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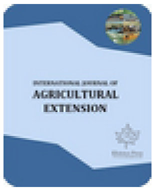

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INTENSIFICATION OF HIGH-QUALITY BREWING PROCESSES

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ABSTRACT

Brewing is a complex process that involves many stages and successive operations. The issues of intensifying the brewing processes are of great importance in improving the ways to obtain a high-quality finished beer product and maintain high standards of its quality in the future. The relevance of the subject matter is conditioned by the stable demand for high-quality beer products in society and the urgent need to create effective technologies for the production of high-quality beer, taking into account the introduction of the latest technologies for the intensification of brewing processes. The purpose of the study is to determine the main factors that are important from the standpoint of intensifying the processes of quality brewing, in the context of assessing the prospects for their subsequent consideration when planning the beer production processes. The leading approach of this study is a combination of a systematic analysis of the peculiarities of brewing processes in the context of searching for opportunities for its intensification, with an analytical study of real options for intensifying the brewing processes, from the standpoint of maintaining high-quality standards of finished beer and increasing the overall production rate. The main results obtained in the course of this study should be considered the substantiation of the main factors of the brewing processes intensification in the context of creating a mathematical model for calculating the possibilities of its implementation in the activities of breweries to increase the rate of brewing high-quality beer. The prospects for further research are determined by the preservation of a stable demand for high-quality beer products, combined with an increase in the need to intensify the processes of its production, in accordance with the set standards for the quality of beer production.

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INTRODUCTION

Due to the growing competition, in recent years in Ukraine and Belarus, there has been an increase in beer production, leading to the improvement of technology and reduction of economic costs due to the introduction of more advanced methods of raw materials processing and reducing the duration of technological stages while maintaining the quality of the resulting product (Borodulin *et al.*, 2018; Koshova and Matsulevych., 2011; Nartsiss, 2003; Romanova *et al.*, 2020). The brewing industry is one of the leading branches of the food industry in Ukraine. The main directions of improving the brewing efficiency are: improving the quality of products, increasing the productivity of technological equipment and rational use of energy and material resources. The brewery has all the characteristics of a complex organisational and technical system.

Effective management of such a facility is possible taking into account all its features: a high level of uncertainty, which is manifested in the assessment of technological parameters, especially indicators of raw materials quality, semi-finished products and finished products; the complexity of behaviour due to internment phenomena, that is, in the alternation of deterministic technological modes, stochastic and chaotic; the presence of many management goals that have a dynamic priority, depending on production situations, and the assessment of certain factors of brewing processes is carried out in a qualitative fuzzy form; the development of the facility is multivariate depending on the aspects of technological, technical, and economic nature. Beer production is complex, long-term, divided into five stages: production of malt, production of beer wort, fermentation of wort with special brewer's yeast, fermentation (maturation) of beer and its filtration, bottling. The basis of the technological processes of malt and beer production is the biochemical transformation of substances in a living organism, which occurs under the influence of enzymes and physico-chemical processes of interaction of these substances. To accelerate the pace of scientific and technological progress, it is necessary to create and implement fundamentally new progressive technological processes in the industry, replace and modernise obsolete equipment (Ilyina, 2005).

The technology of beer production is quite complex and demanding to the conditions because it involves the flow of many physico-chemical, biochemical and other processes that determine the quality and taste characteristics of the finished product. It is known that the key and very important stage of brewing is the process of malt mashing, in which ground malt is mixed with water and kept at certain temperature. This is done to activate various enzymes in order to break down glucans, starches, and proteins (Popova and Potoroko, 2018). Notably, in the process of beer preparation, the development of specific organoleptic parameters of the finished product, the chemical and microbiological stabilisation of the wort, is significantly influenced by the process of hopping beer wort

The conventional methods used in the industry do not provide a sufficiently effective yield of extractive substances and specific aromatic components of hops. In this regard, numerous studies were aimed at developing devices that allow increasing productivity, saving raw materials, reducing energy costs and the preparation time of beer and beer products. The solution to this problem can be achieved through the introduction of modern equipment and new technologies (Romanova *et al.*, 2020). The problem of controlling such equipment can be solved based on the scenario approach, that is, the control object should be considered as a complex dynamic system that operates in conditions of situational uncertainty. In such conditions, it is necessary to conduct a complex of scientific studies to determine the properties and characteristics of the control object based on the assessment of the features of the functioning of brewing processes using system and categorical analysis, expert assessment, cognitive modelling, identification of network mathematical models in situationally significant areas of the object, synthesis of algorithms for scenarios of multi-purpose management of the brewing process under uncertainty (Ermolaeva, 2004; Mamaruslov *et al.*, 2017). Therefore, the development of automated intelligent control systems for the technological complex of the brewery based on network models that would increase productivity, improve product quality, and reduce specific energy and resource costs is an urgent scientific and technical task. The study of the issues of improving the quality indicators of beer produced using the intensified hopping technology, which allows the maximum extraction of bitter substances from hops (Borodulin *et al.*, 2018), largely determines direction of this study. The methods used for solving problems are based on the provisions of the modern theory of automatic control, methods of system analysis, analysis of categories-functions, qualifiers, identification of control objects, the basic principles of the scenario approach, multicritical optimisation, knowledge engineering, modelling. The probability of the main theoretical positions and research results was confirmed by the use of modern methods of mathematical modelling and analysis of experimental data.

