in the technological process have been identified: raw material factors, technological factors, and organizational-technical factors. Within these three groups, eight specific determinants of bread quality operate.

In response to the ongoing transformations in the bakery sector, particularly concerning the automation and robotization of production lines, empirical research was conducted in 51 bakeries located in the Pomeranian Voivodeship between 2020 and 2023. The aim of this research was to assess the influence of one of the technological process factors-namely, innovation-on the remaining determinants of bread quality.

2. CURRENT STUDIES – CHARACTERISTICS OF BREAD QUALITY DETERMINANTS IN THE TECHNOLOGICAL PROCESS

2.1. Raw material factors

Raw material factors that shape the quality of bread are currently influenced by the growing popularity of a healthy lifestyle among consumers, who prefer high-quality products made from high-quality raw materials. The most important raw material factors related to bread quality in the technological process include: the quality of the raw materials used in production, properly established bread yield standards, and the composition of the raw materials (Drozd, 2022).

According to the professional literature, raw materials accepted into the warehouse of a production facility should possess high nutritional and health quality as well as appropriate technological suitability. All raw materials accepted into a bakery's warehouse should be checked primarily for organoleptic properties, expiration dates, declared weight conformity, packaging damage, and appropriate storage conditions during transport (Soares Geraldes et al., 2023).

The basic raw materials for bread production are: flour, water, yeast, salt, and fats. These materials must meet the recommended standards, including (Ambroziak, 2002):

- wheat flour – high gluten content and quality, high falling number, high sedimentation index, high water absorption capacity;
- rye flour – high falling number, appropriate granulation;
- solid fats – uniform consistency throughout the mass and even coloring;
- clarified oils.

The quality of flour, as the primary raw material, is greatly influenced by agroclimatic conditions, the genetic properties of cultivated cereal varieties, proper selection during grain procurement, and milling technology (Cappelli, Cini, 2021). Depending on the storage conditions, flour's technological suitability and health quality may either improve or deteriorate. The optimal storage conditions for flour are temperatures between 15 and 18°C with relative air humidity ranging from 65 to 70%. Flour-mainly wheat flour-is stored in silos, but it may also be kept in sacks. Bakery facilities usually have several silos, which are equipped in various ways, including control systems with scales and strain gauge sensors. Thanks to such systems, bakeries can fully control the delivery and consumption of flour during the technological process. Additionally, the use of sieve systems and airtight silo containers guarantees high quality and cleanliness of the raw material. The internal tanks of silos, due to the cyclical aeration of flour (the so-called flour massage), ensure good flour maturation properties (Djonovic et al., 2024).

The quality of flour in bakery production has a decisive influence on the course of technological processes. Baking value-meaning the quality of the flour-is a set of features that determine how it behaves during baking. These include the ability to produce and retain gas, the color of the flour and its tendency to darken, and granulation (milling coarseness).

Another factor that shapes the quality of bread during the technological process-and simultaneously affects raw material costs in the baking industry – is the proper determination of bread yield standards while maintaining high product quality. The average bread yield standard, known as "baking output", refers to the number of kilograms of bread obtained from 100 kg of flour. Every bread producer is obligated to establish an average yield standard for each type of bread based on a control bake. When setting the average bread yield standard, it is recommended to follow allowable bread composition standards that ensure good flavor. Bread yield standards should be periodically reviewed and adjusted. An appropriate raw material composition-that is, the formulation-is a basic requirement for producing high-quality bread. The formulation should ensure the intended nutritional value and desirable taste qualities of the bread, using proper technology. These parameters are achieved through the correct selection of basic raw materials and substances that enrich nutritional value or enhance and improve the final product (Zgodavova et al., 2020).

Each bakery product should be manufactured based on a formulation, and its basic quality parameters should be defined by an appropriate standard, such as a Polish Standard or an Internal Company Standard. An Internal Company Standard is developed when a product, based on a proprietary formulation, differs in parameters from the PN. The internal formulation should include all elements of the reference formulation and must also be approved by the bakery manager or owner (Drozd, 2019b).

The shape and unit weight (grammage) of bread are not mandatory, as current Polish Standards allow for the production of bread in various shapes and weights.

2.2. Technological Factors

The next group of factors shaping the quality of bread is directly related to the production technology (technological factors). Proper bread quality can be ensured through the selection and stability of optimal process parameters, including controlled process efficiency (Linzalone, Lerro, 2022).

The technological parameters that particularly affect bread quality include: temperature, fermentation time, yield and degree of multiplication (acidification) of individual dough preparation phases, dough mixing time and intensity, proofing time of dough pieces, and baking time and temperature. The values of these parameters can be modified only within certain limits.

