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ҒТАХР 65.43.31 https://doi.org/10.48184/2304-568X-2024-1-149-160

QUALITY AND QUANTITATIVE TRAITS OF NON-ALCOHOLIC BEER WITH FLAVOUR-IMPROVED TASTE

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The non-alcoholic and low-alcohol beer market has grown significantly in recent years and is predicted to continue growing. However, non-alcoholic and low-alcohol beers have organoleptic problems and are not recognized by many consumers. The increasing popularity of alcohol-free beers (AFBs) fosters the industry's interest in delivering the best possible product. Yet, a remaining sensory issue of AFBs is the over-perception of wort flavor, caused by elevated concentrations of small volatile flavor compounds (i.e.aldehydes)still remains. Previously, molecular sieves (hydrophobic ZSM-5 type zeolites) were found as most suitable to remove these flavors by adsorption with high selectivity from the AFBs. In this work, a flavor-improved beer is produced at a pilot-scale using this novel technology, and its chemical composition, sensory profile, and stability are evaluated against a reference. Aldehyde concentrations in the flavor-improved product were found 79–93% lower than in the reference. The distinct difference was confirmed with a trained sensory panel and could be conserved even after three months of ageing at 30◦C. Future work will focus on the process design to scale up this technology. It is established that the release of a new kind of beer is economically profitable, since the expansion of the range contributes to a more complete use of production capacity, and consequently, reduced costs per unit of production, which ultimately leads to an increase in the profit of the enterprise.

Keywords: Alcohol-free beer, zeolite, aldehydes, wort flavor, ageing, sensory evaluation, adsorption.

ЖАҚСАРТЫЛҒАН ДӘМІ БАР АЛКОГОЛЬСІЗ СЫРАНЫҢ САПАЛЫҚ ЖӘНЕ САНДЫҚ СИПАТТАМАЛАРЫ

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Алкогольсіз сыра нарығы соңғы жылдары айтарлықтай өсті және өсуді жалғастырады деп болжануда. Дегенмен, алкогольсіз және төмен алкогольді сыралардың органолептикалық проблемалары

бар және көптеген тұтынушылармен таңдалмайды. Алкогольсіз сыраның (AFB) танымалдылығының артуы саланың ең жақсы өнімді дайындауға деген қызығушылығының артуына ықпал етеді. Дегенмен, алкогольсіз сыраның қалған сенсорлық ақауы ұсақ ұшпа хош иісті қосылыстардың (мысалы, альдегидтер) концентрациясының жоғарылауынан туындаған сусланың дәмін шамадан тыс сезілетіндігінде болып табылады. Бұрын молекулалық електер (ZSM-5 типті гидрофобты цеолиттер) алкогольді сырадан жоғары селективті адсорбция арқылы осы хош иістерді кетіруге ең қолайлы екендігі анықталды. Бұл жұмыста жақсартылған хош иісті сыра осы жаңа технологияны қолдана отырып, тәжірибелік масштабта шығарылады және оның химиялық құрамы, дәмі мен тұрақтылығы эталонмен салыстырылады. Дәмі жақсартылған өнімдегі альдегид концентрациясы бақылау өніміне қарағанда 79-93% төмен болды. Ерекше айырмашылық арнайы сенсорлық сарапшы комиссия көмегімен расталды және 30°С температурада үш айлық экспозициядан кейін де сақталуы мүмкін. Сыраның жаңа түрін шығару экономикалық тұрғыдан тиімді екендігі анықталды, өйткені ассортименттің кеңеюі өндірістік қуаттылықты толық пайдалануға, демек, өндіріс бірлігіне шығындарды азайтуға ықпал етеді, бұл сайып келгенде кәсіпорын пайдасының артуына әкеледі.

Негізгі сөздер: алкогольсіз сыра; цеолит; альдегидтер; сусло хош иісі; ұстау; сенсорлық бағалау; адсорбция.

КАЧЕСТВЕННЫЕ И КОЛИЧЕСТВЕННЫЕ ХАРАКТЕРИСТИКИ БЕЗАЛКОГОЛЬНОГО ПИВА С УЛУЧШЕННЫМ ВКУСОМ.

