The production of non-alcoholic beer requires brewing wort with a low degree of digestion. That is possible with the use of non-traditional raw materials in production. The research object presented below is grain sorghum varieties Kazakhstan-16 and Kazakhstan-20. Nowadays, the production of non-alcoholic beer with technological methods is not studied enough. Therefore, plants with small capacities cannot produce it. This study justifies the use of grain sorghum to produce low-digestion wort. In addition, we justify that Kazakhstan-16 had the best indicators for producing non-alcoholic beer. The following ratio of malt for wort preparation to sorghum 60:40 and hydro module 1:6 are proposed. The prepared wort had an extractivity of 6.62 % and digestible carbohydrates of 25.89 % of the total. The ratio of digestible sugars to non-fermentable substances in the wort was 1:1.79, so 79 % constituted mainly non-fermentable sugars.

Mathematical experiment planning has been used to study the effect of malt and sorghum filling ratio and hydro module on the brewing wort's extractive matter yield.

Based on the results of this study, the brewing wort has a low digestion rate. However, the carbohydrate composition of the wort is due to the presence of mono- and disaccharides. This wort will produce a beer with an ethanol content of up to 0.5 % of alcohol and the organoleptic characteristics set.

High extractivity in the raw materials and their high gelling temperature account for these results. These factors made it possible to select a jumping mashing regime, which resulted in deep hydrolysis of the sugars into dextrins.

This study will allow using non-traditional grain raw materials and producing non-alcoholic beer in breweries of any capacity. These methods are cost-effective and do not require expensive equipment

Keywords: brewing industry, non-alcoholic beer, malt mashing, grain sorghum, carbohydrate composition, extractivity

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THE IMPACT OF GRAIN SORGHUM ON THE CARBOHYDRATE COMPOSITION OF WORT FOR NON-ALCOHOLIC BEER

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1. Introduction

The brewing industry is one of the most progressive and dynamic areas of the food industry in the world. Today, brewing production is a significant part of the domestic economies of many countries [1, 2]. Due to dynamic development, this sector of the food industry can increase further growth and development efficiency. In the long term, it can make a significant contribution to the country's economy and the development of several related sectors, such as agriculture, transport, food machinery, glass and packaging, etc. In addition, the importance of this industry is due to its budgetary specifics, as the products are excisable and in high demand. All of this demonstrates the special strategic importance of the development of the brewing industry. In this context, this issue is of particular relevance to regions with considerable market potential, natural and climatic conditions that allow the development of their raw material base, as well as many years of experience in beer production [3].

For the Republic of Kazakhstan, the industry is innovative and modern. In recent years, production capacity has been increasing, the range of products is expanding, and craft brewing has been developing [4, 5].

Due to the high level of competition and the conditions in which the brewing industry finds itself, companies must continually develop new products that meet consumer, sanitary, high quality and increased nutritional value requirements. It is also essential to redirect alcohol consumption toward beverages with lower alcohol content, a worldwide best practice. In this connection, the production of non-alcoholic beer is an actual direction.

Non-alcoholic beer is the fastest-growing segment of the beer market. The growth of the non-alcoholic beer market (NAB) has increased significantly in recent years due to the strict alcohol policy and the fact that consumers have become more health-conscious [6].

Analysts consider that the release of non-alcoholic beer is primarily needed by companies to increase overall production and practical research into consumer preferences. The global trend in the beer market is that the best-known brands are represented by one, at most two types of beer. Non-alcoholic beer may be a small, permanent niche with its consumers. Under these conditions, manufacturers must produce products that can compete with world brewing leaders.

In recent years, there has been an increasing trend toward the demand for non-alcoholic beer, as well as increasing requirements for its quality and price [7]. It is a well-known fact that product properties and production costs depend mainly on the chosen technology. There are two main methods of producing non-alcoholic beer: physico-chemical and technological. The first ones enable the production of good quality non-alcoholic beer using dialysis or reverse osmosis methods. Whereas suitable only for high-capacity breweries. Technological methods are economical for breweries of any capacity. Therefore, the essence of the process is to reduce the alcohol content in the production stages. At the same time, during the mashing stage, the raw materials and the regimen must be selected to produce wort with some low content of digestible sugars and ferment the specially prepared wort to a certain degree of digestion.