Baking of bread should be conducted with great care. It is a process through which bacteria, molds, and yeasts present in the bread-originating from raw materials, fermentation, the environment, etc.-are destroyed, provided that the appropriate time and temperature have been applied (Martinez-Monzo, 2022).

In every technological process, particularly in food production, controlled process efficiency is essential. This means the systematic monitoring, evaluation, and analysis of all process phases, as well as in-process quality control of semi-finished products.

A decisive influence on the course of process efficiency and on the quality of the bread produced is exerted by the monitoring and assessment of: temperature, phase yield, degree of acidification, and fermentation time (Kot, 2010).

Temperature depends on the yield and time of bread production. For each type of bread, appropriate conditions of time and temperature should be established. At lower temperatures, acidification occurs more slowly, and a significant amount of acetic acid is produced.

The quantitative ratio of acetic acid to lactic acid significantly determines the aroma and taste of bread. The addition of water at an appropriate temperature ensures the desired temperature of the production phase. The use of a specific baking temperature depends on other technological parameters such as consistency, fermentation time, flour quality, and formulation. In large bakery plants, following the example of some EU countries, the internal temperature of the product leaving the oven is adopted as an additional criterion for proper baking (Rosell, 2021).

The degree of acidification, also known as the multiplication of the phase, refers to the ratio of the mass of flour in the prepared phase to the mass of fermented flour introduced from the previous phase. In baking, the applied multiplications depend on the fermentation time of the phase, the quality of the raw material, and the production scheme. A higher degree of acidification, meaning a lower multiplication, is more favorable for yeast, whereas the opposite is true for bacteria. It is possible to regulate the yield of the phase, temperature, degree of acidification, and fermentation time of the phases, thereby influencing the development of microorganisms – yeast and bacteria.

The fermentation time depends on the yield of the phase, temperature, and degree of acidification. It is directly related to changes in acidity. The starting point for developing a fermentation schedule is the assumed fermentation time, and the other parameters are then adjusted accordingly. The fermentation time is thus connected to the changes in acidity (Patel et al., 2022).

In the technological process, so-called technological defects in bread can occur. These defects are mainly caused by inadequate quality of flour and auxiliary raw materials, errors in the technological process, and improper storage conditions. Preventing technological

defects depends primarily on the experience and qualifications of employees, as well as their knowledge of technology and raw material quality (Ambroziak, 2002). Technological defects in bread can be divided into two groups: external appearance defects (shape, volume, crust) and internal defects (crumb texture, taste, aroma).

Producing bread of very good or good quality is a significant opportunity for bakers, especially when working with flour that has poor baking properties. Therefore, the first step is to assess the baking value of the flour, and then to adjust the optimal parameters of the technological process. If technological modifications and the use of natural additives prove ineffective, the use of improvers is permitted (Cauvain, 2003).

Thus, in bakery enterprises, controlled process efficiency is essential. It allows-and even necessitates-the regulation of temperature, degree of acidification, and fermentation time of individual phases, as these operations directly benefit the quality of the final product. Managing the technological process to obtain the desired quality of the final product is based on continuous in-process quality control of semi-finished products. Such control is indispensable because if technological inconsistencies are detected, it is still possible to prevent poor bread quality by altering conditions such as fermentation duration, temperature, or phase yield. Testing of semi-finished products is therefore necessary during both trial baking and regular production. Information from quality control must reach decision-makers promptly. Results delivered with a delay merely document past events and are no longer helpful in process management. Instrumental methods of analysis are generally faster than chemical methods and easier to automate. For this reason, they are increasingly used in laboratory quality control (Mitelut et al., 2021).

The organoleptic method takes into account such quality indicators as: external appearance, aroma, structure, and the maturity of fermentation phases. Each semi-finished product, depending on its degree of maturity, is characterized by a specific scent (Rustamovich, 2022).

The physicochemical method for semi-finished products includes checking: temperature, moisture content, acidity, consistency, and the final proofing time of dough pieces. It is recommended to measure temperature using an electronic meter equipped with a sensor adapted for bakery applications (Rosell, Santos, 2010).

The quality and freshness period of bread are determined by baking conditions; therefore, it is very important that the bakery's technological and laboratory staff monitor the weights of dough pieces and ensure the correctness of baking (Drozd, 2019b).

2.3. Organizational and technical factors

Among the organizational and technical factors shaping bread quality in the technological process, significant influences include: employee qualifications, machine reliability, innovations in the technological process, and hygienic and sanitary conditions.