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Рынок безалкогольного пива значительно вырос в последние годы и, по прогнозам, продолжает расти. Однако безалкогольное и слабоалкогольное пиво имеет органолептические проблемы и не признается многими потребителями. Растущая популярность безалкогольного пива (БП) стимулирует интерес отрасли к созданию наилучшего продукта. Тем не менее, остающимся сенсорным недостатком безалкогольного пива является чрезмерное восприятие аромата сусла, вызванное повышенными концентрациями небольших летучих ароматических соединений (т.е. альдегидов). Ранее молекулярные сита (гидрофобные цеолиты типа ZSM-5) были признаны наиболее подходящими для удаления этих ароматических веществ путем адсорбции с высокой селективностью из БП. В данной работе пиво с улучшенным вкусом производится в пилотном масштабе с использованием этой новой технологии, а его химический состав, сенсорный профиль и стабильность оцениваются в сравнении с эталоном. Концентрация альдегидов в продукте с улучшенным вкусом оказалась на 79-93% ниже, чем в эталоне. Явное различие было подтверждено обученной сенсорной комиссией и сохранилось даже после трехмесячной выдержки при 30◦С. Дальнейшая работа будет сосредоточена на разработке технологического процесса для расширения масштабов этой технологии. Установлено, что выпуск нового сорта пива экономически выгоден, так как расширение ассортимента способствует более полному использованию производственных мощностей, а следовательно, снижению издержек на единицу продукции, что в конечном счете ведет к увеличению прибыли предприятия.

Ключевые слова: безалкогольное пиво; цеолит; альдегиды; аромат сусла; выдержка, сенсорная оценка, адсорбция.

Introduction.

The beverage industry is currently experiencing a surge in the popularity of soft drinks [18], due to various motivators such as responsible drinking, religion, or fitness. However, alcohol-free beer is still struggling to catch up with its alcoholic counterparts due to significant issues that may arise from changes in its production process [7]. A new method has been developed for producing improved flavored alcohol-free beers (AFBs) by using zeolites, a type of molecular sieves, to adsorptively remove the wort flavor from biologically extracted non-alcoholic beer. This results in a product that has significantly reduced Strecker aldehydes, which are known to cause off-flavors [12]. Recent studies have shown that compounds such as 2-methylpropanal (2-MP) are more involved in wort flavor perception than previously thought, despite 2- and 3-methylbutanol (2-MB and 3-MB) as well as methional (Met) being commonly associated with it [6]. Strecker aldehydes can be formed by a thermally induced reaction between an amino acid and a reducing sugar, but alternative pathways are also possible via more reactive carbonyls. Therefore, their appearance is difficult to prevent.

Materials and research methods

The research work was carried out at the test center at Zhangir Khan University. Research materials necessary for the beer brewing process were obtained from the JSC "Nurjanar" industry.

Research methods:

GOST 31711-2012 Beer. General technical conditions

GOST 29294 -2014 Barley malt for brewing beer. Technical conditions

GOST 13586.5-2015 Grain. Humidity determination method.

GOST 10844-2017 Grain. Acidity determination method.

GOST 12136-2017 Grain. The method of determining extractability of barley.

GOST 20264.4-2017 Enzyme preparations. Methods for the determination of amylase activity.

TR CU 021/2014 Safety of food products. Technical regulations of the customs union.

EBC 9.6: Beer color.

EBC 9.3.1: Ethanol in Alcohol Free and Low Alcohol Beers: Enzymatic Method.

EBC 9.27: Fermentable Carbohydrates in Beer by HPLC.

EBC 9.42.1: Foam Stability of Beer using the NIBEM-T Meter.

Triticale malt, Safbrew yeast, Mosaic hops, and water were used to make the beer.

Malt milling. First of all, the malt was sent to the grinder for milling. Malt flour is obtained as a result of milling.

According to the milling method, the following types are distinguished: dry grinding, dry grinding with conditioner, and with a key conditioner.

Figure 1 – Grinded malt

Mashing the wort. Mashing is the process of converting all the valuable substances of the grain into an extractive solution and brewing beer. Under the influence of temperature and several temperature breaks, the grinding particles dissolve and the starch is converted into simpler forms of sugar. At the end of this period, the wort has a sweet taste.

Figure 2 – The process of mashing

Straining the wort. After mashing, the finished wort is pumped into a special filter tank where the original wort is filtered. If the wort is not clear enough, it is filtered again. The clarity of the filtered wort is checked in the factory using an observation glass, which monitors the turbidity indicators and, if necessary, switches the filtration process to recirculation and reverses it. The clearer the wort, the better the beer.

Figure 3 – Wort straining process

Boiling the wort. At this stage, the mass enters the wort boiler, where it is boiled with hops in one or more ways. Usually, hops added at the beginning of brewing give the beer a special taste - biterness. Adding hops at the end of the brewing process adds flavor to the drink and softens the bitterness. Boiling can last from 60 to 120 minutes.