The only possible way to accomplish that is to use non-traditional raw materials of a given level of quality in the beer production process.

The authors [8] have now developed various types of non-alcoholic beer using juice from red dogwood fruit (*Cornus mas L.*), on a quinoa basis, with the addition of buckwheat flakes. Nevertheless, this is not enough for the production of non-alcoholic beer, as the proposed raw materials and production technologies cannot meet the requirements of the world market. Therefore, the search for new types of non-traditional raw materials will make it possible to expand the range of products, to be competitive in the market. As well as, obtain new profiles of non-alcoholic beer and prepare it at plants of any capacity.

2. Literature review and problem statement

The growing popularity of non-alcoholic beer (NAB) has stimulated industry interest in providing the best product.

Physico-chemical, technological and biochemical methods produce non-alcoholic beer with an ethanol concentration of less than 0.5 % alcohol.

Many studies [9, 10] describe the research results on producing non-alcoholic beer by different methods, and the following conclusions exist. First, the dialysis or reverse osmosis method represents the physico-chemical methods for producing a high-quality product. However, this technology can only be used in huge breweries, as the equipment price and operating costs are high. Second, preparing non-alcoholic beer using technological methods has the following feature: low price with losing the organoleptic properties of the beer.

Consequently, producing non-alcoholic beer using a technological method with optimum organoleptic properties is still unresolved. The solution to this problem may lie in selecting non-traditional low-fermentable starch-containing raw materials, mashing regimes and studying their effect on the carbohydrate composition of the brewing wort. In addition, applying technological methods will make it possible to produce non-alcoholic beer at breweries of any capacity and produce an economic effect.

Excepting traditional barley and soft wheat, triticale, spelt, millet, buckwheat, tritordeum and sorghum grains are currently used worldwide in beer production.

It has been proven that the use of 10 % oat malt in the beer recipe has no adverse effect on the beer production process and the quality of the final product. However, the addition of higher proportions of oat malt (50 % and 100 %) leads to a significantly lower yield (less wort) and makes the brewing process more difficult (very long filtering times) [11]. Tritordeum malt has a high potential for beer production, both as an additive and as the main source of starch [12]. Buckwheat is recommended for usage in non-alcoholic beer technology as its low extractivity reduces fermentation activity, resulting in a lower alcohol yield. However, at the same time, the beer profile is lost. Millet and quinoa grains are mainly recommended for the production of dark beers according to their technological characteristics [13].

These cereals are used as unmalted raw materials to increase the extractivity of brewing wort, broaden the range of products, obtain specific organoleptic characteristics and reduce the cost of the final product. Some also have other functional properties that increase the beverage's nutritional value [14].

Replacing expensive brewing malt with unmalted carbohydrate-containing materials is an essential and urgent task. The shortage of malting barley, the primary raw material of the brewing industry, raises the problem of using non-traditional grains at the top of the agenda [15]. For producing non-alcoholic beer using technological methods, it is crucial to select raw materials with a low final degree of digestion, which directly depends on the carbohydrate composition of the brewing wort.

Research by scientists [16] shows the characteristics of grain raw materials and their influence on the physico-chemical parameters of wort. Some authors have researched the use of oats in brewing. The extractability of this grain crop is 54–61 %, which makes it possible to recommend replacing malt with up to 17 % as unmalted raw material in order to increase the profitability of brewing production, but increasing its content will lead to wort viscosity and an increase in the filtration rate. The author [17] studied the characteristics of triticale for use in brewing. The extractability of the grain is 79–85 %, a rather high and significant figure for beer production. Whereas when it is used as unmalted raw material in the recipe, its content cannot exceed 15 % due to the formation of turbidity in the wort. Therefore, it is recommended to produce malt on its basis and then use it in the production of beer.

Sorghum has a high starch content [18] of 68–75 %, on par with conventional unmilled raw materials (barley grains have extractability of 67–69 %, maize 82–90 %, rice 95–97 %, wheat 65–72 %). It has a high gelling temperature (78–85 °C), which is higher than that of other grains (60–72 °C on average). Therefore, when using these raw materials, it is necessary to select appropriate technologies and beer production regimes.