LITERATURE REVIEW

A review of literature sources containing information on the intensification of high-quality brewing processes demonstrates a variety of scientific approaches to the practical solution of this problem. In particular, (Nartsiss, 2003), in his study of the technology of brewing wort, notes that improving the quality of alcoholic and low-alcoholic beverages that meet the accepted international standard ISO 22000 is one of the main tasks of the modern beverage industry, and therefore fermentation production faces urgent technical problems, the solution of which would allow intensifying technological processes and improving the quality indicators of products. In this regard, the set of problems requiring further solutions includes optimising the fermentation process. For its part, a team of authors represented by Z.M. Romanova, S.M. Loiko, M.S. Romanov (Romanova *et al.*, 2020), in a joint study on improving beer technology through the use of aromatic plant raw materials, note that among the many chemical processes that lead to the quality of food, oxidative processes occur, contributing to the "ageing" of beer. The processes of oxidative aging begin not only during the storage of the drink, they accompany the drink throughout its preparation. The consequence of such processes is the accumulation of a wide range of substances that negatively affect the taste and aroma of the drink. In turn, B.D. Mamaruslov, O.A. Nasirova, D.T. Mirzarakhmetova (Mamaruslov *et al.*, 2017) in a joint study on intensification of beer wort fermentation processes indicate the fact that the wort fermentation process is significantly influenced by an electromagnetic field, which has a positive effect on ethanol yield and causes a significant increase in cell mass.

The researchers also note that weak electromagnetic fields (EMF) with cyclotron frequencies for calcium, magnesium, and other biologically significant ions moving in a geomagnetic field had certain biological effects (Mamaruslov *et al.*, 2017). According to the authors, the results of these studies led to the development of various "resonant" hypotheses, in which the calcium ion was assigned the role of the main target for EMF. At the same time, N.V. Popova, L.Yu. Potoroko (Popova and Potoroko, 2018), in their joint work, note the significant role of malt in brewing processes. According to researchers, malt, as the main raw material for beer, is not only a source of extractive substances, but also a source of enzymes (amylolytic, proteolytic, cytolytic, and others), under the influence of which the insoluble substances of the malt itself and unsalted materials (starch, proteins, etc.) are transferred to the solution.

Ilyina (2005), assessing the prospects for intensification of beer wort production, notes that in relation to the processes of beer wort preparation, the following intensification criteria can be noted: the degree of mechanisation and automation, the technical level of production, economic efficiency, the level of social and organisational support. At the same time, according to the researcher, the greatest difficulty is associated with the assessment of the product quality. Thus, the review of the publications devoted to the issues under consideration indicates their scale and a variety of approaches to their resolution.

MATERIALS AND METHODS

The purpose of this study is to investigate the features of the intensification of the high-quality brewing processes in the context of applied technologies. The objects of this study are various technological aspects of brewing, in the context of studying the possibilities of their intensification (Ermolaeva, 2004; Kellershohn, 2016). The leading approach is a combination of a systematic analysis of the peculiarities of brewing processes in the context of searching for opportunities for its intensification, with an analytical study of actual options for intensifying the processes of high-quality brewing, from the standpoint of maintaining high-quality standards of finished beer and increasing the overall intensity of its production. The chosen combination of methods is optimal, since it contributes to the most objective analysis of the issues of intensification of high-quality beer production, due to the possibility of conducting a comprehensive study of both the existing brewing processes as a whole, and assessing the prospects for their intensification in relation to the introduction of the latest production technologies for this drink (Cifuentes, 2020; Kellershohn, 2016).

