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Quality Characteristics of Craft Wheat Beers in Bosnia and Herzegovina and Croatia

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Abstract

This research contributes to the understanding of craft wheat beer characteristics and preferences on the market in Bosnia and Herzegovina and, Croatia. For most consumers, general knowledge about the brewing process and health benefits can enhance the desire to purchase specific beers. For example, content of polyphenols, derived from hops and malt can enrich beer flavour and aroma and provide antioxidant benefits. To attract consumers, bitterness has to be balanced to enhances the complexity of a beer style which is especially pronounced in wheat beers. Sensory evaluations provide insights into beer quality and consumer preferences, emphasizing moderation for potential health benefits from compounds such as polyphenols. The aim of this study was to assess the quality of wheat craft beers, examining polyphenol content, bitterness, color, pH, protein levels, and sensory evaluation. The sensory analysis revealed a predominant alignment with the German Weizenbier style among the samples. Sample 7 CRO emerged as the favourite in sensory analysis, rated with 97 points, featuring higher color, and balanced pH, relating with the German Weizenbier style.

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Wheat Beers;
Witbier.

Abbreviations

EBC	European Brewery Convention
IBU	International Bitterness Units

Introduction

Beer consumption is experiencing rapid growth annually, driven by a perceived higher nutritional value compared to other alcoholic beverages.[1] This trend reflects increasing interest in craft beer production and a shift towards artisanal tastes amidst industrialization. Industrial breweries typically focus on commercial lager beers, whereas craft breweries,

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despite facing regulatory challenges in Bosnia and Herzegovina, and Croatia produce diverse, most often ale beer styles using varying yeast strains, hops, malt, and water compositions.[2] Craft beer has the potential to surpass conventional beer due to its perceived health benefits.[3] Commonly, craft beers are distinguished from industrial beers by their higher polyphenol content and antioxidant activity.[4] Industrial beers, although widely consumed, typically contain lower levels of bioactive compounds like polyphenols due to differences in brewing processes (lack of filtration) and ingredient selection.[5] These distinctions suggest that craft beers may offer superior health benefits compared to their industrial counterparts, particularly in terms of antioxidant properties and potential cardiovascular effects.[6,7]

Consumption of wheat beer traditionally has been bound to Germany and Belgium. There are two main types of wheat beers: German Weizenbier and Belgian Witbier.[8] Weizenbier, or Hefeweizen in the southern parts of Bavaria, commonly called Weißbier, is a beer in which a minimum of 50% of barley malt is replaced by wheat malt.[9] Witbier is mainly produced in Belgium and the Netherlands. It is a descendant of medieval beers that were spiced with a blend of spices and herbs like coriander, orange, and bitter orange. The main difference between Weizenbier and Witbier is that latter are produced from 50% raw wheat. The result is a slightly sour taste due to lactic or acetic acid and greater turbidity due to a higher protein concentration. Suspended yeast in beer causes continuous fermentation, even after bottling.

Wheat beers are gaining popularity in Croatia, and Bosnia and Herzegovina (B&H), but its consummation is still not as recognized as in other countries. Consumers mostly notice the fruity, banana-like smell and somewhat higher carbonation which causes them to recede from consummation as they are not used to it. Haziness is also something that it is not completely acceptable to consumers in Croatia and B&H. There are currently no data about wheat beers in Croatia and B&H, thus this research aimed to give a starting insight into wheat beers on regional market and the acceptance of the style in both countries.

This study categorizes wheat craft beers in Bosnia and Herzegovina and Croatia by assessing physical-chemical parameters including total polyphenol content, bitterness, colour, pH value, protein content, and sensory ratings. It aims to provide insights into general acceptance of wheat beers among consumers since both countries are not historically bound to wheat beers.