As is known [19], in the production of classic beer, the higher the extract of the raw material, the more actively enzymes process the substances into monosaccharides and amino acids. The higher the extractivity of the initial wort, the brighter and more pronounced the malt flavor of the drink, and the more rapidly the yeast ferments the sugars formed into alcohol. Heating the starch suspension in water runs its hydrolyzing process. The hydrolyzed starch is effortlessly exposed to amylases and thus more profoundly hydrolyzes the starch, increasing the yield of extractive substances in the wort [20].

Non-complete hydrolysis of starch is necessary for producing non-alcoholic beer with an increased yield of dextrins. In this connection, according to the monitoring of the scientific literature, the most promising type of non-traditional grain raw material that can be used in producing non-alcoholic beer is sorghum.

Sorghum is a unique cereal plant in its biological features and economic characteristics. It has a distinctive quantitative characteristic. Its main advantages are its exceptional drought tolerance, salt tolerance, high productivity, stability of yields from year to year, ease of processing and versatility of use [21].

Competitive advantages of sorghum over other cereals: high yields, lower seeding rates (2 to 3 times) and seed purchase costs, high ecological plasticity, the possibility of later (including swidden) sowing and harvesting dates, high haying capacity (2–3 mowing), ecological plasticity, versatile use [22].

In beer production technology, the authors [23, 24] investigated the use of soaked and un-soaked sorghum grains, the production of gluten-free beer on their basis, and the use of grain sorghum for the production of classic light beers. Sorghum is also widely used to make traditional beers, commonly referred to as sorghum or opaque beer, in Nigeria, Zimbabwe, Mali and Burkina Faso, Chad and Cote d'Ivoire [25]. However, in the studies presented, sorghum grain in the form of unmalted raw material is used in various classic beer production technologies. All this suggests that a study on the use of grain sorghum in non-alcoholic beer technology, with a selection of optimum content in the mash and mashing mode, to obtain the required carbohydrate composition of wort with a low final degree of digestion, is appropriate.

3. The aim and objectives of the study

This study aims to select grain sorghum and mashing regimes and to study their influence on the carbohydrate composition of brewing wort for producing non-alcoholic beer.

In order to achieve the aim, the following objectives were set:

– to determine the usage of grain sorghum varieties Kazakhstan-16 and Kazakhstan 20 for the production of low-digestion wort by using the method of mathematical planning of experiments;

– to study the carbohydrate composition of brewing wort based on sorghum grain for the production of non-alcoholic beer.

4. Materials and methods

4. 1. Object of research

The research objects are varieties of grain sorghum, Kazakhstan-16 and Kazakhstan-20, which were experimentally produced and presented for the study by the "Kazakh Research Institute of Agriculture and Crop Production" LLP (Almaty region, Republic of Kazakhstan), used as unmalted raw material. Also, for wort preparation, light brewing malt "Pilsen", light caramel malt 150, granulated bitter variety El Dorado (α – acid 13.2 %) and aromatic variety Cascade (α – acid 4.8 %) are used.

Experimental studies on brewing wort quality parameters were carried out at the Food Safety Research Institute of the Almaty Technological University. Control brewing of finished beer was carried out at the fermentation products research and education center of Almaty Technological University in a NANO BREWERY TYPE 50 L4 mini-brewery.

4. 2. Determination of the mass fraction of carbohydrates by high-performance liquid chromatography Agilent-1200 according to GOST 33409-2015

The method is based on separating a mixture of carbohydrates and glycerol by using a chromatographic column in isocratic elution mode.

The components were quantified using a refractometric detector based on the signal value of the time-integrated refractive index. Samples with brewing wort and working solutions were prepared for the study.

The sample was tested on a chromatograph at least twice. The peaks of the components in the sample had to be correctly integrated. The results were processed mathematically. The amount of sugar to non-sugar was calculated from the wort concentration and the maltose content:

$$C/H = 1:\ H/C, \tag{1}$$

where H, C – the non-sugar and sugar content of the wort correspondingly, %.

The non-sugar content is the difference between the extractives and the sugar content.

4. 3. The method of mathematical planning

The search experiment was carried out to identify important factors, selecting the two most significant factors independent of each other. During data processing, the factors were subjected to correlation regression analysis. The result showed the absence of multicollinearity; a regression equation was derived. Finally, correlation and regression analyses were performed in MS Excel.