This study focuses primarily on beer production technologies in Ukraine and Belarus, with a partial focus on beer production processes in Germany. In this regard, a certain part of the materials of this study was borrowed from the works of foreign authors dealing with the issues under consideration. In order to create the most objective picture of the research and facilitate the perception of the information provided, all the materials presented were translated into English. In addition, practical developments of schemes for the intensification of high-quality brewing processes were carried out using modern methods for forecasting the effectiveness of their practical implementation (Hill, 2015; Bamforth, 2016).

A system analysis of the peculiarities of brewing processes in the context of the search for opportunities for its intensification helps to identify the main trends in these processes and the availability of opportunities to improve their flow in terms of modern technological capabilities (Guimarães *et al.*, 2020; Smart, 2019). An analytical study of actual options for intensifying the processes of high-quality brewing, in terms of maintaining high quality standards of finished beer and increasing the overall intensity of its production, is necessary to identify specific measures that should be developed and implemented in practice to create the necessary conditions for increasing the intensity of beer production processes while maintaining the necessary quality standards. In this context, it is essential to assess the quality of malt, which is an important component of raw materials for the beer production. The dependence of the malt extractivity on the accompanying factors of the beer production process is expressed by the equation (1):

$$EK, C_{red}, t_{sacch}, t_{dry}, W_{malt}) = 0.629K + 0.040083C_{red} + 0.2004417t_{sacch} + 0.675639t_{dry} + 0.040861W_{malt} - 0.01366K2 - 0.00174KC_{red} - 0.0087Kt_{sacch} - 0.00055C_{red}t_{sacch}, \qquad (1)$$

where: E – malt extractivity, %; K – Kolbach number, %; C_{red} – the total content of reducting sugars, g/100 g of dry matter; t_{sacch} – total saccharification time, min; t_{dry} – drying temperature, °C; W_{malt} – moisture content of malt, %. Thus, the malt extractivity is a function of several variables, such as the total content of reducing sugars, the total time of saccharification, the drying temperature, the moisture content of the malt. In general, the combination of materials and methods chosen in this study can be successfully used in the future to conduct further research and to form a reliable scientific base for studying the possibilities of intensifying the processes of high-quality brewing, taking into account the features of modern technological development in this line (Gecim *et al.*, 2020; Muster-Slawitsch *et al.*, 2014).

RESULTS

The study of the issues of high-quality brewing processes intensification has led to the following results. The system analysis of the control object allowed identifying the main technological factors and performance indicators of the main stages of beer production. Taking into account the importance of assessing the quality of raw materials and products, a significant number of indicators and the complexity of assessing their interrelationships, an analysis of control facilities (technological complex of the Obolon brewery in Kyiv) and CJSC Bobruiskiy Brovar (Bobruisk, Belarus) was carried out, from the standpoint of the categorical and functional approach. Such an analysis allows distinguishing the categories of quality, productivity, and losses (Rodman and Gerogiorgis, 2016; Sohn *et al.*, 2021).

The categorical and functional approach reducing the share of subjective assessment of quality parameters by using algorithmic procedures verbally. Using the theory of categories and functionaries, it is possible to calculate the quantitative characteristics of the state of the system (in particular, quality indicators) and determine the optimal states of the system with their help. In the description of the categories and functions of systems, the emphasis is transferred from the "frozen" states of the object to various forms of their behaviour and transformation. The main feature of this description is that the category, along with structured objects, necessarily uses all (their acceptable structure) methods of changing the object. This allowed replacing the theoretically-repeated representation of an object as a "frozen" structure with a real representation of its processes.

The connection between the various categories was established based on the functionary, which allowed, for example, for the quality category, to determine the properties of various quality indicators through functional transformations by determining the structure and parameters of the functions (the relationship between individual quality indicators). A category consists of a combination of two classes – an object class and a morphism class.

Morphisms as characteristics of relationships between categories were formulated verbally and implemented in the knowledge base in the form of product rules. The analysis of categories and functions was carried out for such quality categories as: physico-chemical indicators of water, quality indicators of fresh malt, quality indicators of commercial malt, indicators of laboratory wort, quality of hops, quality of grinding of grain products, degree of grinding of grain products, parameters of grout of grain products, degree (quality) of wort filtration, degree of wort clarification, transparency of wort, quality of yeast promotion, degree of digestion, degree (quality) of beer filtration (Sheppard *et al.*, 2019). The quality of raw materials was assessed by the integral dependence of the indicators (2):

$$K = f(K_1, K_2, K_3 \ldots K_n), \quad (2)$$

where: K_1, K_2, $K_3 \ldots K_n$ – individual quality indicators. In general, the complex quality indicator is described by the equation (3):

$$K = f(K_i \times M_i), \quad (3)$$

where: M_i – importance coefficient of the i^{th} relative indicator of product quality ($0 \le M_i \le 1$); K_i – relative i^{th} indicator of product quality. Using the principles of qualimetry, complex indicators of product quality assessment (K_1-K_8) were obtained. Stage of preparation of freshly sprouted malt (4):

$$K_1 = 0.271\,EA + 0.162W_{malt} + 0.216M_{ch} + 0.243E_{malt} + 0.198B \quad (4)$$

