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# Keptinis – The brewing and fermentation characteristics of a traditional farmhouse ale from Lithuania

Keptinis is a historical beer style from Lithuania which is brewed from a mash that is baked in parts or in total in a special oven. According to historical sources, one viable method to brew Keptinis is to mash-in with small amounts of brewing liquor at temperatures of approximately 65 °C and to bake the whole mash afterwards at ambient temperatures ranging from 280 to 300 °C in a so-called Duonkepis, a traditional bread oven. Maillard reactions, caramelisation products and eventually pyrolysis of the remaining starch can therefore be expected. The baked mash is then mashed in again in brewing liquor and lautered. The collected wort is not boiled but fermented subsequently with top-fermenting yeast strains. Available data on the brewing and fermentation characteristics of Keptinis is scarce. Hence, in a reproducible experimental design to reconstruct one method to brew this historical beer style, three brews and one control were conducted. For each experimental brew a grain bill of 6 kg Pilsener malt was mashed in at a grist-to-water ratio of 1:3 and mashed for 60 minutes at 65 °C. The mash of the three brews then was baked at 300 °C for 30, 60 and 120 minutes in a combination steamer using dry air. The mash of the control brew was not baked. The wort of all four brews was fermented with top-fermenting ale yeast at 20 °C. Prolonged baking time affected the pH of wort and beer, the degree of fermentation and the beer colour. The apparent degree of fermentation of the control was 91 %, whereas the prolonged baking time of the mash lowered it to 85 % (30 minutes), 84 % (60 minutes) and 82 % (120 minutes). EBC beer colour units were measured with 4 EBC in the control, 15 EBC units in the beer gained from the mash baked for 30 minutes, 35 EBC units (60 minutes) and 88 units (120 minutes) respectively. In addition, the thio-barbituric acid index (TBI) and the free amino nitrogen (FAN) of the final beers were determined.

Descriptors: Lithuanian farmhouse ales, keptinis, baked mash, historical brewing techniques, maillard reactions, caramelisation reactions

## 1 Introduction

Keptinis is a historical beer style originating from Lithuania. It is particular regarding its mashing procedure, since the mash is baked at high temperatures after partial saccharification. Temperatures distinctively above 200 °C suggest that Maillard reactions, caramelisation and even pyrolysis of partially saccharified starch

will occur. These chemical reactions and degradations of carbon bonds will have a distinctive effect on the resulting beer. It can be assumed that the original gravity, the pH-value, the degree of fermentation, the colour, and in particular the aroma profile of the final beer will be perceptibly affected. The term Keptinis is Lithuanian and means “baked” or “fried”. The traditional brewing process of Keptinis can be broken down into the following fundamental steps: Ground pale malt, usually barley malt, is mixed with a small amount of water to form a mash. From this mash, loaves are shaped and baked in the Duonkepis (a traditional bread oven). The wooden lauter tun is prepared, equipped with a central drainage hole at the bottom. Wood chips are evenly distributed on the bottom. Into the drainage hole, a round wooden stick wrapped with a bundle of straw is inserted, with the ears of grain facing downward. The straw is bent over the wooden logs at the bottom, without breaking the straw forming a false bottom. The baked mash loaves are then broken into pieces and placed into the lauter tun. Only at this stage is hot water added. The tun is covered with a cloth and left to rest for an undetermined period. Afterward, the stick is carefully pulled just far enough out of the drainage hole to allow the wort to flow. The straw bundle and stick remain in the lauter tun. The collected wort is not boiled.

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brewing parameters. Before describing the conducted experiments, the historical and traditional background of Keptinis is briefly summarised to at least outline the importance of this very special farmhouse ale for the Lithuanian drinking culture.

Written historical sources regarding the brewing characteristics of Keptinis are rare and mainly based on oral history, household books and ethnographic descriptions. Regarding this, descriptions of Keptinis are summarised in *Žydinti taurė: baltų gėrimai ir apeigos* (Blossoming cup: the beverages and rituals of the Balts) by Daiva Vaitkevičienė, although authors such as Lars Marius Garshol and Mika Laitinen also collected and published reports on this beer style in recent years [2, 13, 14]. The first mentions of Keptinis in Lithuania and the Baltic region date from the 17<sup>th</sup> century. Matthaeus Praetorius in his work *Deliciae Prussicae* mentions that old Prussians (Baltic tribes) used to drink the fermented beverage from loaves of bread baked from a mixture of rye, peas and oats [15].

Household books and recipes, also dating back to the 17<sup>th</sup> century, provide additional information on the used ingredients and the brewing process. In 1686 the chef of the noble Radziwiłł family provides detailed information on baked beer in his notebook, which was published by Jarosław Dumanowski and Rafał Jankowski almost 340 years later, related to their work on *Monumenta Poloniae Culinaria, Part 2*. The chef describes the preparation of an instant beer, based on loaves of baked cereals such as barley or rye, which are broken into four parts, then soaked in water and left overnight. The liquid then is drained into another vessel, hop is added and the mixture is boiled. The process is concluded by adding yeast [16–18]. It is very noteworthy that in contrast to other referenced sources, here the wort is boiled. Detailed information regarding the cereals, herbs and grist-to-water ratios used to brew Keptinis can also be found in cookbooks. In 1893 a cookbook was released by Liudvika Didžiulienė-Žmona, in which the author describes in detail the recipe of a variant of Keptinis, based mainly on barley malt and additional parts of rye, wheat or buckwheat [19].