To ensure the proper execution of processes within an enterprise, appropriate resources are necessary. At the forefront of these resources are employees, followed by infrastructure, the working environment, and the necessary information (Szczepańska, 2011). In the bread production process, the role of employees is crucial (Obłój, 2001). Under a strict technological regime, bread quality depends not only on employee qualifications but also on their engagement-particularly in phases involving temperature regulation, acidification levels, and fermentation time. The role of the technologist is also critical and responsible. Their knowledge and involvement may, for instance, prevent the proliferation of harmful microorganisms. It is equally essential to uphold hygienic behavior standards among employees. According to technologists, the most difficult issue is preventing foreign

objects from entering the production area due to personnel contamination (Dan Pop et al., 2018).

Even if bread has good quality after baking, it is disqualified by most consumers if it shows any signs of staleness during consumption. Customers highly value fresh bread. Therefore, bread deliveries to retail networks are made daily, and for this reason, bakery machines must be maintained in full technical efficiency and reliability (Drozd, 2019a).

There is consensus in the professional literature that machine reliability affects bread quality. However, innovations introduced into the technological process (e.g., production lines, machines) are not explicitly listed as factors influencing bread quality. Nevertheless, there are formulations in the literature suggesting that bread quality and its technological parameters are influenced by raw materials, the knowledge and skills of the baker, and high-quality machines and equipment (Gupta et al., 2021).

Long-term improvement in machine reliability cannot be achieved through continuous repairs. Investment in new machines tailored to the demands of a competitive market is essential. It is increasingly evident that without the implementation of innovations, achieving a sustainable competitive advantage becomes virtually impossible. Innovations are currently the most effective means of attaining long-term market success.

Technological process innovations often determine the feasibility of product innovations and are frequently present in the background of such developments.

Hygienic and sanitary conditions in bakeries have a significant impact on the quality of bread during the technological process. These conditions pertain particularly to machines, personnel, storage of bread, packaging, and transportation.

The conditions under which bread is stored immediately after baking also influence its quality. First and foremost, bread should be cooled to a temperature of 30°C in conditions that prevent secondary contamination (from raw materials, equipment, people, or the environment) in clean rooms where personnel movement is restricted (Gupta et al., 2022).

A comprehensive assessment of the quality of all types of bread after baking is conducted through a scoring evaluation. This includes an organoleptic assessment while also taking into account physicochemical indicators expressed as point values. The scoring evaluation involves assigning numerical values to each quality characteristic (indicator) based on an established point scale (Luning et al., 2005). The total score obtained in this evaluation forms the basis for classifying the quality of the bread.

Bread that does not achieve the minimum number of points is disqualified. It is also a fact that evaluating only the final product is insufficient for determining its quality; therefore, controlled process efficiency is essential.

Bread packaging mainly includes slicing and wrapping. Individual bread packaging is used for hygienic reasons and to extend shelf life. However, packaging does not eliminate microbiological processes. Thermal stabilization is also possible. Bread with an extended shelf life is packaged in a modified atmosphere (Kotsianis et al., 2022). Some bread is sold unpackaged; thus, it is particularly important to maintain hygienic environmental conditions and personal hygiene of employees.

In the bread production chain, one remaining step is delivery of the product to the retail network. According to the identified technological process, deliveries to retail are not formally part of this process but are considered part of the broader production chain.

Bread should be transported to stores by individuals who do not pose a health risk. Specialized transport, i.e., vehicles dedicated exclusively to the transport of bread, must be free of foreign odors. Means of transport should be cleaned daily and periodically disinfected (Galankis, 2020).

3. METHODS – FUNCTIONAL MODEL OF DETERMINANTS OF BREAD QUALITY IN THE TECHNOLOGICAL PROCESS

According to E. Pająk, the description of a process structure is referred to as a model. In the most general sense, the objective for which the model is used may be defined as the description and explanation of reality treated in a comprehensive manner (Pająk, 2006).

For the purpose of a comprehensive assessment of the determinants of bread quality, these factors were identified, systematized, and characterized. Due to the interrelations and connections between individual determinants, a functional model of the determinants of bread quality in the technological process was developed, as illustrated in Figure 1.