Materials and Methods

Chemical Reagents

The following chemicals and reagents were used in the study: hydrochloric acid, sodium hydroxide (Kemika d.d., Zagreb, Croatia); 2,2,4-trimethylpentane (LGC Standards GmbH, Augsburg, Germany); carboxymethyl cellulose (CMC), ferric reagent (Sigma-Aldrich, Steinheim, Germany); ethylenediaminetetraacetic acid (EDTA) (Semikem, Sarajevo, Bosnia and Herzegovina); ammonia solution (Sigma-Aldrich, St. Louis, USA); sulfuric acid, boric acid (Merck KGaA, Darmstadt, Germany); copper sulfate (KREATIVA d.o.o., Zagreb, Croatia); and Tashiro's indicator (Reagecon Diagnostics Ltd., Clare, Ireland).

Beer Samples and Analytical Methods

Wheat beer samples were collected from craft breweries in B&H and Croatia that produce wheat craft beer. Beers from Sample 1 to Sample 9 were declared on bottles as Weizenbier types and Samples 10 to 12 as Witbier types. Sampling criteria was to collect wheat beers produced in both countries and to evaluate the planned parameters.

Prior analysis beer samples were tempered at 20 °C and degassed with a Bunsen MC8 magnetic stirrer (Madrid, Spain), followed by centrifugation (Eppendorf, Hamburg, Germany) at 3000 rpm per 10 minutes.

Determination of Total Polyphenols, Bitterness, and Color

In degassed and centrifuged beer, total polyphenols at 600 nm, bitterness at 275 nm, and beer color at 430 nm were measured using a spectrophotometer (UV-Vis, Perkin-Elmer Lambda 25, Waltham, Massachusetts, USA) according to the EBC methods.[10] Total polyphenols were expressed in mg/L, bitterness in EBC units, and color was calculated and expressed in EBC units.

pH Determination

A pH meter was used for determining pH values (PB-11, Sartorius, Goettingen, Germany) according to EBC method.[10]

Protein Determination

The protein content of beer was measured according to the Kjeldahl method.[11] 10 mL of beer was distilled by the classical distillation method. After distillation, 10 g of sulfuric acid and 0.2 g of copper sulphate were weighed into twelve cups and added to Kjeldahl cuvettes where previously 3 mL of sample had been added. Then 20 mL of sulfuric acid was added and allowed to stand for half an hour. After half an hour, turbo-therm was used to perform a quick nitrogen and protein analysis. The samples were cooled for at least one hour before working on Vadopest. A 50 mL of boric acid was added to a flask with Tashiro's indicator, and the distillation unit was turned on. The contents of the cuvette were spilt after distillation, and the contents of the flask were titrated with 0.1 mol/L hydrochloric acid. The protein content was expressed in g/mL.

Sensory Evaluation

The sensory evaluation was performed according to the procedure described in[12] and adjusted from.[13]

Data Evaluation

Three replicates were performed for each sample, and the data are expressed as the arithmetic mean (M) ± standard deviation (SD). Analysis of variance (ANOVA) and Fisher's least significant difference test (LSD) were conducted, with the least statistical significance set to $p < 0.05$. Statistica 13.1. (TIBCO Software Inc., Palo Alto, CA, USA).

Results

The results of total polyphenols, bitterness, color, and pH of all analyzed beer samples are presented in Table 1.