Figure 4 – Boiling the wort with hops

Whitening and cooling the wort. The obtained hot wort is pumped into a special device - a hydrocyclone, in one cooking volume, to facilitate the precipitation of small particles of hops and proteins. The working principle of the device is as follows: the stream of beer wort is directed tangentially, so the rotation of the wort takes place inside the device. Particles suspended under the influence of hydrodynamic forces are collected in the form of a cone in the center of the bottom of the device. After the solids settle, the wort becomes lighter and is removed from the sediment, first from the upper level of the hydrocyclone and then from the lower level as clarity increases. The wort treatment process takes 20-30 minutes, after which the wort is cooled for about 1 hour to the temperature required to start fermentation.

Fermentation. Sterile compressed air is first injected into the cooled brewer stream through a special unit for yeast aeration and dosing, and then the brewer's yeast is dosed. Yeasts need air to multiply rapidly during the first 12-24 hours of brewing. Fermentation takes about 7 days, at a temperature of 12 to 16°C, during which time all the sugars in the wort are fermented to form alcohol, carbon dioxide, and some substances, the amount of other substances: glycerin, acetaldehyde, vinegar, amber, lemon and milk acid. As by-products of fermentation, high alcohols are formed from amino acids, which affect the aroma and taste of beer, and then the beer that has passed the fermentation stage is sent to the next stage - fermentation and maturation. For final ripening, "young beer" is aged at a temperature of 0°-2°C. During this period, it is saturated with carbon dioxide, where the remaining extract is slowly fermented, and the bouquet and flavor are brightened and formed. After chemical analysis, which confirms the readiness and taste of the product, the beer is sent for filtering.

Filtering. Since the compounds that cause beer opacity are complex in structure and have a wide range of particle sizes, the best way to remove them is to filter the beer with an auxiliary material: diatomaceous earth.

Kieselgur is a sedimentary rock that creates a porous surface for beer to pass through, and particles of substances that affect turbidity remain. Most importantly, the beer goes through a fine purification stage, during which the smallest particles are removed.

Important indicators of the quality of finished beer are its transparency and stability to the formation of turbidity, which is especially relevant in recent years due to the need to increase the warranty period of product storage.

The main technological method of beer whitening is filtering. Natural zeolites are promising filter materials and sorbents of natural origin.

In the past, brewing researchers have treated this substance in various ways, such as fermentation using thermal or membrane technologies, or adding masking additives by co-separation with ethanol. Until now, the degree of wort aroma reduction or selectivity has been limited.

The advantage of using adsorbents and, in particular, zeolites for separation is their double selectivity based on the size and hydrophobicity of the molecules. Thus, only small (volatile) hydrophobic compounds are removed from the product. In this paper, we present the qualitative characteristics of this new product, as well as its sensory characteristics. In addition, the AFBs retention process for individual compounds is investigated. The chemical and physical analysis presented in this paper includes a comprehensive representation of chemical groups and quality indicators. However, special attention is paid to four common Strecker aldehydes, whose taste characteristics are orthonasal (direct or inhaled smelling) and retronasal (reverse or mouth smelling) AFBs thresholds are listed in Table 1. In addition, furfural (FF) as a representative of compounds resulting from heat-induced reactions and trans 2-nonenal (t2H), a general index of retention, were studied in more detail.

Table 1 – Odor detection thresholds in non-alcoholic beer determined by logistic regression and corrected for false positives.

Composition	Taste/ Scent	Detection limit in AFB (μg /l)	
		Orthonasal	Retronasal
2-MP	Fruit, grain, nut, chocolate	4,32	0,86
2-MB	Fruit, sweet, almond, malt	23,4	8,99
3-MB	Malt, nut, chocolate	0,61	0,44
Мет	Boiled potato, metal, wort	0,47	0,73

Table 2 – Characterization of the primary extract, its alcohol content, pH, and color.

Characteristic	Amount
Extract (◦P)	12,12
Ethanol (%, by volume)	0,015
pH	4,2
Color (EBC)	8,54
Total amount of iso-α-acids (mg/l)	<0.4

1. Chemical substances.

The ZSM-5 G-360 adsorbent was purchased from ACS Materials. Solutions were prepared in the laboratory using quality water or analytical grade absolute ethanol.