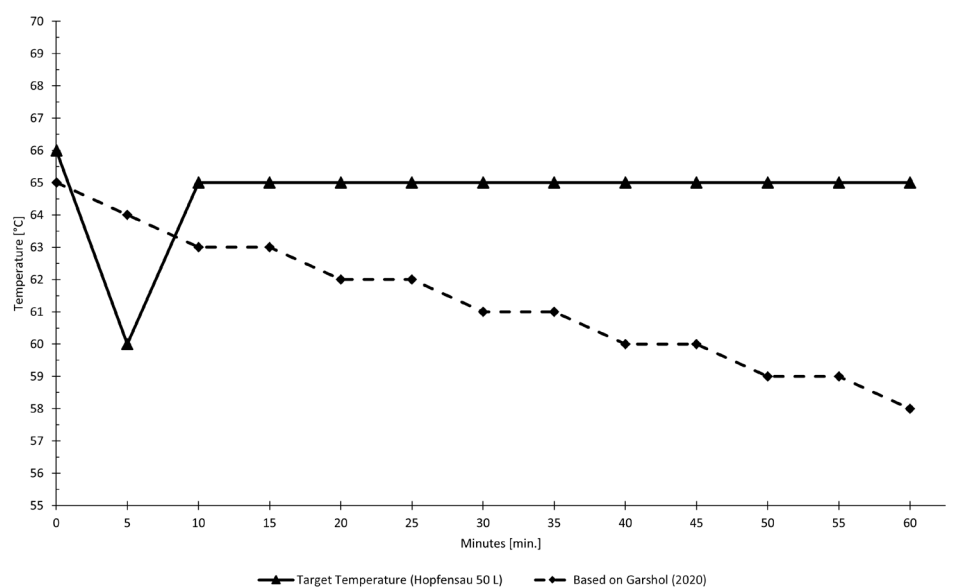
According to Juozas Petrulis, an ethnographer who described beer brewing in the Kupiškis region between the wars, the main ingredient of Keptinis was brome (genus *Bromus*) mixed with barley and oat. In addition to wild hops, which are mentioned in all sources, also wormwood (*Artemisia absinthium* L.), dried apples or pears and strawberry stems are sometimes referenced. Petrulis also reports that pea stems, strawberry stems and blossoms of Meadowrue (*Thalictrum flavum*) were used as filter beds in the lauter tun [20]. The plant genera and species mentioned in context with Keptinis also belong to the same plant families, which are traditionally used in the production of other fermented beverages in Eastern Europe [21]. Although the ratio of grist and water is not defined in any metric or another nominal system in the referenced sources, according to Petrulis,

brewers simply measured the mash thickness with a mash paddle: a paddle stuck into the mash should stay straight. Keptinis was fermented using open fermentation. Wooden mash tuns, which were cleaned and steamed, were used for the fermentation. Keptinis was also fermented in barrels. During fermentation bungs were left open, and corked when the brewers determined that the fermentation was subsiding, with sufficient residual sugars left for the carbonisation [20].

Lina Dumpe, in *Alus Tradīcijas Latvija*, attributes a description of the brewing process of Keptinis by Dionysius Fabricius as follows: "They prepare barley flour (polentae), mix it with cold water, then inflame (pinsunt) oven; when (the flour mixture) is well roasted, they pour hot boiling water over it and it brings out the flavor and sweetness, after which they can make delicious beer right away" (page 67) [22]. While Lina Dumpe in *Alus tradīcijas Latvijā* attributes this description of traditional beer production to Fabricius, his major works, including *Livonicae Historiae Compendiosa*, do not reveal such content [23]. This suggests that the attribution might stem from a secondary source.

Similar brewing procedures, including the baking of the mash, or the forming of loaves from malt and cold water and subsequent baking of these loaves, have also been documented for Estonia and, according to Garshol and Samorokov (2020) this oven-based mashing was the preferred brewing process in Estonia. However, the oven-based beers in Estonia, such as Seto koduolu, differ greatly from those brewed in Lithuania. The baked mash produced in Estonia is made mainly from rye malt, contains hardly any sugar, and is primarily used to add color to the beers produced [2, 24].

Keptinis can be brewed with any equipment found at home and it is easily done in small volumes, which is one of the reasons for the longevity of this brewing tradition and the cultural significance of Keptinis as a farmhouse ale. It is very noteworthy that according to Vaitkevičienė, the brewing of baked beer, Keptinis, was associ-



**Fig. 3** Mash diagram of the applied mashing process in comparison to the mashing process based on Jančys Vytautas (documented by Garshol) [2]. The applied mashing process was loosely based on the Isothermal 65 °C Mash Method according to MEBAK to facilitate better reproducibility

**Table 1 Applied methods in the analysis of the samples**

Method [25, 27]	Application
MEBAK WBBM 2.9.1	Degassing of samples
MEBAK WBBM 2.9.2.3	Original Gravity [% w/w], Extract [% w/w]
MEBAK WBBM 2.9.6.3	Alcohol by volume [% vol.], Apparent and Real degree of Attenuation [% w/w]
MEBAK WBBM 2.13	pH-value
EBC 9.6	EBC beer colour
MEBAK WBBM 2.4	Thiobarbituric Acid Index (TBI)
EBC 9.10.1	Free Amino Nitrogen FAN
MEBAK online. Method R-207.00.002*	Isothermal 65 °C Mash Method. Rev. 2016-03

\*Modified for the mashing process

ated with women, whereas the brewing of conventional beer was associated with men („nors įprastą, markytinį alų dažniausiai daro vyrai, keptinis alus išliko susietas su moterimis“) [13]. Although the consumption of Keptinis beer, or any other beer, was depended on social status and the level of welfare of the farmers, even the smallest farm made beer for the most culturally important events in Lithuania, such as Christmas, Easter, weddings, baptism, birthdays, communal fests like Sambariai and the Beekeepers Day [20]. Farmers defined the scale of brewing with didelis alus for large brews and mažas alus for small brews. Due to limitations of the Duonkepis, Keptinis was limited in volume. Hence, it was usually brewed for and consumed on family or community fests.

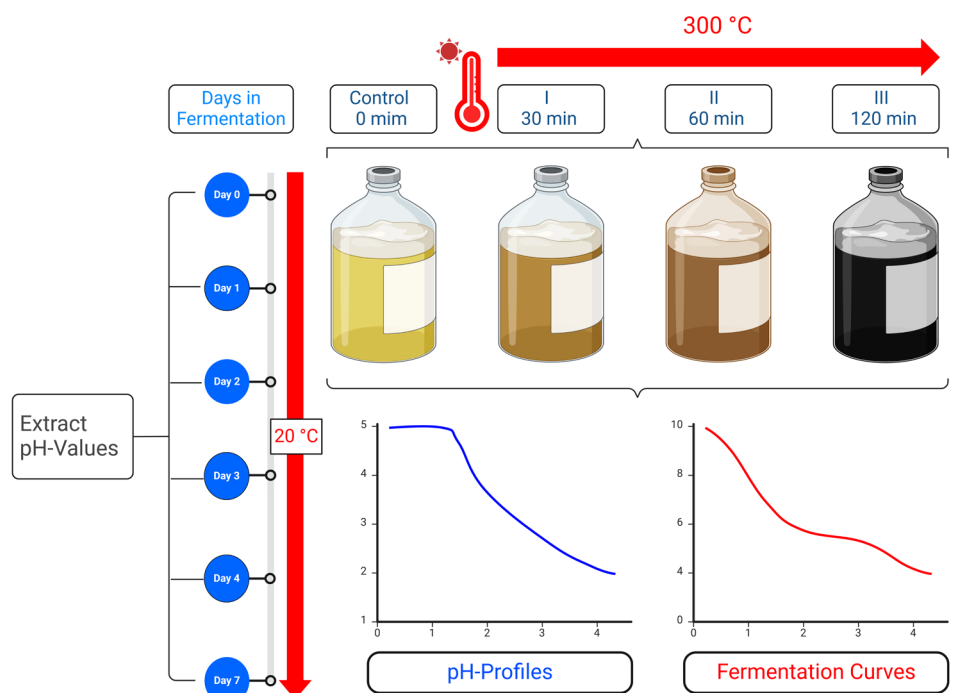
Keptinis is a living brewing tradition and differs from many other historical beer styles in this respect. The traditional production methods and cultural customs surrounding Keptinis are deeply rooted elements of Lithuanian cultural heritage.