Stage of preparation of commercial malt (5):

$$K_2 = 0.072Fr + 0.132W_{malt} + 0.17EA + 0.118E_{malt} + 0.126KN + 0.176\,E_{malt} + 0.116N + 0.09\beta_{gl} \quad (5)$$

Mash preparation stage (6):

$$K_3 = 0.043W_{malt} + 0.05W_{grain} + 0.117m_{malt} + 0.126m_{grain} + 0.132\,E_{malt} + 0.121E_{grain} + 0.069n_{malt} + 0.073n_{grain} + 0.133Br_{wort} + 0.039\,\mu_{mash} + 0.017\pi_{test} \quad (6)$$

Stage of filtration (production) of wort (7):

$$K_4 = 0.258\pi_{filt} + 0.322Br_{wort\ filtr} + 0.194\mu_{mash} + 0.226A \quad (7)$$

The stage of boiling wort with hops (8):

$$K_5 = 0.22Br_{hop\ wort} + 0.144\mu_{hop\ wort} + 0.23Q_{hop} + 0.115\,A_{hop\ wort} + 0.129pH_{hop\ wort} + 0.162PTK \quad (8)$$

Stage of clarification and cooling of hopped wort (9):

$$K_6 = 0.206Br_{clar\ wort} + 0.154\mu_{clar\ wort} + 0.098\rho_{clar\ wort} + 0.085A_{clar\ wort} + 0.101pH_{clar\ wort} + 0.193PTK + 0.163O_{clar\ wort} \quad (9)$$

Fermentation stage (main fermentation and post-fermentation) (10, 11):

$$K_7 = 0.143C_{init\ wort} + 0.098A_{beer} + 0.07pH_{beer} + 0.125C_{co2} + 0.131C_{yeast} + 0.135E_{act} + 0.117C_{alc} + 0.052\,\rho_{beer} + 0.119C_{diac} \ldots\ldots\ldots(10)$$

$$K_8 = 0.167C_{init\ wort} + 0.102A_{beer} + 0.119pH_{beer} + 0.153C_{co2} + 0.165E_{act} + 0.051C_{alc} + 0.064\rho_{beer} + 0.179S_{test} \quad (11)$$

where: EA – indicator of enzymatic activity; E_{malt} – malt extractivity, %; M_{ch} – morphological characteristics, mm; B – mass fraction of protein; KN – Kolbach's number, %; β_{gl} – βg-glucan, mg/100 g; N – concentration of free amine nitrogen (FAN), %; Fr – indicators of a freeabilimeter (powderiness and visibility), %; W_{malt} – moisture content of malt, %; W_{grain} – moisture content of grain, %; m_{malt} – weight of malt, kg; m_{grain} – weight of grain, kg; n_{malt} – fraction composition (grinding) of malt, %; n_{grain} – fraction composition (grinding) of grain, %; Br_{wort} – extract composition, %; μ_{mash} – mash viscosity, mPa's; μ_{wart} – wart viscosity, mPa's; π_{cash} – saccharification time, min; $Br_{clar\ wort}$ – concentration of clarified wort, %; A – amino acid composition of hopped wort, mg/dm^3; $Br_{hop\ wort}$ – hopped wort concentration, %; $A_{hop\ wort}$ – acidity of hopped wort, %; PTK – protein-tanning complexes, %; $O_{clar\ wort}$ – opacity of clarified wort, units; $C_{init\ wort}$ – mass fraction of dry extracts in the initial wort, %; C_{co2} – CO_2 concentration, %; C_{yeast} – yeast concentration, %; E_{act} – actual extract, %; C_{alc} – alcohol concentration, %; C_{diac} – diacetylene concentration, %; S_{test} – tasting score, points.

Figure 1 shows the data on changes in the concentration of wort during the intensification of high-quality brewing processes at CJSC Bobruiskiy Brovar (Bobruisk, Belarus). To form control scenarios and take into account the uncertainty in the behaviour of technological processes of beer production, a linguistic approximation of technological indicators was carried out. Figure 1 shows an example of the function of belonging to the linguistic variable "Initial wort concentration", and Table 1 shows the characteristics of the terms of this variable. Table 1 shows characteristics of the terms of the initial wort concentration.