2.1. Developing beer with reduced wort flavor.

The adsorbent was prepared by soaking it in 70% ethanol for 1 hour. Three stages of water washing were used to remove less volatile hydrophobic compounds that may have been adsorbed during storage. The adsorbent was then dried at 220°C until it reached a constant mass. After cooling, 4 kg of dry adsorbent was poured into a 20 cm diameter and adjustable height column. The column was blown with sterile filtered nitrogen gas for 3 hours to remove as much oxygen as possible. Finally, the column was rinsed with deoxygenated process water to wet it. AC as a substrate was obtained by fermenting hop wort at 2-4°C. The composition of the hop wort is given in Table 2. Ethanol formation was inhibited due to the low fermentation temperature. The resulting crude, alcohol-free product was stabilized using polyvinylpolypyrrolidone and silica, and filtered through a beer membrane filtration system. The mixture was filtered with a slight excess to prevent foam formation. It was then divided into two containers, each with a liquid capacity of 20 L. One of the containers was connected to a zeolite-filled column, and as much air as possible was eliminated. The activated carbon (AC) in this container was then circulated through the column and frequently sampled. After 42 hours, the container was disconnected, and both AC (enhanced flavored and reference) were filtered again. The filtered liquid was then standardized to 5.3°C (1°C equals 10 g of sugar per kilogram of wort), pasteurized with 50 PU (1 PU equals 1 minute of pasteurization at 60°C), and bottled. The final product is poured into 0.3-liter brown glass bottles.

2.2. Storage of samples.

Bottled samples were stored in a dry, dark room at 30°C for a maximum of 4 months. Each month, two bottles were selected for analysis of exposure rates. After 3 months, the samples were tested using a touchpad as described.

2.3. Analysis of initial extract, oxygen content, pH, and color.

The original extract and product pH were determined using an oscillating type digital pressure sensor and a pH meter, respectively. Oxygen content was analyzed using a Haffmans CO2/O2 Gehaltemeter analyzer type C-DGM according to the supplier's instructions. The color of the product was measured using the EBC 9.6 method, i.e. spectrophotometrically, and converted to EBC units according to equation (1):

$$\text{Color (EBC)} = A_{430\text{nm}} \cdot 25 \cdot d \quad (1)$$

where A430 nm is the absorbance at 430 nm, and d is the dilution factor.

2.4. Analysis of volatile aldehydes.

Aldehydes other than acetaldehyde were analyzed by a method adapted from Vesela et al. The sample was then concentrated by solid-phase microextraction in the free space on a pdms/DVB fiber and then introduced into a gas chromatograph equipped with a 30 m × 0.25 mm × 0.25 m cell and a mass spectrometer as a detector in negative ionization mode. To increase selectivity, O-(2,3,4,5,6-pentafluorobenzyl)-hydroxylamine was used as a derivatizing agent.

2.5. Analysis of other volatile substances.

Ethanol concentration was determined enzymatically using a test kit from Thermo Fisher Scientific according to the recommended EBC method 9.3.1. Diacetyl and 2,3-pentanedione were quantified by an adapted method, using open-space gas chromatography equipped with a wide-bore (50 m × 0.53 mm × 1 m) fused silica WCOT CP Sil CB column and an electron capture detector. To improve accuracy, 2,3-hexanedione was used as an internal standard. Acetaldehyde, ethyl acetate, isoamyl acetate and isoamyl alcohols were analyzed by mass gas chromatography equipped with a flame ionization detector according to the EBC 9.39 method. Compounds were separated on a polar capillary narrow-bore column (DBWaxETR, 60 m * 0.32 mm ID, 1 m fused silica), and 4-heptanone and 1-butanol were added to each sample as internal standards.

2.6. Analysis of non-volatile compounds.

Total fermentable sugars were calculated by adding glucose, fructose, sucrose, maltose, and maltotriose. These sugars were quantified using a UPLC equipped with a Ri detector and a 1.7 m (2.1 × 150 mm) BEH Amide column as described in EBC Method 9.27. CDR beerlab test kit from FoodLab was used to determine free amino nitrogen (FAN) according to the procedure described by the manufacturer.

2.7. Sensory evaluation.

Three different sensory evaluation sessions were conducted to evaluate the taste improvement of AFBs in contact with the selective adsorbent. In the first session, unrefined base products were tested, i.e. taste-enhanced (I A) and reference (I B). To understand the effect of the adsorptive removal step on the final product, base AFBs (flavor-enhanced A and reference B) were mixed with a mixture of fruit and ether flavors (Sample III), as well as a mixture of fruit flavors and isoacid solution (Sample IV) and mixed with base AFBs (sample II) were compared in the second session. In addition, the primary AFBs were tested again in the third session after 3 months of storage at 30°C. An overview of all flavors is given in Table 3. Sensory evaluation of the AFBs produced was performed using a trained sensory selection panel consisting of a total of 16 trained raters with a modified quantitative characteristic analysis (QDA). First, a list of attributes was determined during a group discussion. Attribute intensity was quantified in duplicate on a 100-point linear scale during two separate sessions. Panelists were aligned using a linear scale and samples were presented one at a time in a randomized order. In the next session, panelists were seated in individual sensory booths and received 100 mL of each sample presented in black-coated glasses coded with three-digit codes. They were given about 10 minutes to rate each sample, allowing them to neutralize the taste in between. A panel of experts evaluated a maximum of six samples during the session.