## 2 Material and methods

### 2.1 Mashing and baking of the mash

24 kg of Weyermann® Barke® Pilsner Malt (Mich. Weyermann® GmbH & Co. KG, Bamberg, Germany) from one malt bag were used for four brews. Pilsner malt was used because historical sources mention the use of pale malt and because it is the type of malt that experiences a low thermal load during the kilning process. For mashing and lautering a 50 L micro steam brewery (Sudkraft GmbH, 8093 St. Peter a. O., Austria) was used. For each brew, 6 kilograms of malt were conditioned with 2% water by weight. The malt was crushed using a Maltman 55 two-roller mill (Egon Sommer Maschinenbau

GmbH & Co. KG), and mashed in in 18 litres of brewing water at 64 °C. The brewing water for all four brews was prepared by adjusting the residual alkalinity of drinking water with 5.4 ml of food-grade technical lactic acid E270 to gain mash pH-values of 5.4 to 5.6 respectively. The mash was kept at 65 °C for one hour by direct steam infusion, and iodine tests were performed 30 min and 60 min after mashing in. The mashing process was loosely based on the data researched by Garshol and, to facilitate better reproducibility, was implemented as a variation of an Isothermal 65 °C Mash Method according to MEBAK [2, 25]. The related mash diagram is shown in figure 3. After 60 min of mashing and iodine-neutrality, 8 litres of the first wort were lautered into a 40 L brewing kettle. 13 kilograms of the spent grain and the remaining first wort of each brew were moved from the mash tun subsequently and were weighed in one GN 1/1 26.6 L-Gastronorm container (Width x Height x Depth: 530 mm x 325 mm x 40 mm) using a board scale (Kern IFB 30K5DM, Kern & Sohn GmbH, 72336 Balingen-Frommern, Germany). The mash was then distributed in this container with a dough spatula to achieve an even layer thickness of 8 cm. A digital radio thermometer (TFA Radio BBQ-Thermometer TWIN 14) was placed centrally in the mash to monitor the core temperature of the mash, then the mash was baked in an SCC WE 61 combi steamer (Rational Aktiengesellschaft, 86899 Landsberg am Lech, Germany), which was preheated to 300 °C dry heat. While the temperature was kept constant at 300 °C, the duration of the baking time was varied. The mash of the first brew was baked for 30 minutes, the mash of the second brew was baked for 60 minutes and the mash of the third brew was baked for 120 minutes. The mash of the fourth brew was not baked and served as a control. 17 liters of brewing water were added to the 8 liters of first wort in the brewing kettle, heated to 85 °C and kept at that temperature to stop enzyme activity. The baked mash was then removed from the combi steamer and subsequently weighed.



**Fig. 4** Fermentation experiments in overview. All brews were fermented with the same top fermenting yeast strain at 20 °C fermentation temperature. Extract and pH-value was measured regularly. Created in BioRender. Rehorska, R. (2024) <https://BioRender.com/a61y408>

A mash bag was placed in the brewing kettle and the whole baked mash was then removed from the GN container and stirred thoroughly into the prepared 25 L of wort for 15 minutes. Using the fixed mash bag as mash filter, the spent grain then was removed from the wort. Concurrently, 50 g of hop pellets type 90 (Magnum, 14.5 % alpha acid, derived from MashCamp, Vienna, Austria) were preisomerised in 2 L of brewing water by boiling the pellets for 30 minutes, targeting 50 IBUs for the resulting wort. The preisomerised aqueous hop extract was then added to the wort by straining it through a stainless-steel sieve. The control was prepared in the same manner. According to the source material, the wort was not boiled, cooled to 20 °C using a stainless-steel cooling coil and subsequently fermented in temperature-controlled GF30 Conical Fermenters, connected to a GF GC4 glycol chiller (Bevie Limited, 0632 Auckland, New Zealand). The wort of all four brews was fermented at 20 °C with 11.5 g of rehydrated Fermentis SafAle™ S-04 dry yeast (Lesaffre International, 59700 Marcq-en-Baroeul, France). Extract degradation and pH-value was monitored regularly.

## 2.2 Extract, apparent degree of fermentation, alcohol by volume, pH-values and beer colour

Extract and pH-values were measured according to MEBAK (see Table 1), using a DMA 35 Standard portable Density Meter (Anton Paar GmbH, Anton Paar GmbH, 8054 Graz, Austria) and a WTW 3110 (ATC) pH meter with a Sentix® 41 integrated temperature probe (Xylem Analytics Germany Sales GmbH & Co. KG., 82362 Weilheim, Germany). The apparent final extract, the degree of fermentation, and the alcohol by volume of the final beers was determined with the modular Anton Paar Packaged Beer Measurement Systems (consisting of: DMA 5001, TPO 5000, AlcoLyzer 3001 Beer, Haze 3001, pH 3201, CarboQC ME), according to MEBAK (see Table 1). After a total of 7 days of pressureless fermentation and maturation, the beer was bottled and stored at 6 °C in a refrigeration cell. After 4 weeks of cold conditioning, the samples were labelled as follows: Keptinis I (30 min at 300 °C), Keptinis II (60 min at 300 °C) Keptinis III (120 min at 300 °C) and Keptinis IV (Control). The bottles then were transferred to the Leibniz Institute for Food Systems Biology at the Technical University of Munich for orthonasal aroma profile analyses.