The scatter plot (Shepard diagram), which plots the dependence of the distances played on the original distances, is shown in Figure 2. As a result of building the final configuration diagram (Figure 3), a three-dimensional graph was obtained which shows how the process indicators and the new lower dimension scales correlate with each other.

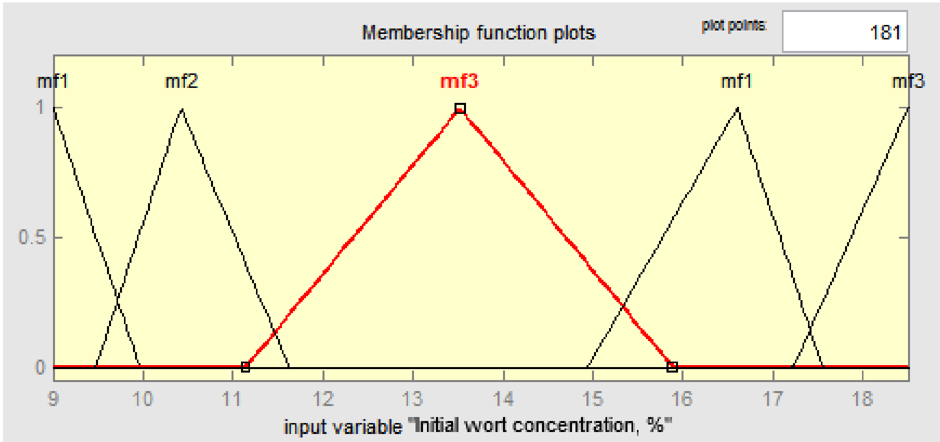

Figure 1. Changes in wort concentration during the intensification of brewing processes at CJSC Bobruiskiy Brovar (Bobruisk, Belarus).

Table 1. Characteristics of the terms of the variable "Initial wort concentration"

Designation of factors	Initial wort concentration, %	Actual coordinates of the function
F6	Very low (less than 9)	[7.57 9 9.97]
F7	Low (9-11.5)	[9.47 10.42 11.6]
F8	Normal (14.9-16.9)	[11.14 13.52 15.88]
F9	High (16.5-17.6)	[14.94 16.6 17.55]
F10	Very high (over 17.6)	[17.23 18.5 23.01]

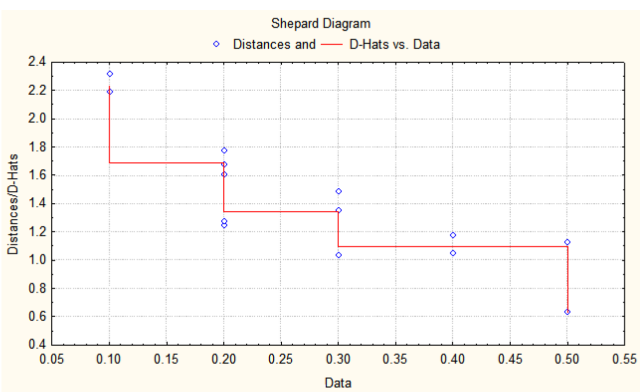

Figure 2. Shepard diagram.

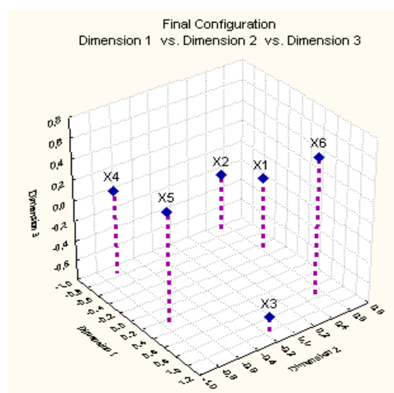

Figure 3. Final configuration explanation diagram.

The use of multidimensional scaling methods allows evaluating expert data to obtain high-quality models with a minimum stress value. Taking into account the multifactorial nature of the analysed objects and the uncertainty of their behaviour, depending on the influence of factors, cognitive modelling was carried out, which allows predicting the consequences of the influence of certain factors and choosing the necessary measures to improve the processing efficiency and prevent conflict situations (Iurciuc *et al.*, 2017).

Thus, to build cognitive models of situations that arise in the brewing process, based on the analysis of categories and functions, the main directions of the situational behaviour of the control object were determined, depending on a number of technological factors (quality indicators of raw materials and semi-finished products, parameters of the mode at all stages of production).