Table 1: Quality characteristics of sampled beers

Sample	Polyphenol (mg/L)	Bitterness (IBU)	Color (EBC)	pH
1B&H	164.82 ± 7.54^{b}	25.01 ± 0.30^{c}	4.24 ± 0.43^{j}	4.42 ± 0.01^{ab}
2 B&H	170.23 ± 3.93^{a}	26.05 ± 0.20^{b}	5.68 ± 0.14^{f}	4.04 ± 0.01^{ef}
3 B&H	121.69 ± 0.08^{h}	13.70 ± 0.12^{f}	4.47 ± 0.12^{i}	4.32 ± 0.01^{bc}
4 B&H	128.25 ± 0.66^{g}	10.26 ± 0.20^{j}	5.16 ± 0.18^{g}	4.23 ± 0.01^{cd}
5 B&H	114.72 ± 0.25^{k}	14.64 ± 0.12^{e}	8.00 ± 0.13^{e}	3.96 ± 0.01^{fg}
6 CRO	130.89 ± 0.45^{f}	13.59 ± 0.01^{fg}	18.00 ± 0.14^{b}	4.14 ± 0.19^{de}
7 CRO	116.64 ± 0.21^{j}	10.30 ± 0.13^{j}	9.10 ± 0.12^{d}	4.40 ± 0.01^{abc}
8 CRO	157.89 ± 0.07^{c}	28.07 ± 0.12^{a}	24.22 ± 0.02^{a}	4.42 ± 0.07^{abc}
9 CRO	113.23 ± 0.12^{l}	12.76 ± 0.15^{h}	10.34 ± 0.11^{c}	4.12 ± 0.32^{e}
10 B&H wit	134.32 ± 0.82^{e}	13.49 ± 0.11^{g}	3.76 ± 0.14^{k}	3.88 ± 0.01^{g}
11 CRO wit	120.56 ± 0.17^{i}	10.90 ± 0.14^{i}	4.86 ± 0.09^{h}	4.50 ± 0.01^{a}
12 CRO wit	147.21 ± 0.15^{d}	15.80 ± 0.34^{d}	5.50 ± 0.08^{f}	4.46 ± 0.23^{ab}

Means within rows with different superscripts are significantly different ($p < 0.05$);

Additional analysis of protein content done only for B&H beers, as shown in Table 2.

Table 2: Total proteins in samples

Sample	Proteins (g/mL)
1B&H	0.004 ± 0.000^{c}
2 B&H	0.004 ± 0.000^{c}
3 B&H	0.005 ± 0.000^{b}
4 B&H	0.003 ± 0.001^{d}
5 B&H	0.006 ± 0.000^{a}
10 B&H wit	0.006 ± 0.000^{a}

Means within rows with different superscripts are significantly different ($p < 0.05$);

Results of sensory evaluation are presented in Table 3.

Results for bitterness, determined separately using sensory panel are shown in Table 4.

Table 3: Results of sensory evaluation of investigated beers

Sample	Appearance	Smell	Off-smell	Taste	Off-taste	Mouthfeel	Total Score
Max, points	10	20	20	20	25	5	100
1B&H	10^{a}	16^{b}	16^{b}	20^{a}	25^{a}	4^{b}	91^{ab}
2 B&H	10^{a}	12^{c}	16^{b}	20^{a}	25^{a}	4^{b}	87^{b}
3 B&H	10^{a}	16^{b}	16^{a}	20^{a}	25^{a}	5^{a}	92^{ab}
4 B&H	8^{b}	12^{c}	20^{a}	16^{b}	25^{a}	4	85^{bc}
5 B&H	8^{b}	16^{b}	20^{a}	20^{a}	25^{a}	5^{a}	94^{ab}
6 CRO	10^{a}	20^{a}	20^{a}	20^{a}	25^{a}	5^{a}	96^{a}
7 CRO	8^{b}	20^{a}	20^{a}	20^{a}	25^{a}	4^{b}	97^{a}
8 CRO	8^{b}	20^{a}	16^{b}	16^{b}	25^{a}	4^{b}	89^{b}
9 CRO	10^{a}	16^{b}	20^{a}	20^{a}	25^{a}	5^{a}	96^{a}
10 B&H wit	8^{b}	12^{c}	12^{c}	16^{b}	20^{b}	3^{c}	71^{c}
11 CRO wit	10^{a}	16^{b}	16^{b}	20^{a}	25^{a}	5^{a}	92^{ab}
12 CRO wit	10^{a}	16^{b}	16^{b}	20^{a}	25^{a}	5^{a}	92^{ab}

Means within rows with different superscripts are significantly different ($p < 0.05$);