The search experiments were carried out according to a full-factor plan. The optimization was carried out using the steepest ascent method.

In order to characterize or compare the results of the observations, the following parameters need to be calculated for each resultant factor, such as arithmetic means of the results, standard deviation, coefficient of variation characterizing the relative dispersion of the result, % (Table 1).

Table 1

Variables and their levels of variation in a multivariate experiment

Name of the factor	Coded factor's designation	Variation interval of the factor	Levels of variation		
			Lower –1	Medium 0	Higher+1
hydro module	X_1	2	3	5	7
filling	X_2	45	10	55	100
mashing mode	X_3	1	1	1.5	2

Using a software package significantly reduces the time required to plot the standard distribution curve of a random variable. To plot the standard distribution curve in MS Excel, we use the NORMRASP function that calculates the probability values of the normal distribution function for the indicated mean and standard deviation.

The planning of the experiment is performed in Statistica 12.0. We make the planning matrix and confirm each point with three parallel experiments.

5. Research results of grain sorghum used for low-digestion wort production

5. 1. Substantiation of grain sorghum Kazakhstan-16 and 20 usage for producing low-digestion wort

In order to produce non-alcoholic beer using technological methods, it is necessary to conduct research on the selection of the mashing mode and the production of low-density brewing wort, which will ensure an alcohol yield of up to 0.5 % alcohol in the process of subsequent fermentation.

In the study's first phase, the most suitable sorghum varieties for producing low-density wort were determined as Kazakhstan-16 and Kazakhstan-20.

Search experiments and optimization of the results by the steepest ascent method were carried out during the study. A 2^3 full factorial experiment (FFE) was used for the search experiments. The influencing factors were the filling (x_1), hydro module (x_2), mashing mode (x_3) and the resulting dependent factor was extractivity (y_1).

A study was conducted on selecting the amount of unmalted raw materials to be introduced into the main grain products. For this purpose, Kazakhstan-16 and Kazakhstan-20 sorghum varieties were brought in the malt: sorghum ratio from 95:5 to 50:50. Since at small capacity plants it is allowed to bring unmalted raw materials in the amount of up to 50 %, the control was a 100 % malted backfill without using unmalted raw materials.

The hydro module was set at a mash/pour ratio from 1:3 as this ratio for classic beers up to 1:7 is not practical because the mash concentration drops drastically.

Two mashing modes with intermittent temperature pauses have been selected to ensure a low carbohydrate yield. The first mashing mode has 45–72–78 °C pauses and the second 45–78 °C pause mode. The mashing takes place without holding protein and maltose pauses. That will slow the action of α–amylase and inactivate β–amylase. As a result, it is expected to result in fewer monosaccharides and a higher dextrin yield. Based on the above data, Tables 2, 3 present the results of the effect of filling and hydro module on the yield of extractive substances for Kazakhstan-16 and Kazakhstan-20 sorghum varieties.

The data from the tables allow a multivariate analysis of the experiment to identify and justify the most suitable variety of grain sorghum for low-digestion wort production.

The two factors, hydro module and filling, which influence the final dependent factor, extractivity, are shown in Tables 2, 3.

The minimum level for both varieties of the hydro module is 3; the maximum level is 7. The minimum level for the filler is 10, and the maximum level is 100. Calculation and a correlation-regression analysis with obtaining regression formulas of all the results obtained were carried out in MS Excel:

– formula for wort by using Kazakhstan-20 is:

$$y_1 = 18.24 - 0.04x_1 - 1.53x_2 - 0.25x_3,$$

– formula for wort by using Kazakhstan-16 is:

$$Y_1 = 17.48 - 0.04 \times x_1 - 1.66x_2 + 0.215x_3.$$

In the following research stage, a mathematical model for analyzing the selected factors' influence on the extractive substances' yield was produced (Fig. 1, 2). Extractivity plays an important role in the organoleptic characteristics and the wort density and depends on the type of raw material, its ratio in the recipe and the hydro module.

