A. Dymchenko, M. Geršl and T. Gregor

Brewing beer using bakery leftovers as a substitute for malt

The present study aims at the sustainable use of bakery leftovers and their application as a partial substitute for malt in beer production. We made seven samples of Lager beer where we substituted malt with up to 60 % of bread, three samples of Brown Ale with up to 50 % of bread, and four samples of Porter with up to 80 % of bread. We made a sensory evaluation of the finished beer and determined its chemical composition. Water plays an important role in beer quality, especially in the sensory profile. We did a chemical analysis of the water to compare its chemical profile with that of the brewed beer. Samples with bread that substituted malt up to 30 % showed satisfactory results in the total rating of sensory evaluation. The results of chemical measurement show that the more bread, the saltier the taste of the beer due to the increased Na and Cl- indicators. Therefore, we suggest not using more than 30 % of bread because the salty taste can be more distinct. We noticed that the quantity of K depends on the type of fermentation and the availability of bread decreases the quantity of the element. We also measured foam stability and beer colour; the results serve as indicators of beer quality. We found that the beer colour and the foam quality in top-fermented beers are not affected by bread. We calculated that 30 % substitution with bakery leftovers could save around 6 – 7.5 kg of barley per 1 hl. Brewers can collect bread leftovers from local supermarkets, cafeterias, etc.

Descriptors: beer, malt substitutes, bakery leftovers, food waste

1. Introduction

Nowadays, the world encounters the problem of a large quantity of food waste that disappears in vain, although we could use them to create new products. According to the Global Initiative on Food Loss and Waste Reduction, around 1.3 billion tonnes of food are lost or wasted annually [1]. In this research, we focused on bakery waste, which makes up 18 % of the total amount of food waste [2]. The purpose of the study was to decrease the number of bakery leftovers using beer production technology and explore this process from a scientific point of view. We collected bakery leftovers free of food-based foreign material from the local supermarkets in the Czech Republic and used them as a partial substitute for malt during beer production. The used bread did not contain seeds, herbs or other additives.

We chose beer because it is one of the most-consumed alcoholic beverages in the world. In 2019, 1.91 billion hectolitres of beer were produced worldwide [3]. In 2018, Europe produced over 405 million hectolitres of beer [4]. Bakery leftovers can partially replace barley due to similar chemical composition [5, 6]. This substitution also decreases the quantity of malt needed for beer production. Around 20 – 25 kg of barley is needed to produce 1 hl of the wort. If we recalculate the efficiency of using bread leftovers instead of barley, in a ratio of 30 : 70, we will eventually save 30 % of barley – that is 6 – 7.5 kg/hl. For this purpose, we need about 10 – 11.6 kg of fresh bread per hl that can be dried before brewing. Some eco-breweries already use up to 30 % of bread to substitute the malt; examples include Toast Ale (UK), Crumbs Brewing (UK), Instock (NL), Brussels Beer Project (BE) and Troggeling (BE). In the present study, we attempted to substitute more malt with bread and test how it would affect beer properties. Production of beer from bread leftovers has ecological savings in the category of global warming, which is the result of replacing malted barley with bread leftovers [7]. The carbon footprint of an 800 g loaf of bread ranges from 977 to 1,244 g CO_2 equivalent [8]. As every 800 g loaf of bread produces around 100 l of biogas (60 – 65 % is methane and 35 – 40 % is CO_2), it is possible to use bread to create products based on fermentation [9].

There is a report of using bread waste for ethanol production with the help of hydrolytic enzymes isolated from *Hymenobacter* sp. CKS3 strain. Waste bread hydrolysate contained 19.89 g/l of reducing sugars and was used with waste baker's yeast to obtain 1.73 % of ethanol [10]. A previous study showed that 1 g of waste bread could generate 0.332 g of glucose [11], which in beer production will be used by yeasts to produce ethanol and CO_2.

We produced bottom-fermented Czech Lager beer, which is a high-bitterness beer that has a hoppy and malty character and a fruity aroma [12]. Also, we made top-fermented beer, Brown Ale and Porter, using special malts. To evaluate beer quality, we

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conducted a sensory panel and physical measurement of foam stability and beer colour.

Beer foam forms not only by the action of carbon dioxide but also due to proteins which accumulate in the foam. Furthermore, protein characteristics and origin affect foam properties [13]. Proteins with lower surface hydrophobicity, such as Z protein [14], play an essential role in foam formation. Another investigation showed that lipid transfer protein 1 (LTP1) is also associated with foam quality [15], as it is binding lipids that harm foam stability. High-gravity brewing induces greater losses of LTP1 [16] and denaturing of LTP1 reduces its ability to bind lipids; thus, the content of this protein is crucial for foam stability [17]. The quality of the foam depends on the choice of malt as malt is the source of LTP, but this does not negate other factors that affect the foam's properties. Iso-α-acids extracted from hops are factors for light stability and beer foam as they strengthen the bubble film [18, 19]. Therefore, a small addition of hydrogenated iso-α-acid hop can optimise foam quality [15]. Non-toxic metal cations in beer have a positive effect on foam stability [20], while lipids, basic amino acids and high levels of ethanol destabilise beer foam [18]. Brewers use sorbents to stabilise the foam without affecting the beer's colour, bitterness, or sensory profile. These sorbents are activated carbon, Florisil and polytetrafluoroethylene [21]. Another option to increase foam stability is adding wheat malt to the beer as the malt is higher in protein and starch content compared with barley malt. The foam skeleton could be provided by barley malt proteins, while the low molecular weight proteins in wheat malt could be more scattered in this skeleton. In cooperation, barley malt and wheat malt can contribute to the cloudy foam [13].

We also investigated the chemical composition of the brewed beer and the water we used for beer production. The chemical composition helps to determine the number of trace elements that can affect the taste differences between conventional beer and beer made with the addition of bread.