Table 4: Bitterness determined by sensory evaluation

Sample	Bitterness
Max. points	10
1B&H	6^{c}
2 B&H	5^{d}
3 B&H	5^{d}
4 B&H	5^{d}
5 B&H	5^{d}
6 CRO	10^{a}
7 CRO	8^{b}
8 CRO	10^{a}
9 CRO	8b
10 B&H wit	5^{d}
11 CRO wit	6^{c}
12 CRO wit	6^{c}

Means within rows with different superscripts are significantly different ($p < 0.05$);

Discussion

Beer quality can be determined by many characteristics, such as color, bitterness, pH, extract content, etc. Many breweries rely on these analyses to ensure the maximum quality of final product. It is important that quality parameters fit the limitations set by the beer style. In that sense, wheat beers are often produced with minimum 50% of wheat malt and are classified as ale beers, because they are produced with *S. cerevisiae* yeast. Some of them by-pass the filtration and are served with yeast, which gives them a cloudy and opaque appearance.[14] Thus, they can contain higher protein levels than lager or pilsner beer or filtered wheat beers. As for witbier, they are produced using 40-60% of unmalted wheat as addition to the mash.[15] This results with characteristic white haze that can be contributed to unfiltered starch and yeast. Such beers are traditionally bottle conditioned and served cloudy.[14] Nine samples collected in B&H and Croatia were designated as wheat beers and 3 were designated as witbiers. Wheat and witbiers were not especially popular in both countries as the consumers were used to traditional lagers and pilsners. However, the expansion of the craft movement enabled consumers to try different and novel beers.[2]

This research was focused on categorizing wheat craft beers in B&H and Croatia market based on total polyphenol content, bitterness, color, pH value, and sensory evaluation. Protein content was determined only in B&H samples. Total polyphenol

concentrations in the tested samples varied from 113.23 mg/L in Sample 9 CRO to 170.23 mg/L in Sample 2 B&H. Such differences between samples are caused by various factors like barley and wheat quality, hops variety and amount, and production procedures itself. Wheat grains lack husk, which subsequently results in lower polyphenols (up to 40%) when compared to barley. Lower soaking temperatures, pH, and hops with low acid also decrease polyphenol extraction.[16] According to the literature, weizenbier can contain around 120 mg/L of polyphenols, while Witbier can have more than 125 mg/L.[16] The results of this research indicate that samples 3 B&H, 4 B&H, 5 B&H, 7 CRO and 9 CRO (Weizenbier type) are in accordance with these polyphenol levels. Samples 1 and 2 were similar to Italian wheat beers (177 mg/L).[17] Samples 10 B&H, 11 CRO and 12 CRO (Witbier) had total polyphenol levels closer to German wheat beers (139 mg/L).[17] Polyphenols, derived from hops and malt, enrich beer flavor and aroma and may offer antioxidant benefits.[18]

Higher polyphenols can be correlated to bitterness units. Namely, all samples which had higher polyphenols content showed higher bitterness. Even though wheat and wit beers are not known for high bitterness (10-15 IBU), due to heavier notes these styles allow somewhat higher bitterness when combined with higher residual extract (final gravity).

Table 1 reveals pronounced bitterness in Sample 8 CRO, amounting up to 28.07 IBU, which had relatively high polyphenols content (157.89 mg/L). Similarly acted Samples 1 B&H and 2 B&H where in 2 B&H polyphenolic content reached 170.23 mg/L and bitterness was 26.05 IBU. Prolonged fermentation can increase beer bitterness as well.[16] Samples 3 B&H, 4 B&H, 5 B&H, and 10 B&H, 6 CRO, 7 CRO, 9 CRO and 11 CRO have low bitterness. This could be related to lower polyphenolic content, however, samples 3 B&H, 4 B&H are not as low in polyphenols. This could indicate a well-adjusted temperature, and hopping time, as well as appropriate selection of hop variety which resulted in harmony of bitter components. Nevertheless, sensory analysis is to acknowledge the physical-chemical results. Samples 1 B&H and 2 B&H can be designated as moderately bitter. Weizenbier bitterness ranges from 10 to 15 IBU, while Witbier can be slightly higher, 10 to 17 IBU.[19] Not only do polyphenols and bitterness show a significant positive correlation but various phenolic compounds, identified in hops, impact beer quality and shelf life.[20] Bitter acids from hops have potential as natural therapeutic agents for preventing hepatic fibrosis in chronic liver disease by inhibiting the profibrogenic transformation of hepatic stellate cells, which are key players in hepatic fibrosis.[21] In general, it can be derived that Croatian wheat beers have higher bitterness than the B&H wheat beers.