Table 3 – Overview of alcohol-free beers (AFBs) flavors with enhanced flavor (A) and reference (B) obtained from the selection panel.

Session	Added products	Storage condition	Number of participants in the panel
1	(I) base AFBs (A and B)	Freshly made	13
2	(II) base AFBs (A and B)	Freshly made	13
	((III) base AFBs (A and B) flavored with a mixture of fruit flavors		
	(IV) To obtain 15 BUa the base AFBs (A and B) were flavored with a mixture of fruit flavors and isoacids		
3	(V) base AFBs (A and B)	Stored	11
BU (bitterness unit) = 50·$A_{275\ нм}$, where $A_{275нм}$ is the absorption of beer isooctane extract at 275 nm.			

2.8. Statistical analysis.

The sample standard deviation and standard error m of each measurement were determined according to equations (2) and (3), respectively. The transmitted mQ error was determined as described below. In this case, the statistical error of the sample, as well as the systematic error of the regressed calibration parameter, were taken into account. All errors in the results section represent the distributed standard error unless otherwise stated.

$$\sigma = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x_i - x^{-2})} \quad (2)$$

$$\sigma_m = \frac{\sigma}{\sqrt{n}} \quad (3)$$

Results and discussion

3.1. A product with improved flavor.

Nonalcoholic beer was sampled frequently to monitor the decline in wort aroma over time during adsorptive removal by recycling it through a zeolite-filled column. The normalized results are shown in Figure 5.

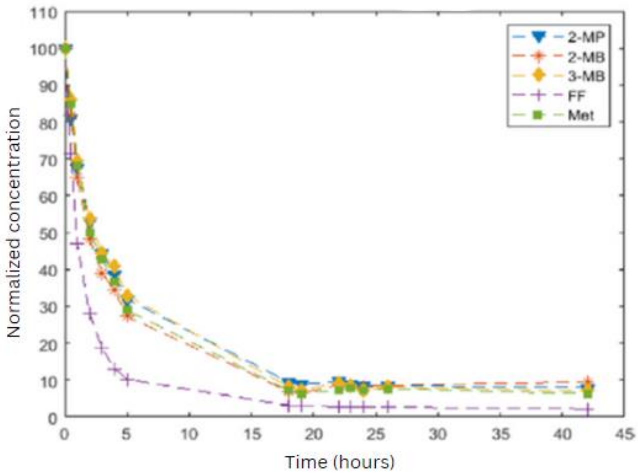

Figure 5 – Changes in aldehyde concentration in the adsorption removal stage.

Over time, the concentration decreases exponentially, leveling off at 6-10% of the initial concentration, thereby significantly reducing the taste of the wort in the product. However, according to previously published data, the theoretical capacity of the adsorbent should allow reducing the content of free aldehydes to zero [12]. There could be several reasons for this observation, but given the absolute concentration range (<15 g/L) and the significant increase in oxygen levels during the test (≈210-1000 g/L), it can be suspected that oxygen caused the formation of new Strecker aldehydes. The concentration of furfural shows a different composition, it decreases to 2% of its initial amount, and the concentration decreases further after 42 hours. Unlike the Strecker aldehydes, 2-MP, 2-MB, 3-MB, and MET, whose formation is closely related to oxygen, furfural is formed by an imine reaction with an amine or amine group of a pentose called a Schiff base, which reacts with an additional 3-deoxyozone at pH < 5. During the condensation reaction, rings are formed and the product is furfural. Thus, since oxygen is not involved in the mechanism of furfural formation, the observed difference from Strecker aldehyde supports the theory that oxygen is the cause of the lower threshold for Strecker aldehyde elimination. However, in general, the concentration of aromas in the wort is significantly reduced. Figure 6 shows the absolute concentration of selected aldehydes in the treated product and the final product of the reference.