Water is the primary ingredient of beer and contains minerals necessary for human health. In addition, these microelements influence the taste and colour of the beer. The maximum permissible level of nitrates in water is 50 mg/l; for nitrites, it is 0,5 mg/l [22]. Alkalinity is the primary buffering system in water and exists in the form of carbonate activity. The carbonate system includes carbonate ions (CO_3^{2-}) at high pH levels, bicarbonate ions (HCO_3^-) at medium pH levels and carbonic acid (H_2CO_3) at low pH levels. H_2CO_3 with dissolved carbon dioxide (CO_2) equivalent made chemical equilibrium [23]. High alkalinity gives a bitter taste to water [24] and can buffer the pH of dark beer styles, preventing them from tasting acrid [23]. Low levels of alkalinity (< 50 ppm) prevent the beer from tasting watery [23].

Malt is another ingredient in brewing; it can provide minerals such as magnesium (Mg) and potassium (K). Depending on their concentrations, they can activate or inhibit enzymes during beer production. Zinc (Zn) and iron (Fe) are the main microelements for yeast activity [25]. Calcium (Ca) removes oxalates and plays a role in yeast flocculation [26, 27]. In addition, calcium and magnesium affect the bitterness and pH of the beer. There is a report that metal ions mostly originate from malt [28].

Table 1 Parameters of Lager beer

Alcohol (% vol.)	IBU (Bitterness)	SRM (Colour)
4.5	21.19	4

Table 2 The ratio of bread to malt for Lager beer

Bread to malt ratio	Czech Pale Malt (g)	Undried bread (g)
00:100	3 124	–
10:90	2 811	520
20:80	2 499	1 040
30:70	2 187	1 561
40:60	1 874	2 081
50:50	1 562	2 603
60:40	1 249	3 123

Table 3 Hops quantity for Lager beer

Hops	Grammes	Alpha Acids (%)	Boil Time	Type
Sladek	9	7	90	Pellet
Sladek	11	7	45	Pellet
Saaz	30	4	–	Pellet

When the brew production was finished, we used the malt mash as a fertiliser for plants. In addition, some companies found more ways to use brewery by-products: Nutrinsic transforms brewery wastewater, waste beer, spent grain and yeast into fish food, Great Lakes Brewing Company uses beer by-products as fertilisers for plants and Marmite Ltd makes a Marmite spread from the brewer's yeast. In addition, brewer's spent grain, hot trub and residual brewer's yeast are used to cultivate lactic acid bacteria [29]. Spent grain is mostly used as a feedstuff for domestic animals.

Table 4 Parameters of Porter

Alcohol (% vol.)	IBU (Bitterness)	SRM (Colour)
4.5	33.31	40

Table 5 The ratio of bread to malt for Porter

Bread to malt ratio	Pale Ale (g)	Roasted chocolate wheat (g)	Brown Malt (g)	Dry bread (g)
00:100	1 328	78	156	–
30:70	859	78	156	468
50:50	547	78	156	781
80:20	–	78	156	1 249

Table 6 Hops quantity for Porter

Hops	Grammes	Alpha Acids (%)	Boil Time	Type
Chinook	11	13	70	Pellet
Chinook	9	13		Pellet

2. Material and Methods

2.1. Materials

For brewing beer, we used water from the tap. We did a chemical analysis (see section Results and Discussion) that showed compliance with parameters set by the limits for drinking water in Decree No. 252/2004 Coll. of the Czech Republic.

We produced three different beer styles with the use of bread (Tables 1 to 9) and three control samples without the use of bread.

We used bottom-fermenting yeast Saflager W 34/70 (Lager) and top-fermenting yeasts US-5 (Porter) and US Ale 01 (Brown Ale).

Bread without other food-based foreign material and additives (seeds, herbals, etc.) was collected from supermarkets. We used undried bread for Lager beer and Brown Ale because of environmental savings and the need to keep the beer light.

We converted undried bread into the dry matter following this formula:

- Bread contains approximately 40 % of water and 60 % of dry matter.
- For example, the bread-to-malt ratio is 10 : 90.
- The total quantity of malt is 3,124 g per 20 litres of beer for the resulting 4.5 % vol. alc.
- 3,124 x 90 % = 2,811.6 g (malt)
- 3,124 x 10 % = 312.4 g (dry bread)
- Dry bread / 60 % of dry matter = undried bread
- 312.4 / 60 % = 520.6 g (undried bread)

2.1.1. Lager beer

Parameters of Lager beer, the ratio of bread to malt and hops quantity are shown in tables 1 to 3.

Table 7 Parameters of Brown Ale

Alcohol (% vol.)	IBU (Bitterness)	SRM (Colour)
4.5	21.19	24

Table 8 The ratio of bread to malt for Brown Ale

Bread to malt ratio	Finest Pale Ale Maris Otter (g)	Red Active (g)	Crystal Mahogany (g)	Undried bread (g)
00:100	896	416	250	–
30:70	427	416	250	781
50:50	115	416	250	1 301

Table 9 Hops quantity for Brown Ale

Hops	Grammes	Alpha Acids (%)	Boil Time	Type
Bramling Cross	13	6.5	70	Pellet
Bramling Cross	20	6.5		Pellet

2.1.2. Porter

Parameters of Porter, the ratio of bread to malt, and hops quantity are shown in tables 4 to 6.

2.1.3. Brown Ale

Parameters of Brown Ale, the ratio of bread to malt, and hops quantity are shown in tables 7 to 9.

2.2. Workflow

One batch: Lager – 20 l, Porter – 10 l, Brown Ale – 10 l

Stirring/Mashing: Boil 6 l (11 l for Lager) of water to 40 °C. Add milled malt (%) and bread (%), mix it and boil for 10 min. Increase the temperature of the boil to 52 °C for 10 min, to 62 °C for 30 min and 72 °C for 30 min. Run an iodine test. Increase the temperature of the boil to 85 °C for 5 min.

Filtration/Lautering: Filter the mash through the sieve. Pour 10 l (16 l for Lager) of water (85 °C) into the filtrating mash and allow resting for 15 min.

Wort boiling/Hopping: Boil the wort to 100 °C. Add hops and boil for 70 min (90 min for Lager). Allow resting for 20 min.

Filtration: Filter the wort through a small sieve.

Cooling down: Cool the wort down to 18 – 20 °C (12 °C for Lager). Add yeast and do aeration.

First fermentation: Fermentation runs at 18 – 22 °C (12 °C for Lager) roughly for 14 days.

