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Sensory Analysis Coupled with Gas Chromatography/Mass spectrometry Analysis in Craft Beer Evaluation

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Abstract: The beer market today shows extremely diverse styles and offers many possibilities for consumers to try new aromas and tastes. Most modern breweries have a similar technology and equipment and use quality raw materials, but the differences between beers' physical–chemical properties are always detectable. In ensuring the same beer quality is being delivered to the consumers, sensory analysis is in some cases even more important than the chemical or physical–chemical analysis, since consumers focus on constant quality and sensory properties of their chosen beer. Sensory evaluation is not an easy task and involves flexible methods for determination of differences and changes between beers. It is commonly used in breweries to provide a constant quality in finished products, but also to ensure the quality of different raw materials (water, malt, hops) and to minimize the influence of the production process on final quality of beer. The results of this research indicate that sensory analysis is of great importance, since sheer physical–chemical analysis can be outweighed by it. Certain beers that showed that, despite a high concentration of off-flavors (e.g., dimethylsulphide), the overall sensory score was not affected (10/Koelsch style) while for some beers, a small excess of a sensory threshold lead to extreme sensory deterioration (sample 4/Lager).

Keywords: brewing; fermentation; beer styles; quality control

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1. Introduction

Craft beers have gained extreme popularity over the last decade or two. Beer styles have profusely taken over the market, leaving the comfort zone of draught serves, and entering a serious distribution thanks to aluminum cans and bottles. Different beer styles display various sensory properties, but can be classified into certain categories such as aroma, appearance, flavor, and mouthfeel [1]. However, certain physical–chemical properties, e.g., bitterness, color, haze formation, etc., are also important in beer evaluation. A deeper physical–chemical analysis, using GC-MS instruments, can provide extensive insight in beer quality as well. A combination of these methods results in more accurate and precise quality evaluation, and is called sensomics [2].

However, it should be taken into an account that beer consists of a huge number of chemicals that result in final aromas, tastes and mouthfeel, thus making sensory analysis of craft beers difficult, especially since every brewery has different raw materials and recipes. For example, two beers from different breweries can have the same IBU, but the sensory analysis will show that one is significantly more bitter than the other or does not agree with the consumer as much as the other. This is why the utilization of volatile compound analysis is important, along with the dedicated sensory training of the panelists, since it allows the analyst to define the fine differences between beers.

The Brewers Association [3] is committed to publishing a list of craft beer styles on a yearly basis. The guidelines contain all known beer styles and describe some of their physical–chemical distinguished properties. Generally, all beers should have a pleasant and characteristic taste and smell, high mouthfeel, fullness, appropriate bitterness and no off-flavors [4].

The aim of this work was to assess the correlation between sensory analysis of different beer styles and their physical–chemical properties, including the volatile compounds analysis via GC-MS. The physical–chemical analysis (original extract, apparent extract, real extract, alcohol by volume, CO_2 content, clarity, bitterness, color), alongside analysis of 11 volatile compounds (acetaldehyde, ethyl acetate, n—propanol, isobutanol, 3—methylbutanol, 2—phenilethanol, isoamyl acetate, "2—phenyletil acetate, DMS, 2,3—butandione, 2,3—pentandione), gave an insight into the measurable properties of each beer. However, since the sensory analysis includes, and depends on, many different factors such as chemicals (volatiles, extract and alcohol content) or sensations (mouthfeel, carbonation, fullness) interpreted by humans, it can outbalance the sheer physical–chemical analysis.

2. Materials and Methods

2.1. Samples

A total of 26 beer samples were collected from different breweries. Samples were divided into five main categories, resulting in 12 different styles, as shown in Table 1.

Table 1. Evaluated beers styles and the number of samples for each style.

Category	Style	Number of Samples
Lager	Lager	3
Ale	Blond Ale	2
	Amber Ale	2
	Pale Ale	4
	Brown Ale	1
	Koelsch style	1
	Indian Pale Ale	4
Porter/Stout	Porter	3
	Stout	3
Wheat	Porter	1
Special	Gruit	1
	Spicy Herbs Ale	1

2.2. Physical–Chemical Analysis

Physical–chemical analysis was performed using an Anton Paar Beer analyzer (Anton Paar GmbH, Graz, Austria). Color and bitterness analysis were conducted according to [5]. All analyses were performed in triplicate.