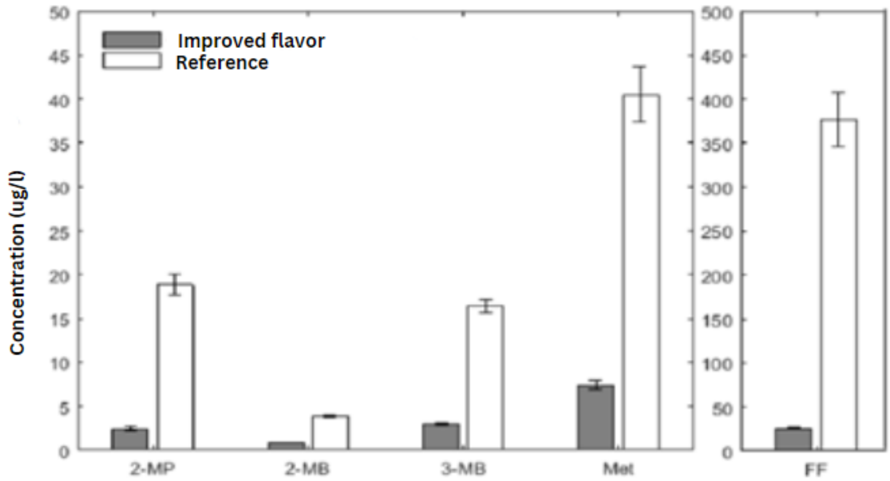

Figure 6 – Concentrations of 2-methylpropanal, 2- and 3-methylbutanal, methanol and furfural in alcohol-free beer after pasteurization.

The reduction achieved was 79-93%. This decrease is less pronounced than measured during the test due to the intermediate stage of pasteurization, where the aldehyde concentration again rises slightly. The data are presented in Table 4. Both products were adjusted to a similar starting extract to make the analysis comparable. Due to the processing implemented in the technological process, the concentration of oxygen in the product with enhanced taste has significantly increased.

However, it is expected that oxygen injection can be avoided in a more complex setting during scaling. The measurements confirm that the optical appearance of AFBs with enhanced aroma is unchanged. It has the same color and transparency as the reference color, even with slightly improved foam stability. Relatively polar compounds such as sugar and ethanol are not removed, and the FAN content is similar to the reference. As expected, the adsorbent removes small volatile compounds such as acetaldehyde, diacetyl or ethyl acetate. Isoamyl acetate (<0.05 mg/L), amyl alcohols (<1.1 mg/L), and 2,3-pentanedione (<2 g/L) were found below their respective detection limits in both samples and were therefore not included in the analysis. Analytical results confirmed that the wort taste was significantly reduced through a descriptive panel prepared and confirmed that it was still observed upon consumption.

In the first set of sample tastings, panelists tried only the non-hopped base products (I A and I B). The result is shown in Figure 7. The experts found a clear difference in the perceived taste of the wort (-8 points) between the two samples. In particular, the taste of raisin and rye bread decreased, which is necessary for AFBs. In addition, the bitter and sour taste is reduced. As a result, the processed sample was recognized as watery and had a low odor and overall intensity (-6/-5 points). A second series of tastings was conducted to evaluate the effect of the flavor enhancement on the final product, a product with a fruit beer flavor (no wort flavor) and bitterness. For this purpose, flavored AFBs (III A and III B) and AFBs flavored basic AFBs (IV A and IV B) were tested, their bitterness was brought up to

15% (IV A and IV B). The QDA results are presented in Table 5. The taste difference between the respective samples is small but remains. For instance, when comparing samples II A and II B, they differ in taste by only 3 points, compared to 8 points when tasted separately (IA and IB). It is important to note that samples I and II are the same sample but seasoned in different sessions. However, there is a noticeable difference in taste, particularly with ground bread. During the interval between samples II, III, and IV, a masking effect was observed in the character of fruit flavor and spicy food. Interestingly, the panelists accepted flavor samples of the improved base with higher tropical fruit content than the reference fruit. Therefore, the amount of flavors in the final product can be reduced to achieve the same flavor profile.

Table 4 - Specifications and standard deviations for bottled products (reference and sample with improved flavor)

		Beer with improved flavor	Reference
Customized	OE (% м/м)	5.23±0.02	5.30±0.02
Depends on the process	Oxygen (μg/l)	61.1±3.2	16.3±1.3
Unchanged	Color (EBC)	3.4±0.0	3.3±0.0
	Ethanol (%, by volume)	0.01±0.00	0.01±0.00
	FAN (mg/l)	88±2	90±2
	pH	4.76±0.02	4.74±0.02
	Total number of fermented sugars (g/l)	34.0±1.5	33.9±1.5
	Transparency (EBC)	0.2±0.0	0.1±0.0
	Transparency after 7 days at 57 °C	0.1±0.0	0.2±0.0
Increase	Foam stability	256±5	217±4
Decrease	Acetaldehyde (mg/l)	1.4±0.1	2.3±0.1
	Diacetyl (μg/l)	3.9±0.3	15.9±1.1
	Ethyl acetate (mg/l)	<0.2±n/a	0.3±0.0