Second fermentation: Transfer beer to bottles and add glucose (2 g/l). Fermentation runs at 12 °C for 14 days (Lager, Brown Ale, Porter). Then Lager must ferment for more than 20 days at 4 °C.

2.3. Analysis

Sensory evaluation of the beer: The sensory properties of beer were evaluated in compliance with ČSN ISO 6658 [30] by ten panellists (f = 2, m = 8, range = 20 – 46 years). The beer panel was performed in a tasting room at 18 degrees Celsius. Before the tasting session, beer samples were cooled down to 7 °C. Beer (150 ml) was poured into clear colourless glasses. We used cheese and pastries as flavour neutralisers. The order of beer samples was determined to start with a control sample without the use of bread until the sample with 80 % of bread was processed. In one series, we tested seven samples of Lager beer. After a few months, we tested three samples of Brown Ale and four Porter. The panellists filled in the sensory evaluation form, which had the following fields: flavour, foreign flavour, taste (fullness and saturation), foreign taste, bitterness and overall impression. The evaluation scale was one to five, where one was Absence and five was Very strong. The overall impression was rated on a scale

Table 10 Methods of analysis

Parameters	Methods of analysis
pH (25 °C)	Electrometric method, TFA 31.3001.06 – pH CHECK
Cl-	HPLC method, Dionex ICS-2000 Ion Chromatography System (ICS-2000, Thermo Fisher Scientific, U.S.) with IonPac® AS 18 analytical (2 x 250 mm) column
SO_4^{2-}	
ANC 4.5	Titration method (0.1 N hydrochloric acid)
ANC 8.3	Titration method
HCO_3^-	Calculation method, results of (ANC4.5) and alkalinity
CO_3^{2-}	
Ca	ICP-MS Agilent Technologies 7700 (Agilent Technologies Inc., U.S.)
K	
Mg	
Na	

from one to five, with one being Excellent and five being Very bad.

Physical parameters: Measurement of beer colour by spectrophotometry: beer sample was poured into a 1 cm thick cuvette; the cuvette was rinsed several times with the same sample of beer. The measurement length is 450 nm [31] for the Standard Reference Method (SRM) and The European Brewery Convention (EBC) [32].

$$SRM = 12.7 \times D \times A_{450}$$

$$EBC = 25 \times D \times A_{450}$$

Where D is the dilution factor (D = 1 for undiluted samples, D = 2 for 1: 1 dilution, etc.), A_{450} = light absorbance at 450 nanometres.

Foam stability measurement: Pour 150 ml of beer into a clear glass; hold the glass at a 45° angle; when the glass is half full, bring the glass at a 90° angle and proceed to pour beer in the middle of the glass; foam height and its disappearance time are measured with the help of a ruler and stopwatch.

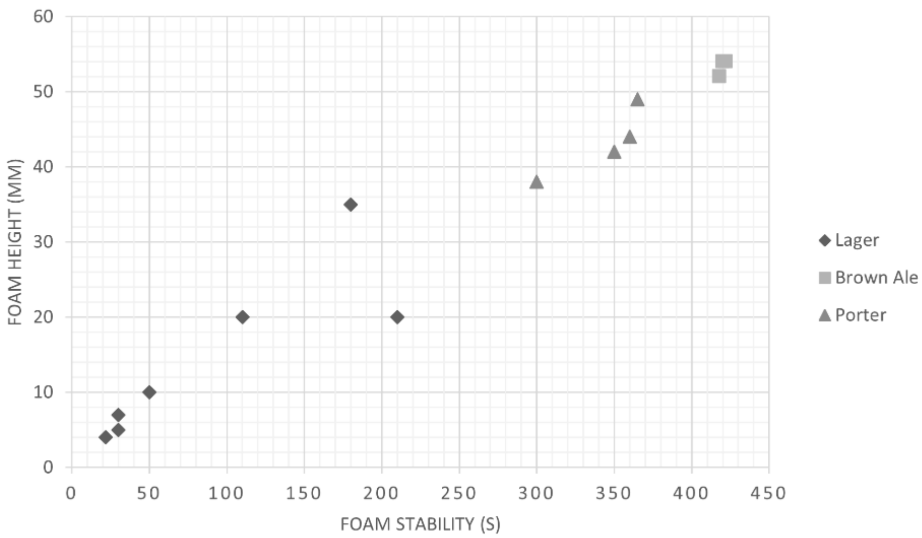

Fig. 1 Foam height and stability of Lager (0 : 100, 20 : 80, 30 : 70, 40 : 60, 50 : 50, 60 : 40), Brown Ale (00 : 100, 30 : 70, 50 : 50), Porter (0 : 100, 30 : 70, 50 : 50, 80 : 20)

Chemical analysis: We conducted a chemical analysis of beer samples and brewing water (Table 10).

3. Results and Discussion

3.1 Foam height and stability measurements

We carried out measurements of foam height and stability (Fig. 1), as both of them are indicators of beer quality. The foam is created by carbonation that makes beer so refreshing beverage. We added glucose to the bottles after draining the liquid from the fermenter to provide carbonation to the beer. Beer foam has a great effect on the flavour, expanding its spectrum. Bubbles play an important role in beer stability; the smaller the bubbles, the more stable the beer.

The Lager beer foam was mostly weak; the problem can be in bottles with caps not twisted tightly enough during the second fermentation. In addition, the Lager samples were six months old, which may have affected the quantity of foam and CO_2 in the beer. When we did a sensory evaluation of Lager after fermentation, the foam was not as strong as in top-fermented beers. The stability and height of the top-fermented beer foam showed good quality; both of them were at the level of store-bought beer. Porter and Brown Ale had a creamy wet foam and retained a foamy head for 3 – 4 min, showing robustness without disproportionation. There is a report that the dark style of beer has much more stable foam and initial foam height compared to light beer [33], which is consistent with our results.