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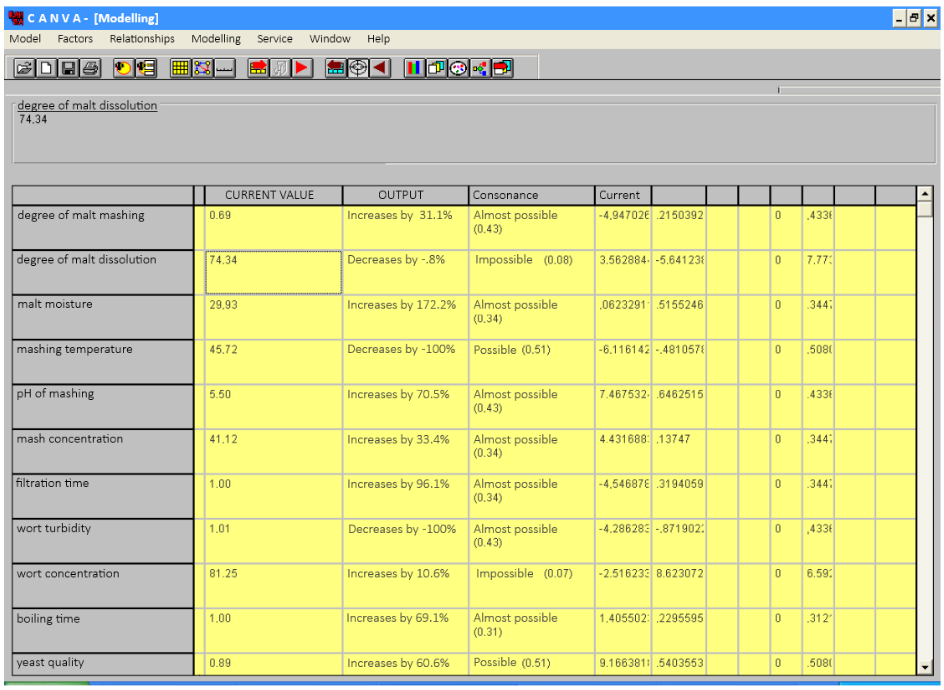
Computer simulation of production situations was carried out using the CANVA cognitive modelling package. Approximately weighted graphs of the situation were constructed, numerical results and graphs of factor changes were determined depending on the selected scenario (Figure 4), the scenarios were compared in terms of predictability and efficiency (Figure 5).

In the production environment of the Obolon and Bobruisk Brovar facilities, a passive experiment was conducted, the results of which (measurement data of technological parameters and laboratory analysis data) determined mathematical models using the smallest squares method in the Matlab environment, where competitive models of certain structures and parameters of these models were evaluated based on criteria: determinism, Maluse statistics, Akaike information criterion, Hawking and Fisher statistics. The above-mentioned adequacy criteria allow choosing the optimal model structures for each situational significant zone in terms of their accuracy and complexity. The system analysis of control objects allowed identifying the main technological factors and performance indicators of the main stages of beer production. Taking into account the importance of assessing the quality of raw materials and products, a significant number of indicators and the complexity of assessing their relationships, the analysis of control objects (the technological complex taken for the study of breweries) was carried out from the standpoint of a categorical and functional approach. Such an analysis allows distinguishing the categories of quality, productivity, and losses.



	CURRENT VALUE	OUTPUT	Consonance	Current							
degree of malt mashing	0.69	Increases by 31.1%	Almost possible (0.43)	-4,947026	.2150392			0	,4336		
degree of malt dissolution	74.34	Decreases by -.8%	Impossible (0.08)	3,562884-	-5,641238			0	7,77:		
malt moisture	29,93	Increases by 172.2%	Almost possible (0,34)	,0623291	.5155246			0	.344		
mashing temperature	45.72	Decreases by -100%	Possible (0.51)	-6,116142	-.4810578			0	.5080		
pH of mashing	5.50	Increases by 70.5%	Almost possible (0,43)	7.467532-	.6462515			0	.4336		
mash concentration	41.12	Increases by 33.4%	Almost possible (0.34)	4.431688:	.13747			0	.344		
filtration time	1.00	Increases by 96.1%	Almost possible (0,34)	-4,546878	.3194059			0	.344		
wort turbidity	1.01	Decreases by -100%	Almost possible (0.43)	-4.286283	-.871902			0	,4336		
wort concentration	81.25	Increases by 10.6%	Impossible (0.07)	-2.516233	8.623072			0	6.59:		
boiling time	1.00	Increases by 69.1%	Almost possible (0.31)	1,405502:	.2295595			0	.312		
yeast quality	0.89	Increases by 60.6%	Possible (0.51)	9.166381	.5403553			0	.5080		

Figure 4. Simulation table.