## 2.3 Free amino nitrogen (FAN), colour units EBC and thiobarbituric acid Index (TBI)

Concurrently, the free amino nitrogen, the thiobarbituric acid index, and the beer colour were determined at the Chair of Brewing and

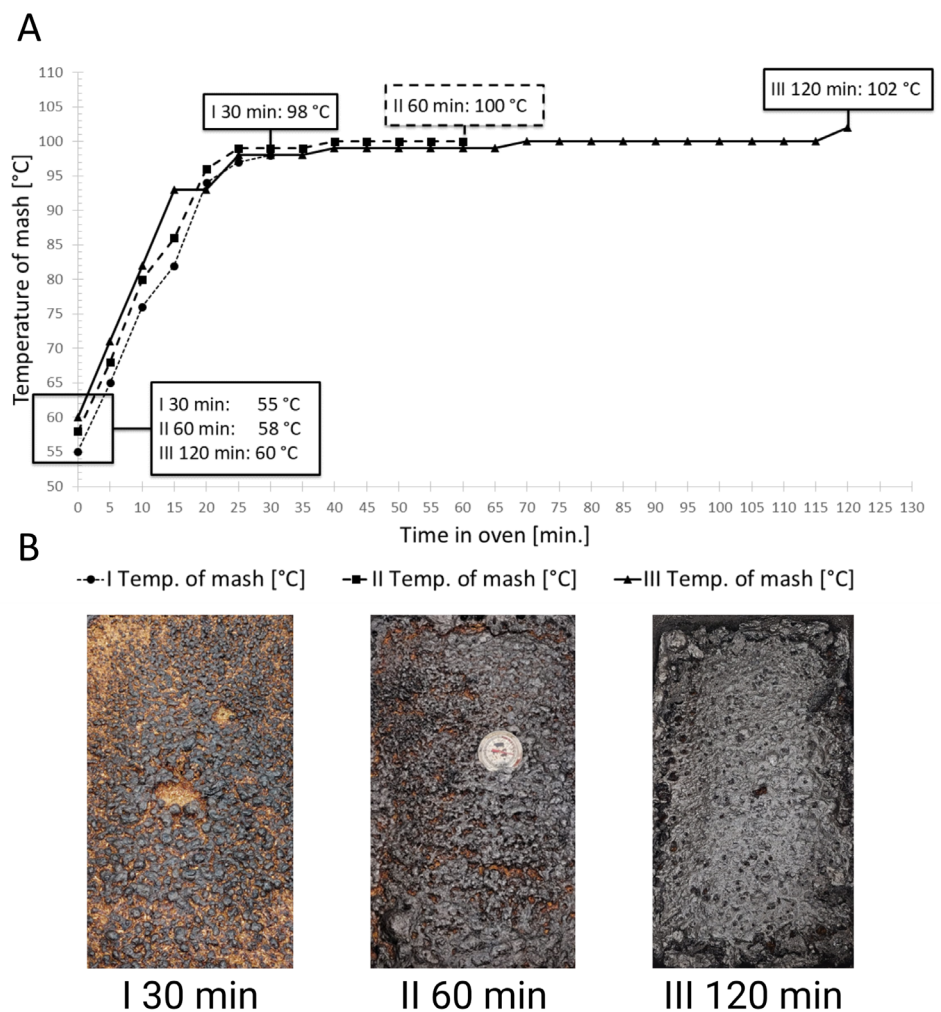


Fig. 5 (A) Core temperature of the mash cake, measured with a digital radio thermometer. (B) Visual changes of mash cakes baked with a layer thickness of 8 cm at a constant temperature of 300 °C for 30 minutes (I), 60 minutes (II) and 120 minutes (III) in a combi steamer using dry heat

Beverage Technology (Technical University Munich) according to EBC 9.10.1, EBC 9.6 and to MEBAK WBBM 2.4, respectively (see Table 1).

## 2.4 Quantitative orthonasal profile analyses

The quantitative orthonasal profile analyses were conducted at the Leibniz Institute for Food Systems Biology in Freising, Germany. The beers were evaluated pairwise in three sessions, with the sample I always present. Sample I, which was the sample with the shortest baking time (30 min), was used as a reference. 10 mL of beer was filled in cylindrical ground neck glasses (height 7 cm, in diameter 3.5 cm) with lids (Merck, Darmstadt, Germany) at approximately 15 °C. 19 trained assessors (13 females and 6 males, aged 24 to 58) orthonasally evaluated the aroma of the beers by rating the intensities of six predefined descriptors on an unscaled line with two guiding anchor points: “weak” and “strong.” The individual descriptors were defined by the odour of a reference compound dissolved in water at a concentration representing its respective odour threshold concentration (OTC) for “weak” and exceeding its OTC by a factor of 100 for “strong.” The following six descriptors and reference compounds were used: “malty” (3-methylbutanal), “honey-like” (phenylacetic acid), “citrus-like, floral” (mixture of linalool

and phenylethanol), "caramel-like" (4-hydroxy-2,5-dimethyl-3(2H)-furanone), "roasted" (2-acetyl-2-thiazoline), and "smoky" (2-methoxyphenol). Sensory test design, execution, and data interpretation were done with EyeQuestion® and EyeOpenR®, version 5.12.15 (Elst, The Netherlands).

### 2.5 Ranking tests

All four beer samples were presented to 18 assessors (12 females and 6 males, aged 24 to 58) simultaneously in random order. In two separate sessions, the assessors were asked to rank the samples according to the perceived intensity of the odour descriptors "roasted" and "caramel". For guidance, the odour descriptors were defined by the odour of a reference compound dissolved in water at a concentration exceeding its OTC by a factor of 100. The ranking totals were determined, and statistical comparisons were carried out as described in the ISO norm 8587:2006 [26]. Ranking test design, execution, and data interpretation were done with EyeQuestion® and EyeOpenR®, version 5.12.15 (Elst, The Netherlands).

### 2.6 List of methods applied according to MEBAK and EBC standards

Table 1 provides an overview of applied standard methods.

The wort of all four brews was fermented in temperature-controlled tanks. The experimental plan for the fermentations with the respective attributes and measurement times is shown in figure 4 (created with BioRender.com) [28].

## 3 Results and discussion

### 3.1 Mashing and baking of the mash

The most notable findings regarding Keptinis were that although the core temperature of the mash reaches the boiling point at 30 minutes at 300 °C, the time needed to exceed 100 °C was more than 60 minutes (see Fig. 5). This can be explained by evaporative cooling, but there is another effect which comes into account here. While evaporative cooling keeps the core temperature of the mash in the range within 100 °C for at least 60 minutes, the surfaces of the mash cake, as the mash will henceforth be called, undergo expected chemical reactions such as caramelisation of residual sugars and even pyrolysis. This seems to lead to a caramelised layer on the surfaces of the mash cake, which seals the water vapour

within and prevents evaporation (Fig. 5). Thus, it is conceivable that a decoction takes place in the mash cake.