Min. foam height of Lager (10 : 90) was 4 mm with a stability of 22 s; max. foam height of Lager (60 : 40) was 35 mm with a stability of 180 s. Min. foam height of Brown Ale (30 : 70) was 52 mm with a stability of 418 s; max. foam height of Brown Ale (00 : 100) was 54 mm with a stability of 422 s. Min. foam height of Porter (80 : 20) was 38 mm with the stability of 300 s; max. foam height of Porter (50 : 50) was 49 mm with a stability of 365 s. The addition of bread did not affect the formation of foam in top-fermented and bottom-fermented beers. There was a study where foam stability was determined in 16 samples of Lager beers (ten domestic and six from Germany, the Czech Republic, Denmark, and Holland) without the use of bread. The first sample had no foam; the other 15 samples had foam heights from 4.8 mm to 48 mm. The time for the foam to disappear was from 20 s to 300 s [34], which is similar to our results with the use of bread. However, our top-fermented beers had higher foam height and stability. We can suggest that it is due to using several types of malt except for Lager where one type of malt was used. Malt proteins play an important role in foam formation as they create foam skeletons [13]. Protein-protein linkages stabilize the foam and are responsible for mouthfeel and flavour stability. During the malting, malt proteins

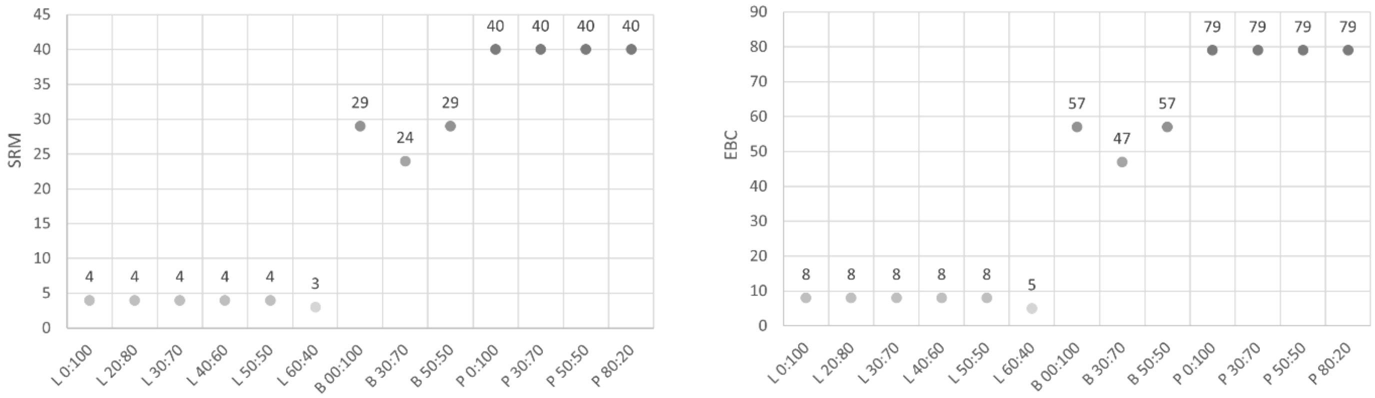

Fig. 2 SRM and EBC analysis of Lager (0 : 100, 20 : 80, 30 : 70, 40 : 60, 50 : 50, 60 : 40), Brown Ale (00 : 100, 30 : 70, 50 : 50), Porter (0 : 100, 30 : 70, 50 : 50, 80 : 20)

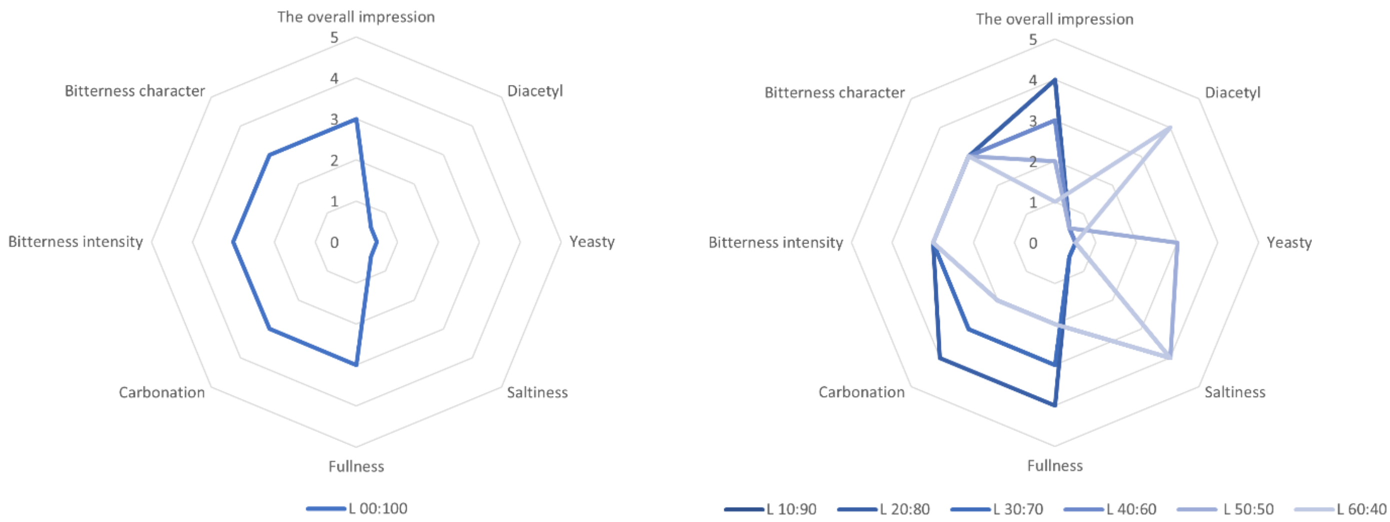

Fig. 3 Sensory profile of Lager without the use of bread (L 00 : 100) and with the use of bread (L 10 : 90, L 20 : 80, L 30 : 70, L 40 : 60, L 50 : 50, L 60 : 40)