The categorical and functional approach reducing the share of subjective assessment of quality parameters by using algorithmic procedures verbally. Using the theory of categories and functionaries, it is possible to calculate the quantitative characteristics of the state of the system (in particular, quality indicators) and determine the optimal states of the system with their help. In the description of the categories and functions of systems, the emphasis is transferred from the "frozen" states of the object to various forms of their behaviour and transformation. The main feature of this description is that the category, along with structured objects, necessarily uses all (their acceptable structure) methods of changing the object. This allowed replacing the theoretically-repeated representation of an object as a "frozen" structure with a real representation of its processes. The connection between the various categories was established based on the functionary, which determined, for example, for the quality category, the properties of various quality indicators through functional transformations by determining the structure and parameters of the functions (the relationship between individual quality indicators). A category consists of a combination of two classes – an object class and a morphism class. Morphisms as characteristics of relationships between categories were formulated verbally and implemented in the knowledge base in the form of product rules.

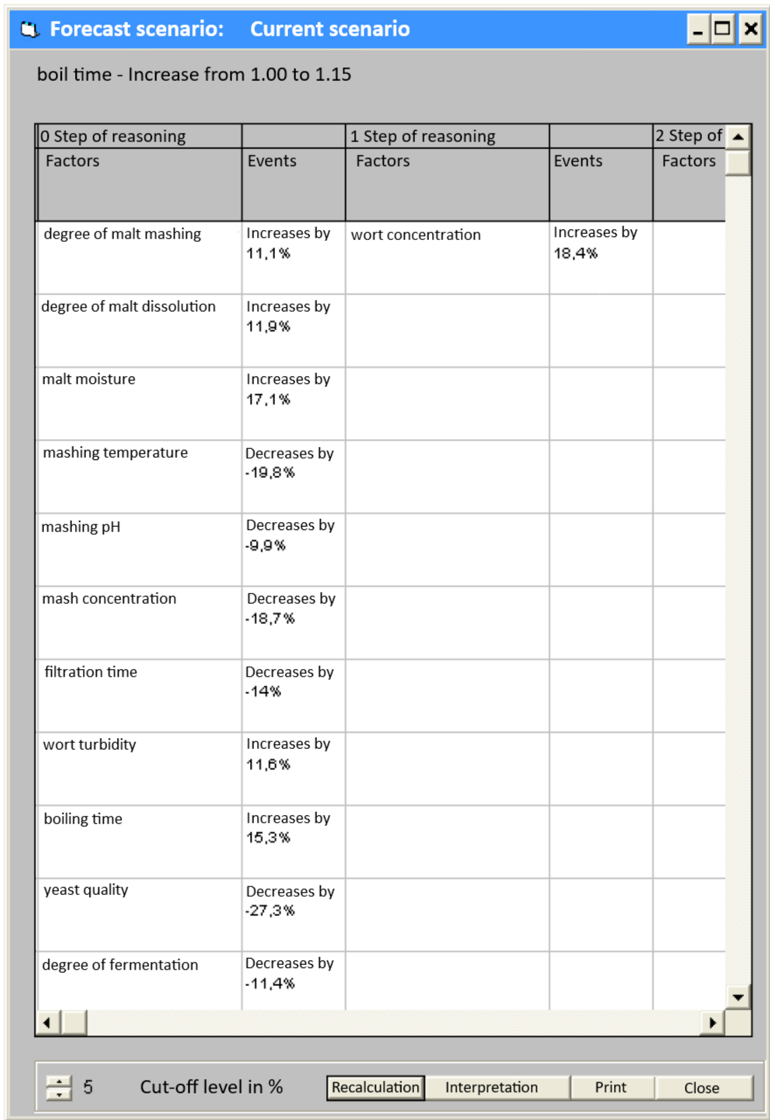


Figure 5. Forecasting results.

The analysis of categories and functions was carried out for such quality categories as: physico-chemical indicators of water, quality indicators of fresh malt, quality indicators of commercial malt, indicators of laboratory wort, quality of hops, quality of grinding of grain products, degree of grinding of grain products, parameters of grout of grain products, degree (quality) of wort filtration, degree of wort clarification, transparency of wort, quality of yeast promotion, degree of digestion, degree (quality) of beer filtration. All of the above components are essential in assessing the possibilities of creating an effective technological scheme for the intensification of high-quality brewing processes on the scale of a single plant.