This could also explain the differences regarding the original gravity of the full kettle wort, but this is only speculative, as the brewing experiments conducted on a pilot scale would need to be repeated significantly more often for a statistically reliable statement. In this context, it should be mentioned that the mean of the measured extract of the first wort, before the addition of the 17 liters, was 19.7 % (w/w) with a range of 0.6 % (w/w). The first wort was determined as 20 °P for the control, and 19.8, 19.4, and 19.5 % extract (w/w), for sample I, II, and III, respectively. In contrast to that, the range in the extract content of the full wort in the kettle was larger here, with an average of 11.6 % extract (w/w) and a range of 1.2 % extract (w/w). Hence, at least it can be assumed that baking of the mash affects the original gravity of the final wort. The wort of raw ales, such as Keptinis, is not boiled. This affects not only the pH-values, but also the coagulation of

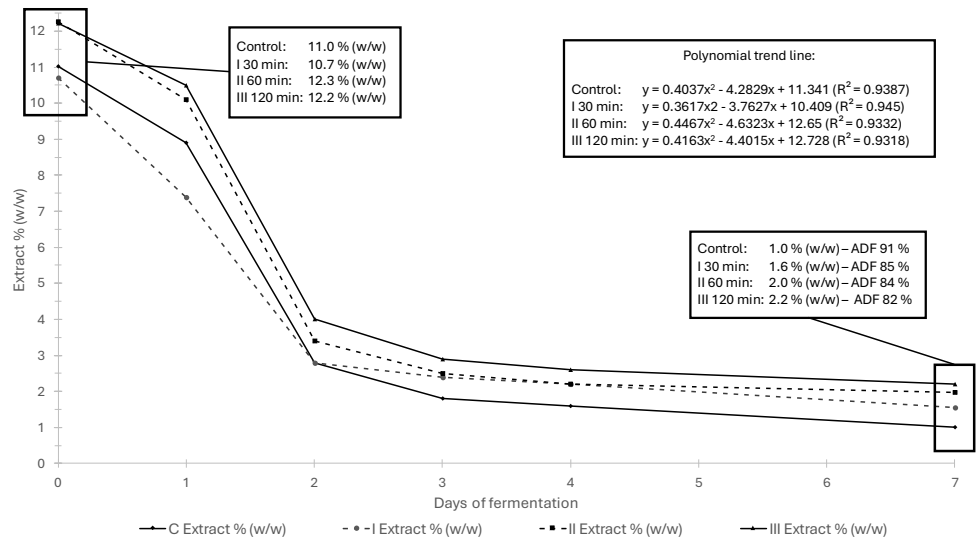


Fig. 6 Fermentation curve of all four brews. Fermentation was performed with rehydrated Fermentis SafAle™ S-04 dry yeast, fermentation temperature was kept constant at 20 °C

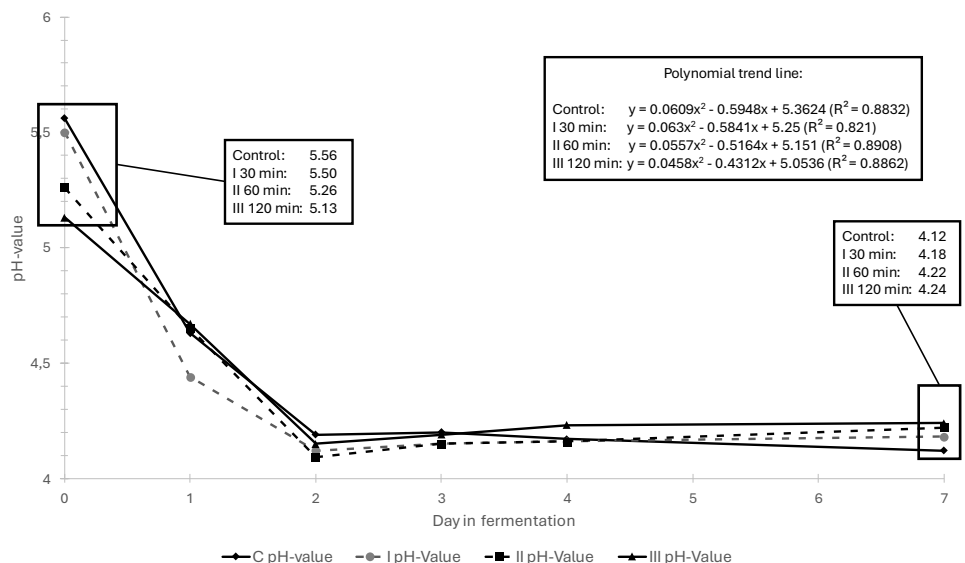


Fig. 7 pH-decrease during the fermentation. Fermentation was performed with rehydrated Fermentis SafAle™ S-04 dry yeast, fermentation temperature was kept constant at 20 °C

wort proteins and the formation of hot trub, which increases with extended boiling time, as does the wort colour [29]. While the pH-value of both the control and the samples, before the inoculation with yeast, did not vary considerably, it became obvious that the wort of the control showed the highest pH-value. Since products of Maillard reactions, caramelisation and pyrolysis can lower the pH-value of mash when added in the form of roasted malt, it seems logical that adding the same reaction products in the form of baked mash can have the same effect when added to the wort [30, 31]. This may also explain why the pH-value of sample III (baked for 120 min) showed the lowest pH-value in comparison to the control and the two other samples. The original gravity and the related pH-values of the pitching wort of control and of samples are given in figure 6 and figure 7.