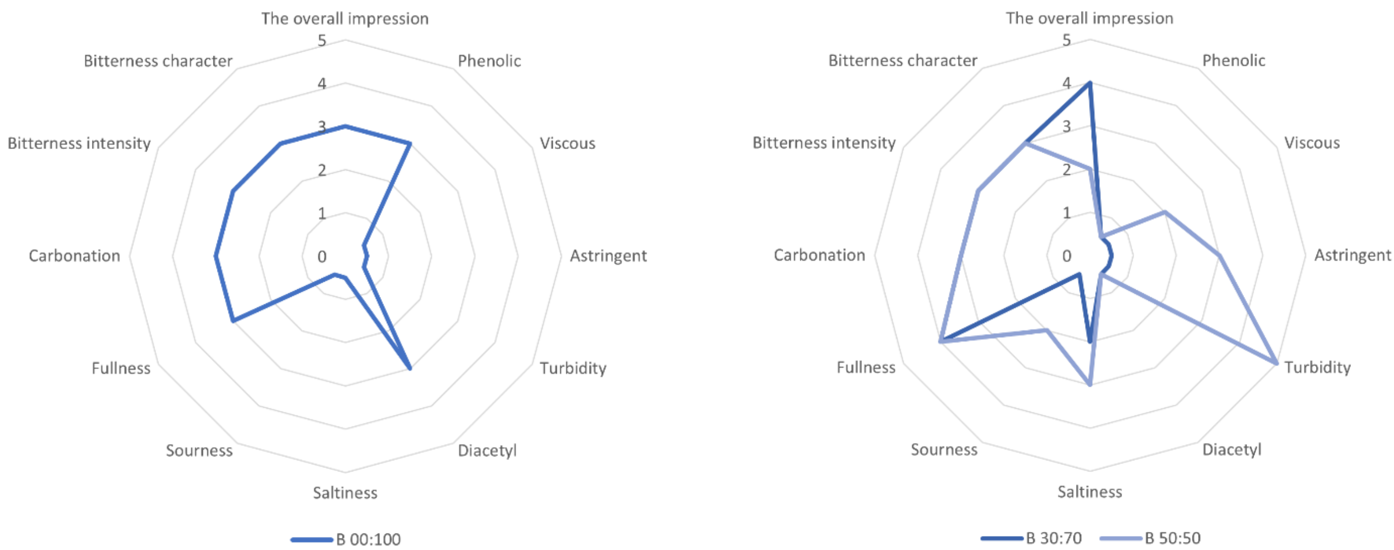

Fig. 4 Sensory profile of Brown Ale without the use of bread (B 00 : 100) and with the use of bread (B 30 : 70, B 50 : 50)

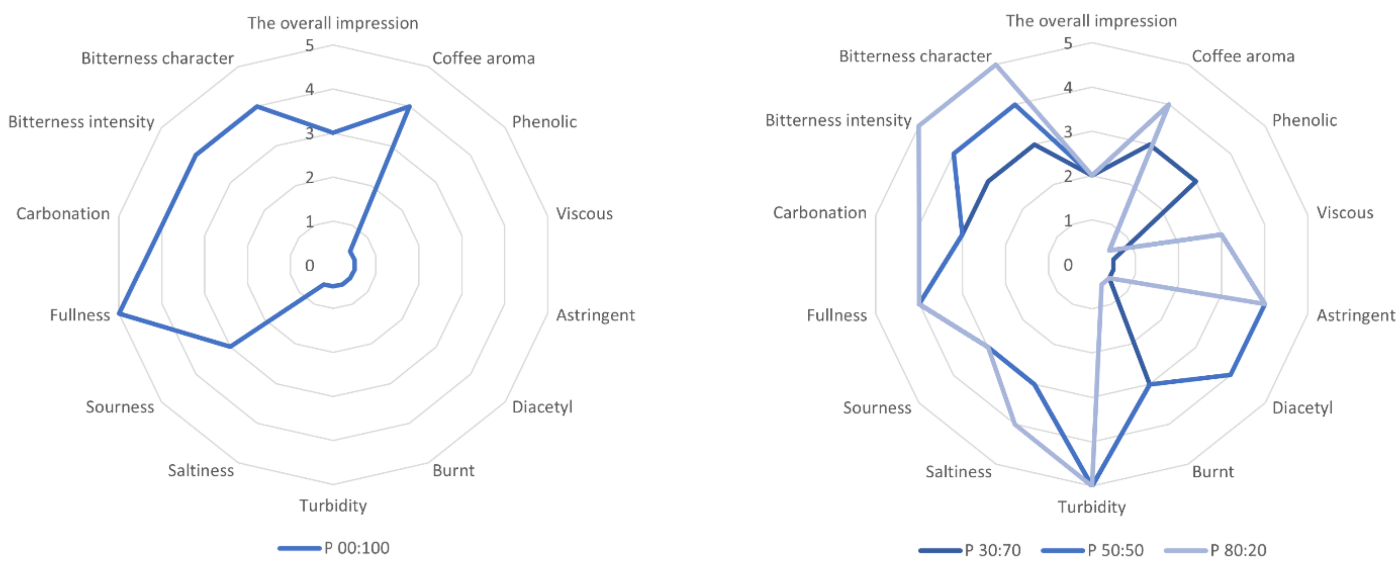

Fig. 5 Sensory profile of Porter without the use of bread (P 00 : 100) and with the use of bread (P 30 : 70, P 50 : 50, P 80 : 20)

break down into smaller peptides by proteases which contributes to foam formation. The more hydrophobic polypeptides, the bigger activity of the substances, such as hordeins that are rich in proline and glutamine content. Foams from albumins, however, are more stable than those from hordeins because albumins can withstand the presence of ethanol. For both albumins and hordeins, the foam stability can be increased by bitter acids contained in hops [35].

There is a report that a low pH level prevents the transfer of negative foam substances to the next production stages of the brewing process [21]. However, we did pH measurements just for the final beer; therefore, we cannot say there was any pH problem in the earlier brewing stages.

3.2 Beer colour measurements

The various styles of beer differ not only in the quantity of alcohol or the use of different malts and additives; indeed, colour is one of the important factors to discern beer styles. The colour of beer can come from malt, hops and other additives often used in craft beer production.

After measuring the colour of beer by SRM and EBC methodology (Fig. 2), we obtained the following results:

All samples of Lager responded to the typical colour of Lager (4 SRM, 8 EBC), except the sample with 60 % of bread, which was a little lighter (3 SRM, 5 EBC) than the other samples. The bread did not affect beer clarity.