Beer color commonly depends on the wort pH and sugar content in it, i.e., on the malt type used for wort preparation,[22] as well as on the non-enzymatic browning reactions such as Maillard reactions, caramelization and pyrolysis.[23] Oxidized polyphenols also significantly impact beer color, especially in the reactions that take place after storage, which is why it is important to pay attention to the exposure of beer to oxygen when filling into packaging.[24] Looking at Table 1, we can see that Sample 8 CRO showed highest color (24.22 EBC) which is a bit over the recommended values.[14] Sample 10 B&H exhibited the lowest value, 3.76 EBC. The color of beer was compared with the results of Palmer's work.[16] Comparing the results obtained by the analyses, it can be noticed that Samples 1 B&H, 3 B&H, and 10 B&H belong to lighter beers, while Samples 2 B&H and 4 B&H are closer to German helles beers. Sample 5 B&H could be designated as pilser stile. If compared with the results from the Brewers Association,[19] according to which the color for Weizenbier wheat beers ranges from 6 to 18 EBC and for Witbier from 4 to 8 EBC, it can be concluded that all samples belonging to witbier style are within the BA's recommendations. However, wheat beer samples deviate in these recommendations. Namely, only samples 5 B&H, 6 CRO, 7 CRO and 10 CRO show accordance with BA's recommendations. Sample 2 B&H is borderline with 5.68 EBC. According to literature values reported for German wheat beer were 14.4 EBC, Czech 16.8 EBC, and Italian 11.1 EBC units.[17] Values obtained in this research fit somewhere in between and could be an indicator of country's signature since it appears that every country has a certain mean value for wheat and witbiers regarding color. There were no large deviations in the pH values of the analyzed samples, however, any change in pH is significant and affects the taste. Color of beers brewed with 40% of different

European unmalted wheat varieties is similar to the one we measured.[25]

As visible from Table 1, there are significant deviations in the pH values of the analyzed samples. The normal pH value of beer range is between 3.8-4.5,[16] from which it can be concluded that each sample is within the limits of the normal value. A study showed that yeast fermentation in semi-aerobic conditions rather than fermenters formed beers with lower pH.[26] Sample 4 (Table 1) was similar to German beer, which had a 4.29 pH value.[17] Higher pH values were measured in Czech and Italian beers than in our analysed beers.[17]

From Table 2 it can be seen that Samples 5 B&H and 10 B&H have the highest protein content, and Sample 4 has the lowest. Commercial beers have lower content of proteins due to filtration, while wheat beers benefit from higher protein levels.[17] Proteins and polyphenols (tannins) form complexes, giving wheat beer its characteristic turbidity.[27] In cloudy wheat beer, the protein fraction with a molecular weight of 100.0–13.2 kDa is crucial during brewing, fermentation, and maturation.[28] Protein fractionation and proteolytic processes effectively enhance the biological activities of wheat flour proteins, promoting the development of nutraceutical and therapeutic applications targeting conditions such as diabetes and hypertension.[29]

As visible from Table 3, appearance was rated with high scores; 7 beer were rated with 10 points and 5 were rated with 8 points. This indicates that appearance-wise brewers make small errors. All Croatian beers were hazy and witbiers had the recognizable white opaque appearance originating from wheat proteins. Samples 7 CRO and 8 CRO had somewhat lower haziness and thus were not rated with highest scores. From Bosnia and Herzegovinian beers, Samples 4 B&H, 5 B&H and 10 B&H received lower scores for appearance.