Table 2

Wort extractive yields from sorghum Kazakhstan-16 as a function of mash and hydro module

Malt/sorghum filling ratio	Extractive yield according to hydro module				
	1:3	1:4	1:5	1:6	1:7
95/5	12.62	12.00	10.20	8.52	5.63
90/10	12.58	11.85	10.00	8.37	5.32
85/15	12.58	11.72	9.81	8.22	5.00
80/20	12.00	11.71	9.73	7.91	4.90
75/25	11.89	11.55	9.52	7.51	4.61
70/30	11.71	11.52	9.32	7.39	4.31
65/35	11.51	11.41	9.01	7.01	4.00
60/40	11.32	11.20	8.81	6.62	3.85
55/45	11.00	10.89	8.72	6.00	3.81
50/50	10.20	10.00	8.50	5.95	3.52
100	12.81	12.51	10.50	8.80	5.80

Table 3

Wort extractive yields from sorghum Kazakhstan-20 as a function of mash and hydro module

Malt/sorghum filling ratio	Extractive yield according to hydro module				
	1/3	¼	1/5	1/6	1/7
95/5	12.80	12.50	11.00	8.51	6.01
90/10	12.76	12.32	10.81	9.01	5.82
85/15	12.71	12.11	10.61	8.84	5.51
80/20	12.52	11.89	10.55	8.52	5.31
75/25	12.31	11.75	10.52	8.34	5.01
70/30	12.00	11.65	10.31	8.00	4.81
65/35	11.80	11.59	10.01	7.92	4.62
60/40	11.61	11.55	9.80	7.52	4.51
55/45	11.52	11.25	9.61	7.36	4.21
50/50	11.30	11.01	9.51	7.21	4.02
100	12.85	12.80	11.32	8.81	6.32

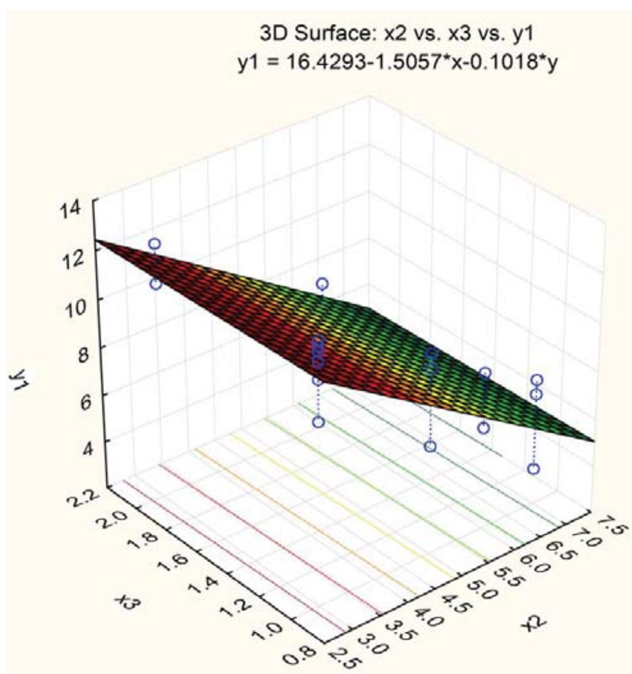

Fig. 1. Graph of the mathematical model of the effect of mash and hydro module on wort extractivity with sorghum Kazakhstan-20