One sample of Brown Ale (30:70) had a colour (24 SRM and 47 EBC) typical of this style. Two other samples had slightly darker colours: 29 SRM and 57 EBC. In addition, the samples featured turbidity.

Porter had intense black colour (40 SRM, 79 EBC) and it was not clear. Consequently, we suggest using less roasted chocolate wheat malt for Porter.

3.3 Sensory evaluation of the beer

Sensory analysis plays an important role in assessing the quality of beer, especially the taste component. This can help improve the recipe for subsequent brewing sessions as well as change brewing techniques or fermentation conditions if needed. The main parameters in the sensory analysis are fullness, carbonation, bitterness and aroma. It is also very important to identify unusual tastes and aromas in beer to understand the cause of the defects.

We provided the sensory evaluation and counted the average result for all beer samples. Figures 3 – 5 show the comparison of control samples of beer with samples in which bread was used. This will help determine whether the presence of bread affects the sensory profile of the beer relative to the control samples. As we can see (Fig. 3), the higher the quantity of bread, the weaker the fullness of Lager beer. There are also some taste defects such as saltiness and others. The salty taste comes from bread; the more bread is present in the beer, the saltier the bread is. The overall impression was good for beers with up to 30 % of malt substitution.

A yeasty taste may be present due to unfermented beer. The beer was not filtered after fermentation. After draining, part of the yeast entered the bottle and remained for fermentation.

Top-fermented beer is more acceptable for using bread as a substitute for malt. However, there is still an undesirable salty taste.

Diacetyl, which we detected in beer, has a buttery flavour produced by aldehydes and ketones during fermentation [22]. In addition, this off-flavour may come from bread.

Phenolic acid in wheat [5] can cause a phenolic taste in a few samples of top-fermented beers. Malt can contribute to around 95 % and 86 % of the phenolic compounds in dark and pale beers [36]. Roasted malt and high mashing temperature at low pH can induce the release of phenolic compounds [37]. Furthermore, the availability of phenolic acids can make beer astringent and bitter

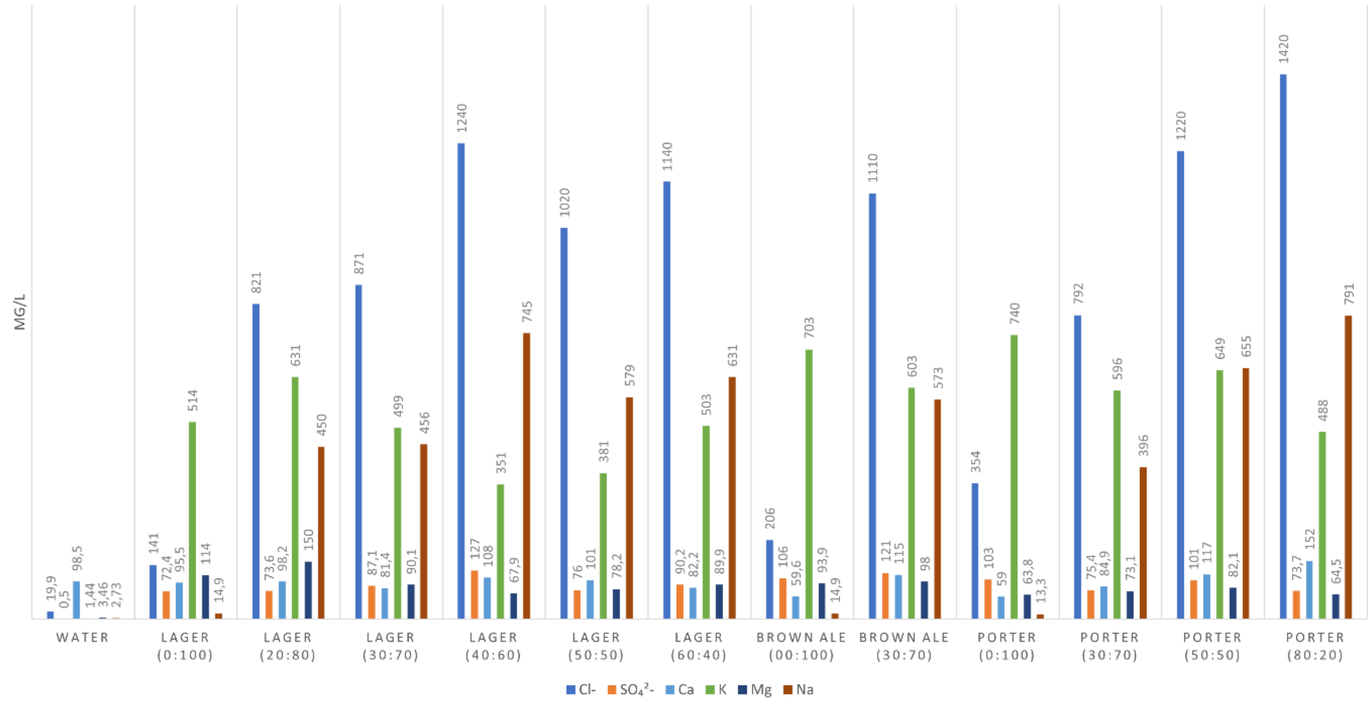

Fig. 6 **Chemical measurements of Cl-, SO_4^{2-}, Ca, K, Mg, Na in water, Lager (0 : 100, 20 : 80, 30 : 70, 40 : 60, 50 : 50, 60 : 40), Brown Ale (00 : 100, 30 : 70), Porter (0 : 100, 30 : 70, 50 : 50, 80 : 20)**

[38]. It has a medicinal off-flavour [39], which we detected in beer samples. Phenolic acids play the role of antioxidants in human health [5].

We can observe turbidity in one of the Brown Ale samples (Fig. 4), which may be caused by the presence of a large portion of bread. In addition, malt globulins can contribute to beer haze because the sulphur-containing b-globulin does not completely precipitate even if the boiling stage is extended. Protein-protein linkages form, in combination with polyphenols, haze [35] as confirmed through the Brown Ale sensory profile. A chill haze is formed when polypeptides and polyphenols are bound non-covalently. Permanent haze forms in the same manner, but covalent bonds form soon and insoluble complexes are created which will not dissolve when heated [35].