DISCUSSION

The discussion of the intensification of the processes of high-quality brewing causes a wide resonance among researchers, due to the significant difference in approaches to the problems under consideration and their complexity. V.M. Koshova, N. Ye. Matsulevych (Koshova and Matsulevych., 2011), in their study of the peculiarities of the influence of polyphenols on the colloidal stability of beer, notes that the preparation of beer is a complex process based on the biochemical transformations of the substances of grain raw materials during malting, various enzymatic reactions when obtaining wort, complex processes occurring during fermentation and post-fermentation. In beer technology, each process requires maintaining certain conditions. The production of high-quality beer is impossible without strict compliance with the biochemical and physical parameters at all stages of production. In turn, the team of authors represented by D.M. Borodulin, E.A. Safonova, I.O. Milenkiy (Borodulin *et al.*, 2018) note that a number of experiments with using hop extract for wort hopping have clearly shown that intensification of beer brewing processes requires further improvement of the wort hopping technology, in view of the experimental confirmation of the positive effect of the introduction of a rotary-pulsed apparatus into the beer production technology, which halves the duration of this process and reduces hop consumption by 1.5-2 times.

At the same time, N.V. Popova, I.Yu. Potoroko (Popova and Potoroko, 2018) in a joint study of modern approaches to the possibilities of mashing beer wort note that there are a large number of ways to change the technology of wort preparation, aimed at increasing the efficiency of extracting useful components from malt and unmalted raw materials by destroying the intermolecular bonds of carbohydrate components of grain raw materials by various influences on it. In addition, the activation of the process of mashing malt occurs when introducing enzyme preparations into the mash or modifying the technology of beer production with additional equipment.

Notably, Ermolaeva (2004) in her study of the peculiarities of brewing processes, from the standpoint of the characteristics of malt mashing, notes that in breweries malt is crushed on four- and six-roll crushers operating at the same rotational speed of the rollers (sometimes the ratio of the circumferential rotational speeds of the rollers is 1.25:1) In these crushers, only the mashing (splitting) of the malt grains takes place. Crushing is mainly subjected to dry malt, processing it sequentially on two or three pairs of rollers, the diameter of which should be at least 25 cm. With a smaller size, the gripping angle is small, which reduces crusher's productivity. Thus, the researcher emphasises the importance of malt mashing processes from the standpoint of studying the possibilities of the brewing processes intensification.

The subject matter is widely reflected in the works of foreign authors who study the problems of intensifying the processes of high-quality brewing. Thus, Kellershohn (2016) in his study of materials and processes of brewing notes that knowledge of the chemical composition of raw materials and continuous improvement of brewing technology are prerequisites for a qualitative solution of the problems of brewing processes intensification. In turn, A. Cifuentes (2020) points out the fact that both the quality of the finished product and the intensity of its production directly depend on the quality of the products used in the beer production processes, without violating the adopted technology. At the same time, Bamforth (2016) notes that brewing continues to be one of the most competitive and innovative sectors in the food industry. Improvements in ingredients, including cereals, supplements, malt and hops, and ways to optimise water use are essential in intensifying the production of quality beer. Thus, the discussion of the issues at hand reveals a wide variety of opinions of researchers, which only emphasises the importance of the subject matter and the need to study it in the future.

CONCLUSIONS

The study of various aspects of the intensification of brewing processes has led to the following conclusions. The high-quality brewing process requires the detailed development and practical implementation of mathematical models for calculating quality criteria, productivity, technological losses and parameters of the beer production mode, ensuring the organisation of effective management strategies in modern network systems for beer production at a modern plant. In this context, the developed scenarios of beer production management, which allow implementing optimal control of the technological complex of the brewery in the designated situational zones under conditions of uncertainty, allow creating the conditions necessary for intensifying the processes of high-quality beer production, taking into account the experience of industrial plants in Ukraine, Belarus and, in part, Germany. To obtain high-quality beer, the brewer should carefully control the brewing process, taking into account the peculiarities of the chemical composition of the raw material, its structure and the quality of auxiliary materials, as well as create optimal conditions for the technological process.

If these conditions are met, it becomes possible to effectively solve the problems of intensifying the processes of high-quality brewing and the production of new varieties of beer that fully meet the declared quality standards. The development and practical implementation of the structure of automated, multi-purpose brewery management, involving the use of an appropriate knowledge base and management scenarios with the use of artificial intelligence and microprocessor technologies based on the concept of centralised network management is the next step towards the intensification of high-quality brewing processes in modern economic conditions. In addition, the development and implementation of modern algorithmic software, with its subsequent practical use in the preparation of existing and new beer styles, would contribute to the further intensification of brewing, which is of great importance in the context of maintaining high-quality standards of the produced hoppy beverage.

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