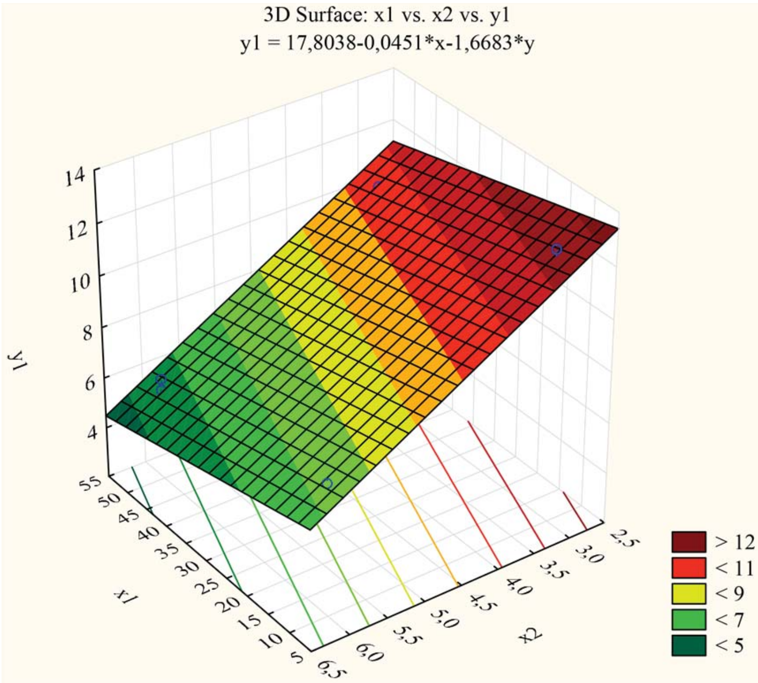

Fig. 2. Graph of the mathematical model for the effect of mash and hydro module on wort extractivity with sorghum Kazakhstan-16

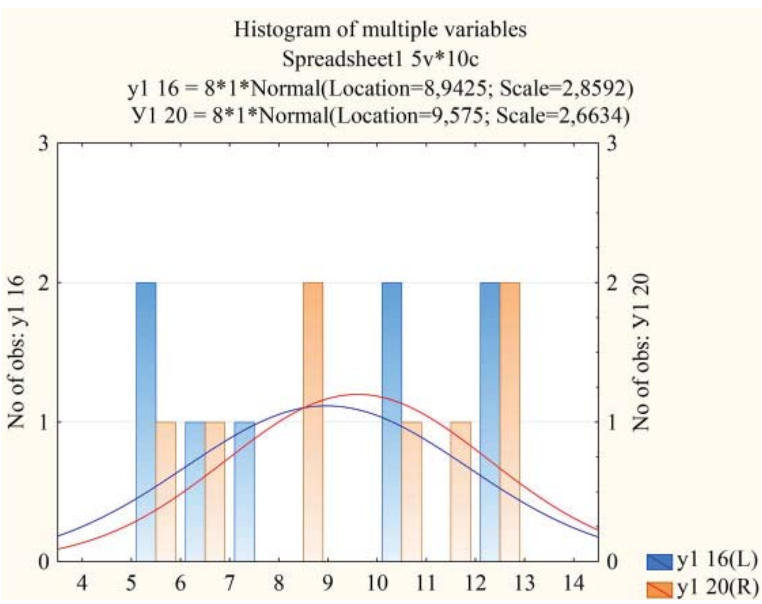

Fig. 3. Graph of the comparative analysis of wort extractivity with sorghum Kazakhstan-16 and 20

5. 2. Study of the carbohydrate composition of sorghum grain based on brewing wort for non-alcoholic beer production

The use of grain sorghum variety Kazakhstan-16 as the most suitable for low-density mash production is justified according to the mathematical experiment planning study.

The next stage of the research was to investigate the carbohydrate composition of the wort using Kazakhstan-16 sorghum as the most suitable.

The data are presented in Table 4.

Table 4

Carbohydrate composition of wort with sorghum Kazakhstan-16

No.	Mass fraction of carbohydrates, g/dm^3	Quantity
1	sucrose	1.95±0.08
2	maltose	2.43±0.08
3	glucose	0.81±0.05
4	fructose	1.0±0.02
5	maltotriose	5.5±0.10
6	oligosaccharides	14.2±0.15
7	dextrins	23.0±0.21

According to Table 4, the developed wort based on grain sorghum Kazakhstan-16 contains 4.38 g/dm^3 of disaccharides and 7.31 g/dm^3 of monosaccharides, which will be fermented in the first place during the following fermentation process. Oligosaccharides and dextrins predominate in the wort. Furthermore, they are largely responsible for the concept of "full flavor".

6. Discussion of the results of grain sorghum usage in the production technology of low-digestion wort

Currently, the production of non-alcoholic beer has particular relevance in the brewing industry. However, the production of such beer is limited by how it is produced. The use of membrane technology is suitable for large-capacity breweries. The solution for small companies is to use technological production methods.

The process is primarily influenced by the raw materials used in the recipe. Low-fermenting ingredients must be used. According to analyses, non-alcoholic beer is currently prepared using buckwheat malt or dark beer with a high content of caramel and roasted malt. Fermentation is also influenced by the use of yeast metabolites and low-fermenting yeasts.