Some samples of Porter (Fig. 5) had a burnt taste because of the toasted bread used for that sort of beer. If the quantity of magnesium exceeds 80 mg/l, beer has a sour and bitter flavour [23], but in the current situation, that sour taste originated from roasted malt. We made a mistake in the roasted malt quantity for the Porter-style beer recipe. Therefore, almost all samples of Porter were evaluated as unsatisfactory.

In addition, some samples had a viscous taste that may indicate that the beer contains gram-positive bacteria *Leuconostoc mesenteroides*. It is a species of lactic acid bacteria associated with fermentation under conditions of salinity and low temperatures [40]. During growth, these bacteria produce excess turbidity and acidity [41].

Weak fullness of the Lager beer can be associated with protease, which did not degrade wheat storage proteins in bread because of high temperatures of mashing [35].

3.4 Chemical measurements

The results of chemical measurement (Fig. 6) show that the more bread, the saltier the taste of the beer due to the increased Na and Cl- indicators.

Mineral elements such as K, Mg and Ca affect beer taste, colour and durability [42]. Furthermore, Mg and Ca are vital yeast nutrients [23]. Ca prevents the thermal inactivation of α-amylase by extending the pH range of the enzyme [43]. We can see that top-fermented beer has more K (pure Brown Ale: 703 mg/l, pure Porter: 740 mg/l) compared with pure Lager (514 mg/l). We can say that the quantity of K depends on the fermentation type. The availability of bread decreases the quantity of K compared with pure beer samples. For Ca, everything is the opposite here – pure samples of top-fermented beer have a lower quantity of Ca, unlike pure Lager.

Voica et al. [44] determined the metal content (mg/l) in twenty commercial beers from Romanian markets. They obtained the following results: Ca (40 – 140 for the UK, 29.0 – 86.2 for Spain, and 3.80 – 108 for Germany), K (135 – 1100 for the UK, 22.9 – 496 for Spain, and 22.9 – 496 for Germany), Mg (60 – 200 for the UK, 42.0 – 110 for Spain, and 23.7 – 266 for Germany), and Na (21.90 – 230 for the UK, 3.95 – 103 for Spain, and 1.19 – 120 for Germany) [44]. As we can see, the beer from the UK contains a large quantity of K, so K depends on the style of the beer.

Rodrigo et al. [45] analysed mean mineral content (mg/l) in 35 Ale beers (Ca 56.1, K 474.3, Mg 84.8, Na 44.9), 7 Bitter beers (Ca 86.0, K 455.5, Mg 73.7, Na 52.7), 6 IPA beers (Ca 76.1, K 647.8, Mg 95.3, Na 51.2), 59 Lager beers (Ca 41.7, K 379.9, Mg 67.9, Na 33.0), 4 Lambic beers (Ca 39.3, K 677.4, Mg 63.6, Na 53.3), 4 Pilsner beers (Ca 25.4, K 462.6, Mg 92.7, Na 32.4) and 10 Stout/Porter beers (Ca 74.2, K 592.6, Mg 103.5, Na 51.9) [45]. Our samples have much more Ca in all types of beer. Water for brewing beer had 98.5 mg of Ca per l. Brown Ale and Porter pure samples had a lower quantity of Ca than samples with bread. The pure Lager sample had more Ca than Brown Ale and Porter. For good mash and lauter pH stability, a Ca level of 100 – 150 ppm is preferred [23].

Rodrigo et al. [45] also analysed 120 beers from Belgium, China, Czech Republic, Germany, Holland, Ireland, Italy, Mexico, UK and USA and had the following results: Belgium (Ca 54.8, K 504.2, Mg 83.3, Na 49.7), China (Ca 35.1, K 298.9, Mg 76.4, Na 53.2), Czech Republic (Ca 24.1, K 416.8, Mg 89.1, Na 20.8), Germany (Ca 41.7, K 450.2, Mg 79.5, Na 19.1), Holland (Ca 29.7, K 506.0, Mg 68.5, Na 20.5), Ireland (Ca 55.2, K 475.3, Mg 76.4, Na 21.2), Italy (Ca 44.0, K 412.8, Mg 72.6, Na 15.7), Mexico (Ca 50.4, K 239.8, Mg 57.3, Na 53.1), UK (Ca 61.5, K 436.5, Mg 73.6, Na 48.3) and USA (Ca 38.7, K 626.2, Mg 99.8, Na 26.8) [45]. They conclude that the geographical origin of a beer determines its mineral content. In our case, not just geographical origin is significant but also the additives such as bread in beer samples.

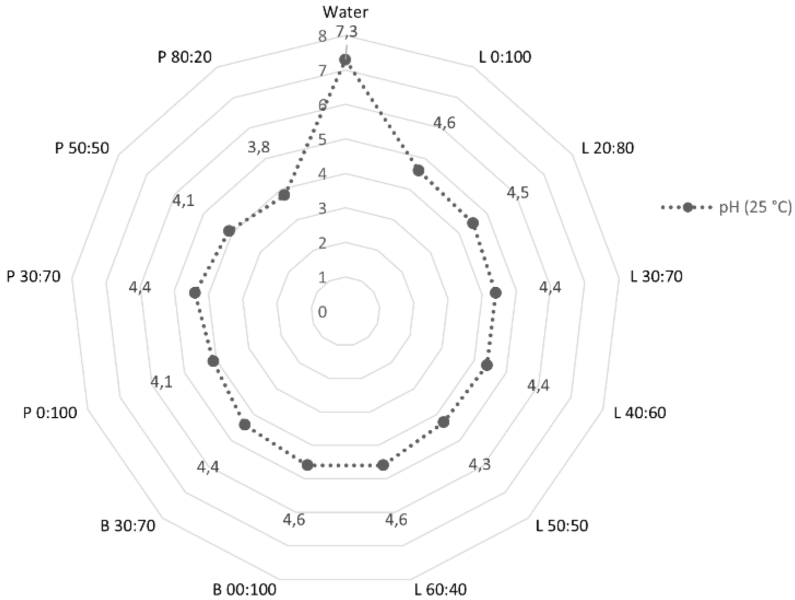

Fig. 7 **pH measurement values for water, Lager (0 : 100, 20 : 80, 30 : 70, 40 : 60, 50 : 50, 60 : 40), Brown Ale (00 : 100, 30 : 70), Porter (0 : 100, 30 : 70, 50 : 50, 80 : 20)**