### 3.2 Extract, apparent degree of fermentation, alcohol by volume, pH-values and beer colour

Regarding fermentation, it can be stated that an extended time period of the mash cake in the combi-steamer causes a decrease in the apparent degree of attenuation, although the course of fermentation, including the drop in pH, did not differ notably across all four brews (see Fig. 6 and 7). The slowest fermentation rate in comparison to the control (C) was observed in sample III (120 min at 300 °C), followed by sample II (60 min), which can lead to the assumption that prolonged baking time decreases fermentation rate. This seems very plausible because of the decrease of available fermentable sugars in the wort due to caramelisation, but there is also evidence that Maillard products and thermally altered carbohydrates can directly affect the enzyme activity of fermenting yeast [32–34]. Interestingly, the fastest rate of fermentation within the first two days occurred in sample I (30 min). After the second day of fermentation, the extract degradation in samples I to III was again slower than in the control (Fig. 6; see also supplementary material). A notable observation in all four brews during fermentation, however, was the pronounced precipitation of proteins during the pH drop. The observation that wort subjected to a shorter boiling time (or wort which is not boiled at all) undergoes faster fermentation and that this effect coincides with the presence of hot trub present in the fermenting wort aligns with the results of Mishra & Speers, who studied the impact of wort boiling time on fermentation [29]. The optimal fitting trend line was an order 2 polynomial trend line (see Fig. 6)

Regarding the pH decrease during fermentation, it was once again, noteworthy that sample I showed the fastest decrease in pH-value within the first two days, while the steepest drop in the pH-value compared to the initial pH-value was observed in the control. Additionally, the control also exhibited the lowest final pH-value (Fig. 7; see also supplementary material). The best fitting trend line was a polynomial Order 2 trend line, the formula is depicted in figure 7.

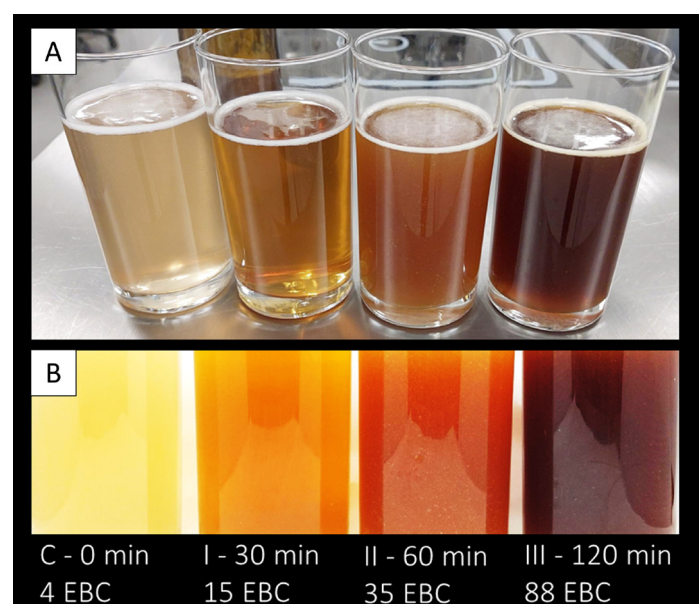
The apparent degree of fermentation (ADF) was above 80 % in all analysed beer samples with the control reaching the highest ADF of 91 %. The alcohol by volume (ABV) correlates with the original gravity and an expected decrease in the degree of fermentation with extended baking time of the mash cake. As expected, related to an extended baking time of the mash cake, there was also an increase in EBC colour units (Fig. 8). The measurement results

of the final beer samples, conducted with the modular Anton Paar Packaged Beer Measurement Systems, are given in table 2. Beer colour EBC was determined according to EBC 9.6. at the Chair of Brewing and Beverage Technology, Technical University of Munich. In context with the beer colour it is worth mentioning that a doubling of the baking time of the mash cake is also accompanied by an approximate doubling of the EBC colour units (Table 2 and Fig. 8).

**Table 2 All measured attributes of the final beers**

Attributes	Control	I (30 min)	II (60 min)	III (120 min)
ABV % [v/v]	5.30	4.80	5.50	4.20
Ea % [w/w]	1.0	1.6	2.0	2.2
Er % [w/w]	2.9	3.8	4.0	4.14
ADF %	91	85	84	82
Colour value EBC	4	15	35	88
FAN [mg/L]	41	37	59	53
TBI	9	19	45	96
Weight of mash after lautering [g]	12,939	12,653	13,145	13,770
Weight of mash after baking [g]	-	6,420	6,987	7,410
Weight loss in % [w/w]	-	49.2	46.8	46.2

Given are the following attributes: alcohol by volume (ABV) in % v/v, apparent extract (Ea) and real extract (Er) in % w/w, and apparent degree of fermentation (ADF) in %. Colour values were determined according to EBC 9.6. Free amino acids (FAN) in mg/L and TBI of control (C) and samples I to III, analysed according to EBC 9.10.1 and MEBAK WBBM 2.4. Reference values from pale lager beers for comparison according to Malfliet et al. (2008) are: FAN: 52.2 to 137.8 mg/L and for TBI: 33.2 to 39.6 [36], and the weight loss of the lautered mashes after baking for 30 minutes, 60 minutes and 120 minutes at 300 °C.



**Fig. 8 Colours (EBC) of the final beers, showing an increase in colour from Control C to III (120 minutes baking time of the mash cake at 300 °C)**

### 3.3 Free Amino Nitrogen (FAN) and Thiobarbituric Acid Index (TBI)

Analyses performed at the Chair of Brewing and Beverage Technology (Technical University Munich) revealed that all beer samples were low in Free Amino Nitrogen (FAN). The importance of FAN in finished beer lies in potential effects on flavour stability, since high levels of FAN can negatively affect flavour stability, as investigated by De Rouck et al. (2007) and Malfliet et al. (2008) [35, 36]. In addition, a high thermal load during malting, mashing, or during the boiling of the wort, which can be indicated by the TB index, can also decrease the assimilability of FAN during fermentation [35]. However, since neither the degree of fermentation of the beer samples I to III was strongly impaired, nor the content of FAN in the finished beer was drastically increased by the baking time, it can be assumed that the process described to produce the mash cakes has no pronounced effect on the fermentability of the wort or the vitality of the yeast during fermentation. In comparison to the values given in table 2, Malfliet et al. (2008) determined values for FAN in pale Lager beers ranging from 52.2 to 137.8 mg/L and TB indices ranging from 33.2 to 39.6 [36]. However, it remains debatable how proteins precipitated during fermentation will affect the flavour stability in beers produced in the described manner and if all raw ales are affected in the same manner.

### 3.4 Quantitative orthonasal profile analyses

The orthonasal profiles were recorded in three rounds, each time using sample I (30 min) as a reference, which was the sample with

the shortest baking time and the assumed lowest caramel, roasted, and smoky notes within the group of Keptinis beers. The results were merged, and panelist-specific effects were considered during the mean calculation. The most obvious result of the compared olfactory profile, given in figure 9, revealed a significant ( $p \leq 0.05$ ) increase in the intensity of the “caramel-like”, and “roasted” odor impression with increasing baking time while the intensity of the descriptor “citrus-like, floral” significantly ( $p \leq 0.05$ ) decreased. The aroma descriptor “smoky” was also evaluated more intensively in sample III with a baking time of 120 min. However, comparing the ratings of this attribute in all samples, there was no significant difference ( $p \geq 0.05$ ).