Wheat beers have characteristic smell, designated as flowery, banana, toffee or clove. These aromas are not always well received among consumers who are not used to such notes. Perhaps this is the reason not one sample from Bosnia and Herzegovina received maximal points, 20, for smell. Highest scores were awarded to Sample 3 B&H and 5 B&H (16), while other samples received 12 points for smell. Samples 2 B&H and 10 B&H reportedly exhibited vague off-smell. Croatian beers scored with 20 points were 6, 7 and 8 CRO while witbiers received lower scores (16) for smell.

According to the results of the evaluation of the off-smell, Sample 5 B&H (20) had a better result than Sample 1 B&H (16), and the lowest score was designated to Sample 10 B&H (12).

Taste was not scored lower than 16 points, all samples received either highest score (20) or a bit lower score (16). This indicates that beer taste was not affected with aromatic compounds mentioned before (banana, clove, etc.). Moreover, not one sample showed any off-taste, and all samples received highest score for this property.

Many samples received highest score for mouthfeel, 5 out of 12. Lowest score was awarded to sample 10 B&H (3).

According to the results samples 5 B&H and 3 B&H were evaluated best score (94 and 92 points). Croatian beers had somewhat higher scores, best rated was Sample 7 CRO with total score of 97 points. Samples 6 CRO and 9 CRO followed with total of 96 points. Lowest total score was awarded to sample 10 B&H, it received 71 point and was described as disharmonious with recognizable errors.

One more property, bitterness, was determined separately using sensory panel. Results for this property are shown in Table 4. Highest score for bitterness was 10. It was important for evaluators to know the difference between bitterness and astringency and to award the appropriate number (points) to each beer sample in accordance with the beer style. Maximal points do not mark only the level of bitterness, but also relate to the retention time of bitter taste in the mouth, and throat.

Table 4. shows that Sample 1 B&H among Bosnian and Herzegovinian beers and that Croatian samples exhibited somewhat higher scores, with maximum points awarded to samples 6 and 8 CRO.

It can be noticed that Sample 5 was rated most positively with an overall average score of 50.5 out of a maximum of 55 points, and it is followed

by Sample 1. Sample 6 has the lowest average score, and respondents rated it as the worst of the ones offered. Based on the preferences detected, it can be concluded that consumer preference in B&H is connected to Weizenbier-type craft wheat beers. Today, consumer preferences appear to be connected to the discovery of new beer flavors, which can increase the consumption of craft beers.

Conclusion

Wheat beers are generally well accepted in upper parts of Europe, but the consumers from this region are not inclined to wheat beers as much. In this work, wheat beer samples were analysed according to their total polyphenol content, bitterness, colour, pH value, protein content, and sensory ratings. The sensory evaluation of beer showed that the analysed samples mainly belong to German Weizenbier-type of craft wheat beers. Sample five was recognized as the best by the respondents to the sensory evaluation, and unlike the other samples, it has the lowest concentration of polyphenols, the intensity of bitterness closer to the upper limit, the most intense colour, pH value, and protein content within the appropriate limits. It is recommended to increase the polyphenol content in sample five to make it more similar to the German Weizenbier. The results of this study showed that for wheat craft beers in B&H there is room for improvement, but the overall quality of the products is acceptable. The sensory assessment reveals that the respondents are unfamiliar with craft and even wheat beers, which is also a problem for beer consumers in B&H. Similar situation occurs in Croatia, but the consumers have a bit higher sense of acceptance of wheat beers. We anticipate that modernization and increased interest in the quality of craft beers will enable the development and expansion of craft breweries and the proliferation of wheat beer styles among consumers of our region.

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This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to Reproduce Material from Other Sources

Not Applicable.

Author Contributions

- **Anita Lalic:** Conceptualization, Methodology, Formal Analysis Writing—Original Draft Preparation, Visualization, Validation.
- **Kristina Habschied:** Methodology, Supervision, Writing—Review and Editing,
- **Krešimir Mastanjević:** Software, Data Curation,
- **Anđela Jurišić:** Validation, Data Curation,
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