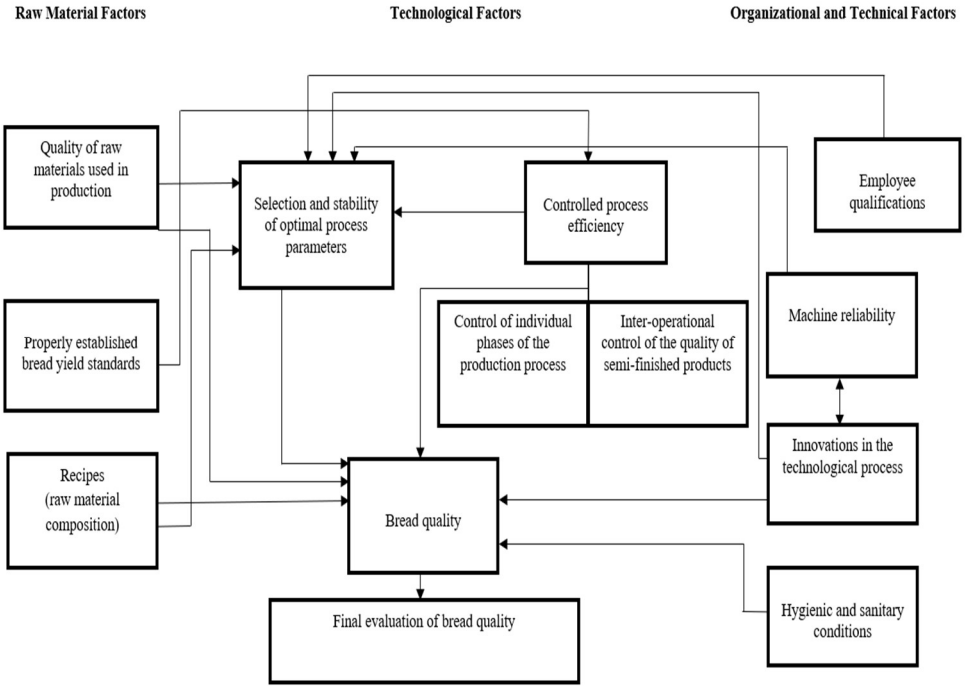

Figure 1. Functional model of determinants of bread quality in the technological process
Source: Author's work.

In the presented functional model of the determinants of bread quality in the technological process, the factors are grouped into three main categories. Each group of factors fulfills a specific function within the technological process:

I. Raw Material Factors, including:

1. Quality of raw materials used in production.
2. Properly established bread yield standards.
3. Recipes (raw material composition).

II. Technological Factors, including:
   1. Selection and stability of optimal process parameters, including: controlled process efficiency (of individual technological phases and inter-operational quality of semi-finished products).

III. Organizational and Technical Factors, which include:
   1. Employee qualifications.
   2. Machine reliability.
   3. Innovations in the technological process.
   4. Hygienic and sanitary conditions of machines, employees, bread storage, packaging, and transportation.

Each of the listed factors influences the shaping of bread quality, but all are also managed under the overarching factor responsible for the selection and stability of optimal technological process parameters.

The mutual interdependencies between the individual factors-and their relative strength-are also indicated by arrows and their directions, which are additionally included in the model. These graphical elements are characteristic of a relationship diagram, also known as a dependency diagram.

4. RESEARCH RESULTS ON THE IMPACT OF INNOVATION ON OTHER DETERMINANTS OF BREAD QUALITY

In response to the ongoing transformations within the bakery industry and considering the growing demand in Poland for bread that meets consumer quality expectations, a study was conducted to identify the impact of innovations in the technological process on improving bread quality.

This research was carried out between 2020 and 2023. A total of 51 bread producers from the Pomeranian Voivodeship participated, during which 56 innovations implemented in the bread production technological process were identified.

The innovations were systematized and divided into two categories: production lines and machines. Among the 22 technological lines implemented were those for the production of bread, bakery products, frozen dough, and robot-assisted production lines. The 34 machines were grouped into the following categories: silos, mixers with bowls, proofing chambers for dough pieces, bakery ovens, and X-ray detectors.

The perceived impact of all implemented technological lines and machines on individual determinants of bread quality, as reported by respondents, was as follows:

- 11.8% – on the establishment of bread yield standards;
- 13.3% – on employee qualifications;
- 13.4% – on recipes;
- 14.6% – on the quality of raw materials used in production;
- 14.8% – on the selection and stability of optimal process parameters;
- 15.8% – on hygienic and sanitary conditions;
- 16.3% – on machine reliability.

This represents a general summary of the influence of all innovations implemented in the technological process on the remaining determinants of bread quality. It is also worth noting that, even during the construction of the functional model of bread quality determinants in the technological process, significant relationships between innovation and machine reliability were observed. These correlations are confirmed by the results of the survey.

Figure 2 presents the model illustrating the impact of implemented innovations in the technological process on the other determinants of bread quality.