Maillard reaction, caramelization, and pyrolysis products formed during mash cake baking supposedly affect the more intensive caramel-like, roasted, and smoky aroma notes. To further elucidate the nature of the causal compounds, further investigations using sensomics would be necessary. In previous studies focusing on caramel malt and bottom-fermented beers brewed with caramel or roasted specialty malt, among others, 2-acetyl-1-pyrroline with a roasty, popcorn-like odour description, 2-methoxyphenol and 2-methoxy-4-vinylphenol, both with a smoky odour, as well as maltol and furaneol, contributing to the caramel-like odour were identified as important odorants [37, 38].

Typical compounds responsible for the citrus-like, floral aroma notes in beer are, among others, linalool deriving from hops and 2-phenylethanol, a typical yeast fermentation product. Since the hop dosage and the fermentation parameters were the same for

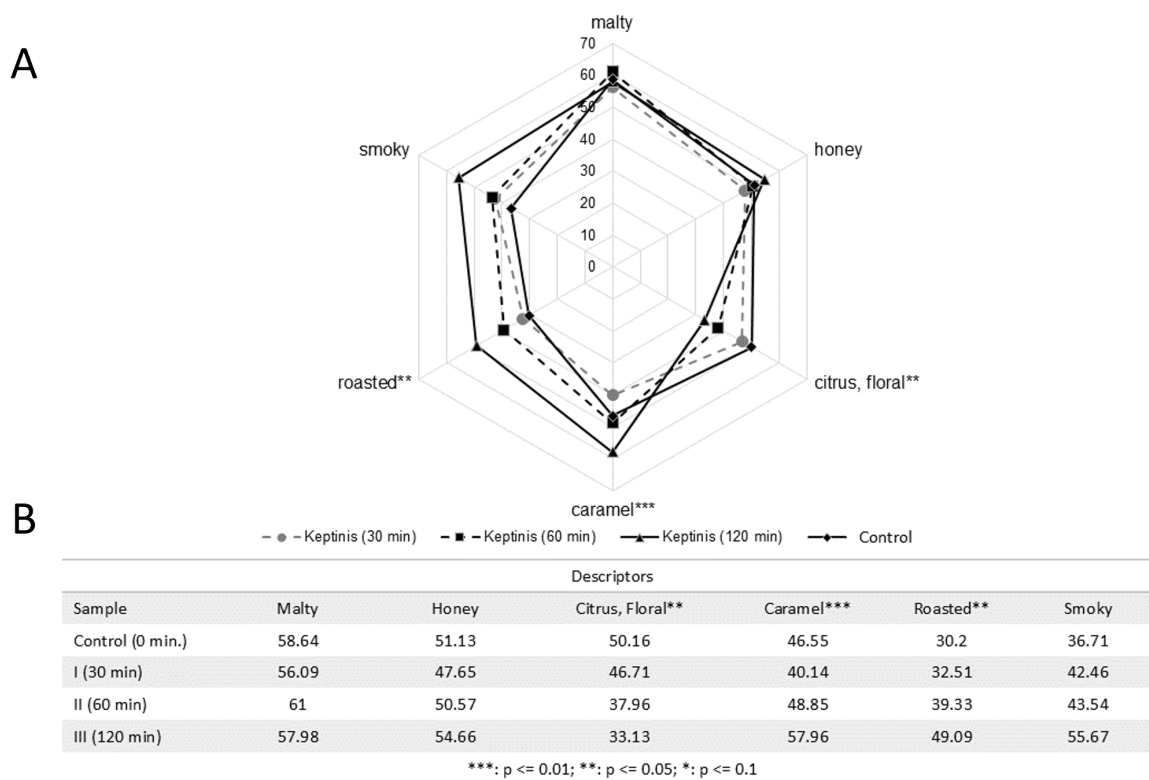


Fig. 9 (A) Compared olfactory profile of control and samples I to III, represented in a spider web diagram (adjusted mean values without outliers). (B) The following reference compounds were used: “malty” (3-methylbutanal), “honey-like” (phenylacetic acid), “citrus-like, floral” (mixture of linalool and phenylethanol), “caramel-like” (4-hydroxy-2,5-dimethyl-3(2H)-furanone), “roasted” (2-acetyl-2-thiazoline), and “smoky” (2-methoxyphenol)

<b>A</b>	III (120 Min)	II (60 min)	I (30 min)	Control (0 Min)
<b>B</b>	III (120 Min)	II (60 min)	I (30 min)	Control (0 Min)

**Fig. 10 A result of ranking test focusing on caramel-like odour impression; B results of ranking test focusing on roasted odour impression**

the control and the Keptinis beers, the decrease in the intensity of the citrus-like, floral aroma note is most probably not related to a decrease in the concentration of the causative compounds but associated with a masking effect caused by the dominance of the caramel-like, smoky, and roasted smelling aroma compounds.

The importance of the Maillard reaction and caramelization-derived aroma compounds raises the question of whether these reactions during mash baking also impact the perceived bitterness of the reconstructed Keptinis. However, in these profile analyses, only olfactory impressions were rated.

Castro et al. (2021) investigated the impact of caramel and roasted malts on beer. They could not observe any effects on the IBU levels, which at least can be assumed to be comparable with the chemical composition of baked mash [39]. However, it seems debatable if the perceived bitterness is not affected despite stable IBU levels because an individual tasting of the samples suggested otherwise (personal experience). Since the samples were not tasted with a panel due to unclear health risks resulting from pyrolysis products, this question remains to be left to further investigations. Regarding the bitterness of the described Keptinis variant, it should also be noted that the observed protein precipitation during fermentation can impact the actual IBU levels of the final beer, as adsorption of iso- $\alpha$  acids onto proteins is conceivable [40].

### 3.5 Ranking tests

Both ranking tests regarding the “caramel-like” (Figure 10, A) and the “roasted” (Figure 10, B) odour notes of the beers showed, based on the Friedman test, that sample III (120 min) and sample II (60 min) were not distinguishable with a risk of 5%. Additionally, sample II (60 min), sample I (30 min), and control (0 min) are not distinguishable from each other (risk 5%). Only sample III (120 min) was significantly distinguished by the ranking test from sample I and control (0 min).

While the quantitative olfactory profile analysis showed clear differences in the odour profiles of the Keptinis beers compared to the control, the ranking tests focusing on the single attributes “roasted” and “caramel-like” suggest that only a baking time of 120 min at 300 °C resulted in a beer with a significant ( $p \leq 0.05$ ) distinguishable odour profile.