A particular feature of the research presented is the use of grain sorghum varieties Kazakhstan-16 and 20. Nowadays it is practiced only in the technology of classical beer production. This raw material has a high content of extractive substances and a high gelling temperature. Those are important factors in the production of wort with a low degree of digestion.

Another innovation of the research is the modification of the brewing wort production parameters during the mashing phase. The result of the research is planned to be low-density wort, which will result in a beer with low alcohol content.

Mashing is the most crucial process in mash production: converting insoluble malt substances into soluble ones. The conversion process and the extract yield are decisive in this process. The mashing process is affected by various factors, including temperature, duration of the process and mash concentration. The temperature regime is significant, which determines the course of biochemical transformations [26].

In order to achieve the goal, it is necessary to make a mathematical planning model of the experiment to study the effect of the amount of malt and sorghum (x_1), as well as the effect of the hydro module (x_2) and mashing mode (selection of temperature and duration of pause) on the extractive substances yield and the carbohydrate composition of wort (x_3).

The task of planning is to determine the following points for experiments. First, select some appropriate experiments and methods for mathematical processing of the results for decision-making. A particular case of this task is the planning of an extreme experiment. This means that the experiment aims to find the optimal conditions for the object's functioning. Thus, planning an extreme experiment is a choice of the number and conditions of conducting experiments, minimally necessary for finding the optimal conditions.

Mathematical planning of the experiment allows the planned results of the study to be justified and revealed in advance. Tables 1, 2 present the results of the fill and hydro module ratios on the yield of extractive substances. The lower the ratio of unmalted raw materials in the charge and the hydro module, the higher the extractivity of the brewing wort. This is explained by the presence of reducing agents in the raw materials.

Following the mathematical calculations and the graphs shown in Fig. 1, 2, the regression equation is statistically reliable. That, in turn, confirms the correctness of the experimental research. Based on this, we can conclude that when the hydro module-fill ratio is increased, the extractivity decreases. The use of hydro module 1/7 and 50/50 allows for the lowest yields of extractive substances in both sorghum varieties. However, at the same time, the organoleptic properties are reduced. In addition, distinct sorghum, venereal flavor and aroma appear in the wort. Therefore, the information can conclude that an optimum hydro module ratio of 1/6 and a 60/40 filler proportion are most suitable for low-extractive brewing wort production. High organoleptic characteristics of the wort were found with the extractive matter content in the range of 7.5 % for wort with sorghum Kazakhstan-20 and 6.62 % for wort with sorghum Kazakhstan-16.

The usage of buckwheat as unmilled raw material to obtain the necessary yield of extractive substances under the same production circumstances makes it necessary to increase the hydro module to 1:8, causing a reduction in the organoleptic properties of the wort. The reason for this is the high carbohydrate content of the raw material and its increased viscosity. Also, the mashing method is required in the production process, which leads to excessive energy consumption. Thus, the use of grain sorghum for producing non-alcoholic beer wort is as justified as possible [27].

The coefficient of determination (R^2), considered a universal measure of dependence of one random variable on many others, was calculated. In our case, (R^2) equals 0.98, which indicates a high degree of dependence of the resulting indicator on the complex influence of factors. We tested models using Fisher's and Student's tests, which showed adequate results.

The data in Fig. 3 show that under the same mashing conditions, the extractivity of Kazakhstan-16 wort is 10 % lower than that of Kazakhstan-20 sorghum wort. Possibly it depends on the anatomic characteristics of sorghum. In this regard, further experiments on the carbohydrate composition of wort were carried out on brewing wort using mash in the malt:sorghum ratio 60/40 and hydro module 1/6 on the basis of non-traditional raw material sorghum variety Kazakhstan-16.

The research described in Table 3 should result in a wort with a low content of digestible sugars, which would allow for a shallow fermentation process and the production of a small amount of alcohol.