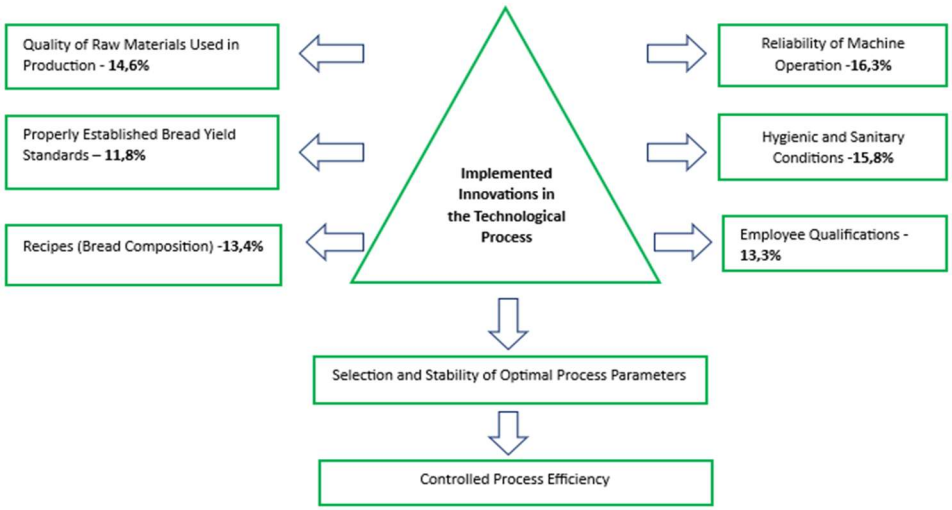

Figure 2. Model of the impact of innovations in the technological process on the determinants of bread quality

Source: Author's work.

5. DISCUSSION

Innovations implemented in the technological process are mainly directed at introducing changes in the methods of manufacturing the product. Although they are the background of product innovations, in the case of bakery products they affect the improvement of the product's quality.

The quality of bread is, next to price, the basic parameter that determines success in the competitive struggle. The dominant problem of modern baking should be the continuous improvement of bread quality to satisfy customers. Although attention to bread quality is essential at every stage of a company's operations, the most crucial element is the technological process.

The literature on the subject lacks a comprehensive study on the determinants of bread quality from the perspective of the technological process. Based on a literature review and participant observations, resulting from the authors' several years of experience in bakeries, the determinants that shape bread quality in the technological process were identified, systematized, and characterized. The identified factors shaping the quality of bread in the technological process include: the quality of raw materials used in production, properly established standards of bread yield, recipes (raw material composition), reliability of machinery, hygienic and sanitary conditions, employee qualifications, selection and stability of optimal process parameters, and innovation.

These determinants constitute a functional whole, and therefore a model of bread quality determinants in the technological process was developed. This model is a conceptual research model. The model of bread quality determinants in the technological process presented by the authors is currently being implemented in practice in bakeries.

6. CONCLUSIONS

Bread quality, alongside price, is a fundamental factor determining success in competitive markets. The dominant challenge facing contemporary bakeries should be the continuous improvement of bread quality to meet customer expectations. While quality must be safeguarded at every stage of a bakery's operations, the technological process remains its most critical element. The literature lacks a comprehensive study of the determinants of bread quality from the perspective of the technological process.

In summarizing the undertaken efforts regarding the determinants of bread quality in the technological process, it should be noted that the factors influencing quality were first identified and systematized through classification into three groups: raw material, technological, and organizational-technical factors. Within the raw material group, the following were recognized: the quality of raw materials used in production, properly established bread yield standards, and raw material composition (recipes). Organizational and technical factors include: machine reliability, innovations in the technological process, employee qualifications, and hygienic and sanitary conditions of machines, equipment, personnel, storage, packaging, and transportation.

The main technological factor shaping bread quality within the production process is the selection and stability of optimal process parameters. This is supported by controlled process efficiency (monitoring of individual production phases and inter-operational quality of semi-finished products). The factor of selecting and stabilizing optimal process parameters also acts as a coordinator of the entire technological process.

The identification and characterization of bread quality determinants based on professional literature and participant observation made it possible to develop a functional model of bread quality determinants in the technological process.

Research conducted in 51 bakeries in the Pomeranian Voivodeship between 2020 and 2023 led to the identification of 56 innovations implemented in the technological process, including 22 related to automated and robotized technological lines and 34 to automated standalone machines. The implemented innovations influenced all determinants of bread quality to varying degrees, from 11.8% (in the area of establishing bread yield standards) to 16.3% (in machine reliability). Based on this, a model was developed showing the impact of implemented technological innovations on the remaining determinants of bread quality.

Technical advancement in the technological process may serve as a prelude to the Fourth Industrial Revolution, the essence of which lies in transferring the majority of decision-making from human operators to the competence of machines.

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