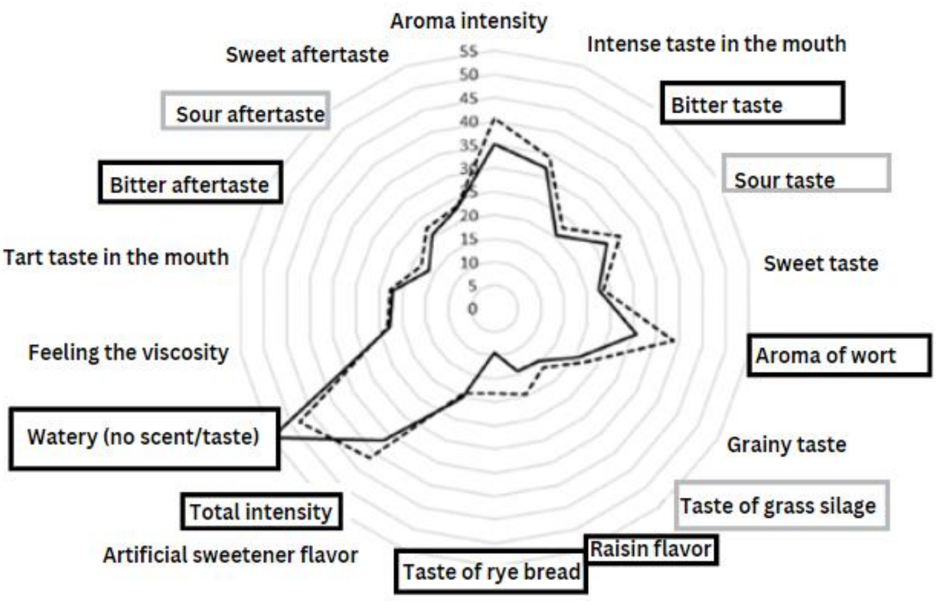

Figure 7 – Base NAB, enhanced taste (solid line) and reference (dotted line) sensory profile. Attributes that differ at the 95% significance level are circled in black, and those that differ at the 90% significance level are circled in gray.

Table 5 - Sensory attributes quantified with a description panel.

	IIA	IIB	IIIA	III B	IVA	IVB	p-Value
Odor intensity	37	40	39	40	38	38	0.14
Intense taste in the mouth	31	31	32	32	31	29	0.19
Bitter taste	24	24	24	24	35	35	0.00
Sour taste	29	29	28	29	30	29	0.72
Sweet taste	22	23	22	22	21	22	0.19
The aroma of wort	34	37	28	32	29	31	0.00
Grainy taste	24	25	18	22	18	21	0.00
The taste of grass silage	16	19	14	17	18	16	0.45
Raisin flavor	12	17	9	12	9	9	0.04
The taste of rye bread	14	17	5	12	5	11	0.00
Fruity / ethereal taste	26	25	39	34	37	35	0.00
A taste of tropical fruits	8	7	20	12	18	15	0.00
Artificial sweetener flavor	16	14	14	15	12	12	0.23
Total intensity	41	41	43	40	43	43	0.02
Aqueous (no taste/odor)	41	41	41	42	39	39	0.35
Feeling the viscosity	22	22	21	22	21	22	0.48
Tart taste in the mouth	22	22	22	19	24	23	0.02
Bitter aftertaste	20	20	20	21	34	33	0.00
Sour aftertaste	24	24	23	23	25	22	0.04
Sweet aftertaste	22	21	22	20	19	19	0.01

Table 6 – Comparison of aldehyde formation rates in flavor-improved beer and reference beer during storage at 30°C with the rates obtained from the literature review.

Composition	Formation rate (μg / month)		Approximate formation rate [μg/month]
	Improved flavor beer	Reference	
2-MP	1.2±0.1	1.8±0.2	4.7–28.8
2-MB	0.7±0.0	0.8±0.1	0.6–1.9
3-MB	2.2±0.3	1.3±0.4	1.4–3.2
FF	53±9	69±15	63–99
Мет	1.3±0.3	−0.1±0.7	0.9–2.1
T2H	−0.006±0.004	0.016±0.026	0.003–0.033

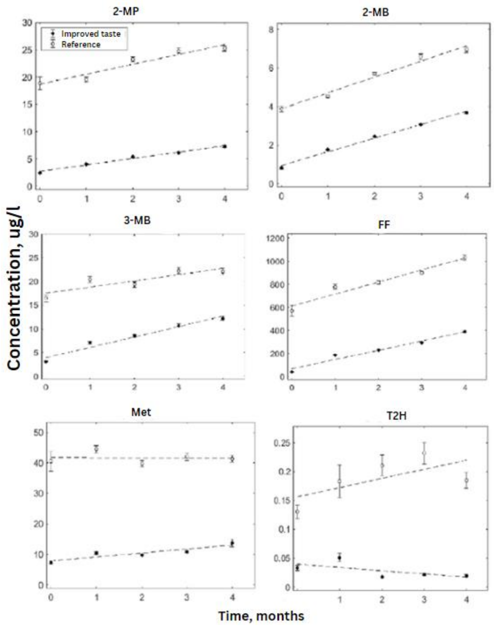

Figure 8- Concentrations of selected compounds during 4 months for improved (black) and reference product (grey).