For wort preparation, we used a 60:40 proportion of malt: 60 kg of malt per 100 kg of grain products, of which 15 % was caramel malt and 40 kg of sorghum Kazakhstan-16. Due to the high gelling temperature of sorghum, a jump mashing method was selected where the maltose pause was bypassed. Mashing time was kept at 50–52 °C – 15 minutes. Then it was sharply raised to 70–72 °C – 15 minutes. Then it was heated to 78 °C and kept for another 30 minutes. The suggested mashing mode preserves the protein pause for protein breakdown, which affects the amine nitrogen content in the wort, which in turn is one of the factors determining the beer profile. This makes it complete, improves the organoleptic characteristics of the wort and subsequently influences the stability and foam stability of the finished beer. This is why a protein pause is mandatory.

Furthermore, unlike the classic brewing wort process, there is no maltose maturation. This is so that the amylolytic enzymes in the malt, particularly β-amylase, are not involved in the starch hydrolysis process and are then inactivated when the temperature is raised. This results in less formation of di- and mono-saccharides, which are responsible for the degree of fermentation of the wort. The proposed stepwise mashing process does not result in the complete hydrolysis of the carbohydrates with a high dextrins content, which does not form alcohol in the subsequent fermentation process.

Also, the proposed mashing method will reduce energy costs and production time, which will have an economic effect on the developed technology.

Then the ready mash was filtered off, boiled with the specified hops, clarified and cooled according to the classic technology.

In the final beer wort, the carbohydrate composition was determined, which is responsible for the subsequent fermentation and determines the beer's profile.

According to Table 4, the wort with an extractivity of 6.62 % produced with unpeeled Republic of Kazakhstan 16 sorghum shows that the amount of digestible sugars is 25.89 % of the total amount of carbohydrates. One characteristic of the extractivity of beer wort is the ratio of digestible sugars to non-fermentable substances in the wort. For traditional beer, the proportion of 1: 0.22...0.31 is considered normal.

The following calculations have been made according to the methodology for determining the sugar to non-sugar ratio. The wort concentration for non-alcoholic beer is 6.62 %, and the maltose content is 2.43 mg per 100 ml. The relative density of the wort is 1.0225. The sugar to non-sugar ratio is: C/H=1:4.25/2.37=1:1.79. Therefore, 79 % of wort consists of indigestible sugars, which was achieved in the experimental study.

In addition to the identified non-fermentable sugars, 21 % of the fermentable carbohydrates will allow the subsequent fermentation process to form secondary products, which will determine the taste of the finished beer. Accordingly, the beer prepared using this mashing process will have a low degree of digestion, releasing up to 0.5 % alcohol in the subsequent fermentation process.

Several difficulties may arise when introducing this technology into the production process due to the quality of the raw materials used. When using raw materials, the extractive content of the malt must be taken into account. The use of low-quality malt and the replacement of 40 % of the mash with unmalted raw materials can lead to poor organoleptic characteristics of the wort and, subsequently, of the finished beer. It is also mandatory to use pre-softened water, as the proposed technology uses a high hydro module (1:6), and the pH of the water will directly affect the beer taste.

Further research on the selection of a specific fermentation mode and yeast types concerning the characteristics of the developed brewing wort is in progress.

7. Conclusions

1. Considering the experimental study and the reviewed literature, sorghum Kazakhstan-16 and 20 for producing brewing wort with a low digestion degree was chosen. This raw material is highly extractive, which in turn has a positive effect on the organoleptic characteristics of the wort with its low density. Furthermore, it has a high degree of starch gelatinization compared to other grains. That enables producing brewing wort with a low yield of highly digestible sugars, high dextrin and low digestive carbohydrate yield. This is possible with an appropriately selected mashing regime.

The following points were determined by mathematical planning of the experimental data on the selection of raw materials and mashing mode for producing non-alcoholic beer. When using grain sorghum variety Kazakhstan-16 in the ratio of malt to sorghum 60:40, with the selected hydro module of 1:6 and a jump mashing mode, a smaller amount of extractive substances (6.62 %) with the highest organoleptic characteristics is formed.

2. The carbohydrate composition of brewing wort obtained experimentally with sorghum grain was studied. As a result, the amount of digestible sugars was 25.89 %, and dextrins 23 %. The sugar to non-sugar ratio was 1:1.79 according to calculations of the experimental study.

The amount of unfermentable sugars was 79 %. The results obtained in the experiments show that the selected raw materials and mashing technology allow obtaining beer with ethyl alcohol content in the output of up to 0.5 % alcohol.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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