Styburski et al. [25] analysed mineral content in 52 beer samples imported from Asia, South America and Europe. Samples with the highest average calcium concentration were from Germany (0.31 g/l) and Armenia (0.28 g/l); beer samples from Portugal had the lowest concentration of calcium (0.05 g/l). Samples with the highest concentration of chlorine were from Ukraine (0.100 g/l ± 0.083), and the lowest concentration of chlorine was found in samples from the Czech Republic (0.023 g/l ± 0.001) and Germany (0.023 g/l ± 0.006). The highest concentration of potassium was identified for samples from Portugal (0.191 g/l ± 0.001) and the lowest for samples from the Czech Republic (0.064 g/l ± 0.005) [25]. All our beer samples had a large quantity of chlorine: 141 – 1,420 mg/l. Samples made with the use of bread had sharply high indicators compared to pure samples. Chlorine plays a role in yeast flocculation and improves clarity and colloidal stability [26].

Zambrzycka-Szelewa et al. [46] also analysed the mineral content of 11 Ale and 18 Lager beers from Poland. Bottom-fermented beers had a concentration of 10.9 ± 0.1 mg/l to 74.2 ± 1.3 mg/l for Na, 367 ± 10 mg/l to 855 ± 16 mg/l for K, 80.2 ± 1.2 mg/l to 169 ± 0 mg/l for Mg and 34.5 ± 1.0 mg/l to 117.2 ± 4.1 mg/l for Ca. Top-fermented beers had a concentration of 7.75 ± 0.04 mg/l to 74.0 ± 2.0 mg/l for Na, 428 ± 10 mg/l to 815 ± 1 mg/l for K, 64.0 ± 1.0 mg/l to 141 ± 1 mg/l for Mg and 19.1 ± 1.6 mg/l to 58.2 ± 1.5 mg/l [46] for Ca. As can be seen, the content of Mg can be decreased or increased even for the same style of beer, but with different types of malt and additives, its quantity can vary. Other indicators in our samples are much increased compared with measurements made by Zambrzycka-Szelewa et al. [46].

The relation between Cl- and SO_4^{2-}-influences the bitterness of a beer. The higher content of Cl- alleviates and softens the bitterness and supports the malty character and fullness of taste. The higher the SO_4^{2-} content (> 150 ppm), the more hops-like (bitterness and dryness) and the less malty the taste [22, 23]. To prevent the bitterness from dominating, brewers must use lower quantities of SO42- ranging from 50 to 75 ppm [23]. In the samples with bread, the content of Cl- is higher than in control samples (Fig. 6). Hence, beer has a maltier and less hoppy taste.

In the previous studies, it was observed that the mineral content of beer depends on the beer style. Top-fermented beers have higher concentrations of Ca, K and Mg than bottom-fermented beers, which may depend on the yeast type used for fermentation. Furthermore, it was noticed that the type of container for beer storage can determine the content of As ($p \leq 0.001$), Mg ($p \leq 0.01$), Na ($p \leq 0.01$) and V ($p \leq 0.01$). Metal barrels can influence Na and As concentrations in beer, while cans can affect the content of V [45]. We provided fermentation in food plastic fermenters and the final beer was stored in PET bottles.

HCO_3^- and CO_3^{2-} are indicators of alkalinity. High alkalinity gives a bitter taste to water [24] and can buffer the pH of dark beer styles, preventing them from tasting acrid [23]. Low levels of alkalinity (< 50 ppm) prevent the beer from tasting watery [23]. We had high HCO_3^- levels of Lager 00 : 100 (87 mg/l), 60 : 40 (64 mg/l) and Brown Ale 00 : 100 (35 mg/l) which makes them taste watery. For the other samples, the level was less than 3 mg/l and the water content was 235 mg/l. The CO_3^{2-} level was less than 3 mg/l for all samples.

We did a pH analysis for our beer samples (Fig. 7). The pH ranged from 4.3 to 4.6 for the Lager beer, from 4.4 to 4.6 for Brown Ale and from 3.8 to 4.4 for Porter. Zambrzycka-Szelewa et al., [46] analysed pH in beer from Poland; 11 Ale samples had a pH from 3.91 to 4.54 and Lager's pH ranged from 4.09 to 4.53 [46]. When compared, Poland and our beer samples have the same (low) pH in top-fermented beers and an optimal range of pH in Lager.

4. Conclusion

The present study aims at the sustainable use of bakery leftovers and their application as a partial substitute for malt in beer production. We tried to find out if bakery leftovers would affect the taste and quality of beer. We produced seven samples of Lager beer (20 l per batch), three samples of Brown Ale (10 l per batch) and four samples of Porter (10 l per batch). In addition, we had one example of each style of beer with no bread used as a control sample. Samples without any bread used and samples with bread substitute (up to 30 %) showed good results in the total rating of sensory evaluation. They almost did not have smell or taste defects. After physical measurements, we found that bread does not affect the beer's colour and the foam's quality in top-fermented beers. The Lager beer foam was mostly weak; the problem can be in bottles with caps not twisted tightly enough during the second fermentation. In addition, the Lager samples were six months old, which may have affected the quantity of foam and CO_2 in the beer.

Compared to other researchers that analysed the mineral content of different types of beer from different countries, our Na and Cl-indicators showed increased levels, hence the salty taste of beer. We suggest not using more than 30 % of bread because the salty taste can be more pronounced, which was proved by sensory analysis. We also noticed that the quantity of K depends on the type of fermentation while the availability of bread decreases the quantity.

We calculated that 30 % substitution could save around 6 – 7.5 kg of barley per hl by replacing barley with bakery leftovers. Brewers can collect leftovers from local supermarkets, cafeterias, etc. It is however important to keep bread uncontaminated by other food.

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