This suggests that compounds contributing to “caramel-like” and “roasted” odour notes only play a significant role in the overall aroma in a beer brewed from mash baked for more than 60 minutes at 300 °C. While colour differences can already be detected in Keptinis beers brewed from mash with shorter baking times, a significant differentiation by their aroma profiles is more challenging. Due to the high thermal load of the mash, not the wort,

the question arises as to what extent the formation and concentration of odour-active compounds in Keptinis production differ from those in thermally highly loaded wort. Since maltol, sotolon, (E)- $\beta$ -damascenone, and 2-methoxyphenol have been detected in liquid dark malt extract, where a concentration of Maillard reaction and caramelisation products can be assumed, it seems logical that the flavour profile of Keptinis may contain similar elements [41]. Regarding the odour-active compounds of Keptinis, compounds formed during the production of caramel and roasted malts deserve also a closer investigation [42]. Fickert and Schieberle detected among other substances 3-methylbutanal, vanillin, and 4-hydroxy-2,5-dimethyl-3-(2H)-furanone as the most odour-active compounds in the tested caramel malt, which the authors describe as rye-bread-crust-like [38]. Parr et al. (2020) investigated the impact of time, temperature and moisture content on the formation of odour-active compounds during the roasting of malt and concluded that maltol, phenylacetaldehyde, 2-furanmethanol, HMF and acetic acid are formed at highest concentrations in roasted green malt products, whereas volatile compounds such as pyrazines, pyrroles, pyridines, 2-methylfuran, 2-pentylfuran, methyl-2-furoate and 2-acetyl-5-methylfuran are formed in dry roasted products, indicating, among other findings, that pyrolysis occurs predominately at higher temperatures and a low moisture content [43]. However, according to Reglitz et al. (2022) the direct transfer of odour active compounds from malt in beer is not significant: only a minor percentage of odour active compounds originates directly from malt, whereas the odour active compounds of beers brewed with caramel or dark malts are formed rather from precursors in these malts during the mashing, boiling and fermentation process. It can be assumed that the reason for this is that the original odour active compounds from the malts are non-covalently bound to unknown aggregates [44]. The similar findings regarding the effect of baked mash on beer support these assumptions. In addition, although Keptinis may most probably contain the compounds mentioned above, the reconstructed brewing and baking process showed that only a thin layer of the mash, approximately 0.5 cm on the surfaces is affected by the high temperatures. This should also be taken into consideration when comparing the results of the quantitative orthonasal aroma profile analyses with the findings of Reglitz et al., who investigated a proportion of 30% caramel malts and 2% roasted malts. This small proportion of roasted malts, in the context of the thin, pyrolyzed layer of the malt cake in the case of Keptinis, likely underscores the comparability of this study with that of Reglitz et al. [44]. The formation of Maillard reaction, caramelisation and pyrolysis products does occur depending on temperature and time, but only a relatively small part of the mash is affected. Hence, the results of the conducted ranking tests indicate that despite the pronounced effect on the beer colour, the odour profile is not strongly affected. The observation that only a thin layer of the surfaces of the mash cakes is affected by caramelisation and pyrolysis also indicates the formation of a thin, but protective and insulating layer for the underlying mash. Hence, the formation of caramelisation and pyrolysis products may be a self-limiting factor, sealing the moisture in the mash and keeping the core temperature within a range in which Maillard- and caramelisation products are formed only very slowly. This assumption is supported by the weighing of the meshes before and after the baking, which after 60 minutes hardly shows any loss of weight due to evaporation (see table 2).

## 4 Conclusion

Keptinis is a traditional Lithuanian farmhouse ale, which is produced by baking the mash at very high temperatures, usually well above 200 °C. Although this traditional beer is still brewed in Lithuania, there is little brewing data on how the production process affects the original gravity, beer colour and degree of fermentation. In this study, a traditional production process for Keptinis was reconstructed and the brewing process attributes were measured. For this purpose, 4 brews were performed. The grist-to-water ration of the four mashes before baking was 1 : 3, the lowest limit of the used brewing system. 3 mashes were baked at 300 °C for 30 minutes, 60 minutes and 120 minutes. One mash was not baked and the gained wort from this mash served as control. The resulting wort from the other three mashes was fermented at 20 °C with the same top-fermenting yeast. Quantitative orthonasal profile analyses were conducted. It must be explicitly noted at this point that the brewing experiments were not conducted in triplicates, as priority was given to maintaining a practical approach closely aligned with conventional brewing processes. This decision resulted in a significantly higher expenditure of time and materials. This experimental approach was favored over smaller experimental batches with multiple repetitions, as it was expected to provide a representative statement on whether the process could be transferred to modern, conventional brewing methods and especially how baking of the mash on a pilot scale would affect the measurable attributes of the final beer. The results of the experiments conducted should therefore be regarded as preliminary and will be verified or falsified in a subsequent study on this topic. However, the results show that although the production process has a distinct effect on the beer colour, the extract content and the apparent degree of fermentation are not significantly affected. The quantitative orthonasal profile analyses also show that the concentration of odour-active compounds does not allow a reliable distinction to be made between the different baking times. However, sensory analysis methods should be applied to create flavour profiles of these beers and to better understand the effects of the brewing process, especially on the perceived bitterness. In addition, as the aroma compounds for this special kind of beer are not discovered yet, an analysis and a quantification of the reason of the sensory shift on a molecular level via Sensomics would be of interest. The overall results indicate that the brewing process used for Keptinis is efficient and results in beer with characteristics similar to conventional brewed beers [36].

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## Supplementary materials

**Table 3** Results of Extract and pH-measurements during the fermentation

Day in fermentation	C - Control		I - 30 min		II - 60 min		III - 120 min	
	Extract % (w/w)	pH-value	Extract % (w/w)	pH-value	Extract % (w/w)	pH-value	Extract % (w/w)	pH-value
0	11.03	5.56	10.7	5.5	12.27	5.26	12.22	5.13
1	8.9	4.63	7.4	4.44	10.1	4.65	10.5	4.67
2	2.8	4.19	2.8	4.12	3.4	4.09	4	4.15
3	1.8	4.2	2.4	4.15	2.5	4.15	2.9	4.19
4	1.6	4.17	2.2	4.16	2.2	4.16	2.6	4.23
7	1	4.12	1.56	4.18	1.97	4.22	2.21	4.24