3.2 Retention.

Aldehydes are not only the characteristic flavor of wort in NAB, but they are also associated with retention during storage [2]. This study focuses on a selected set of aldehydes, investigating their aromas and chemical pathways associated with beer aging. Recent studies have shown that the formation of de novo aldehydes is limited during the aging process of conventional beer. The increase in aldehyde concentration over time is mainly caused by the release of cysteine and bisulfite compounds [3]. This study is the first to measure retention in NAB.

Figure 9 and Table 6 show the concentration profiles of all aldehydes studied over four months in the flavor-improved beer and the reference beer and their regressed formation rates.

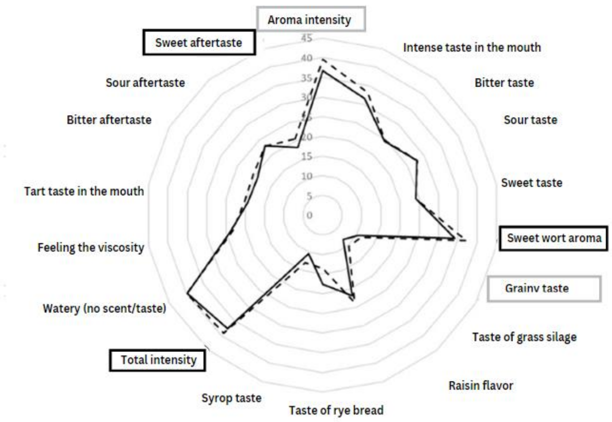

Figure 9 - Sensory profile of base NAB, improved flavor (VA, solid line), and reference (VB, dotted line) stored at 30℃ for 3 months. Attributes that differ at the 95% significance level are circled in black, and those that differ at the 90% significance level are circled in gray.

This means that the concentration difference between the improved and reference NAB will remain the same or may even increase during storage. The same applies to T2H, although in this case, the concentration of the treated product is slightly reduced during the retention process. However, the situation with 3 MB is different. The speed of formation in the improved product is higher, resulting in a reduced difference during the storage process. The concentration of methional increases in the improved product, but remains relatively stable in the standard. It can be assumed that the initial concentration of methional in the standard is already in equilibrium with its adducts, as it is the highest of all measured tracer aldehydes. Another possible explanation is that it is simultaneously formed and converted to degradation products, such as methanethiol and acreolin, as previously reported in the literature. Because beer is fermented at a low temperature resulting in minimal yeast activity, the properties of the studied beer are interesting to compare with the literature. It is important to note that this evaluation is objective and does not include any subjective opinions.

1. The initial concentration of new beer is higher than that of conventional beer, especially in the reference product.
2. Ethanol content is < 0.01%.
3. Yeast does not produce sulfite.
4. The concentration of fermentable sugars is higher than in regular beer because they are not consumed during fermentation.

The panelists were unable to discern any significant differences in flavor between the raisin and rye bread. Although some attributes, such as bitterness and finish, were slightly different in the new product, they are now perceived as being the same. Upon closer inspection, it becomes apparent that the identified attributes are quite distinct from those of the new product. The sweet taste of the sample is more pronounced in the reference beer, and participants noted the taste of the syrup. A cardboard aroma may appear during the holding process, but will disappear after about 4 weeks after peaking. These results are consistent with the literature data. Although the actual concentration of wort aroma in the improved flavor product is still very close to that of the fresh product, the reduction in wort aroma does not affect the sensory evaluation of the product compared to the reference product.

Conclusion.

This work aimed to improve the taste properties of non-alcoholic beer by significantly reducing the concentration of characteristic wort aromas, resulting in a taste closer to pure basic beer. A panel of qualified experts confirmed this difference during sensory evaluation. The adsorbent used in the process was highly selective, removing only small volatile compounds while leaving other parameters such as color, foam stability, and sugar content unchanged. The inclusion of fruit flavors and bitters decreased the relative difference in wort flavor between the improved alcohol-free beer (AFB) and Etalon, but it also resulted in a significant reduction in acidity. Even after three months of forced exposure, differences in quality were still noticeable. Further research will concentrate on creating a large-scale and economically feasible process operation, as well as exploring the potential for absorbent regeneration. Furthermore, additional research on capture, such as utilizing hops, is necessary to gain a better understanding of the involved mechanisms.

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