2.3. Aroma Profile

Beer's volatile compounds (acetaldehyde, ethyl-acetate, n–propanol, isobutanol, 3-methyl-butanol, 2-phenyl-ethanol, isoamyl-acetate, 2-phenylethyl-acetate, dimethyl-sulfide, 2,3–butanedione, 2,3-pentanedione) were analyzed via gas chromatography (Shimadzu GC-2030 quadrupol mass spectrophotometer GCMS-TQ 8050 NX (Shimadzu, Kyoto, Japan) coupled with a headspace/SPME autosampler (AOC-6000 Plus, Shimadzu, Kyoto, Japan) with MS detector and a capillary analytical column (SH-Rxi-5Sil-MS (30 m, 0.25 mm ID, 0.25 µm, Shimadzu, Kyoto, Japan). Beer samples (10 mL) were added to separate 20 mL vials, in which 1 g NaCl (≥99%, Sigma-Aldrich, St. Louis, MO, USA) was previously added, closed immediately and set for analyses. The analyses were performed in triplicate according to the EBC® methods 9.39 and 9.24.2. The integration of obtained diagrams was performed using GCMS Solution Version 4.53SP1 (LabSolutions, Shimadzu, Kyoto, Japan). A detailed description of calibration can be found in the Supplementary Material.

2.4. Sensory Evaluation of Beer Characteristics

Sensory evaluation was conducted by 5 trained panelists (3 males and 2 females). The ranking tests for intensity and sensory descriptors were adjusted from the general evaluation sheet for beer [6]. Descriptors were used to describe the points of the scale. Generally, there were six properties (appearance, smell, off-smell, taste, off-taste and mouthfeel) that were evaluated. Tasting tests were performed in an appropriate room, and beer samples were kept at room temperature for 10 min before the test. Samples were poured into a clean glass and covered with a watch glass to prevent volatile compounds from escaping the glass. All the beer samples were numbered and anonymous. Evaluators were offered flat mineral water between the samples, together with plane white bread and cheese. The final score for each beer was determined as sum of scores from each panelist divided by a number of panelists. The maximal score was 100.

2.5. Statistical Analysis

PCA (principal component analysis) was carried out using Statistica 13.1. (TIBCO Software Inc., Palo Alto, CA, USA). PCA was applied on an autoscaled data matrix made up of all analyzed beers, and the mean values of the 11 identified volatiles and sensory attributes as variables.

3. Results and Discussion

Sensory analysis is an extremely important analysis in the brewing industry, and serves as a control of the final beer exiting the factory. It requires trained panelists and continuous training sessions. Coupling it with physical–chemical analyses gives an insight in evident or less evident/recognized errors in the production.

Table 2 shows the results of the physical–chemical analyses of investigated beers. It is visible that most samples were within the limits for each style. Some samples had much higher concentration of CO_2 than prescribed (3 gL^{-1}) by the national regulation [7].

Table 2. Results of physical–chemical analysis of investigated beers.

Sample/Style	OE (°P)	AE (°P)	RE (°P)	ABV (mL/100 mL)	pH	Haze (EBC)	Color (EBC)	Bitterness (IBU)	CO_2 (gL^{-1})
1/Spicy herb ale	16.66	6.14	8.17	5.82	4.35	2.20	14.7	35.1	4.0
2/Gruitbeer	15.07	3.41	5.65	6.35	4.15	1.25	15.8	20.9	4.8
3/Lager	11.97	2.44	4.27	5.07	4.12	0.84	7.6	20.8	4.3
4/Lager	11.74	2.51	4.30	4.90	3.90	1.12	15.9	26.5	4.6
5/Lager	10.45	2.24	3.82	4.33	4.52	2.25	12.5	18.6	4.6
6/Pale ale	12.64	5.34	6.75	3.94	4.18	1.32	17.9	24.1	4.5
7/Pale ale	13.99	2.18	4.44	6.35	4.68	1.74	11.0	26.4	4.3
8/Pale ale	11.88	2.51	4.32	4.98	4.57	0.76	18.7	39.6	4.8
9/Pale ale	11.43	2.58	4.29	4.70	4.16	0.86	11.0	27.0	5.5
10/Koelsch style	9.93	2.02	3.55	4.16	4.34	0.84	6.2	26.7	4.3
11/Blond ale	10.83	1.22	3.06	5.06	4.30	1.39	17.1	27.7	5.0
12/Blond ale	10.73	2.55	4.13	4.32	4.13	2.08	8.4	15.0	4.8
13/Amber ale	14.56	2.58	4.88	6.48	4.60	1.91	33.8	54.8	5.6
14/Amber ale	12.60	2.70	4.61	5.29	4.30	0.96	19.4	28.4	6.6
15/Brown ale	10.74	1.17	3.01	5.04	4.26	1.22	15.1	33.3	4.8
16/Indian pale ale	14.90	2.43	4.82	6.75	4.64	8.78	23.6	62.2	5.8
17/Indian pale ale	16.08	4.23	6.51	6.51	4.57	3.57	23.1	45.8	5.0
18/Indian pale ale	11.71	0.80	2.89	5.76	3.62	0.71	24.0	30.7	4.8
19/Indian pale ale	13.33	1.89	4.08	6.12	4.40	1.25	12.3	46.7	5.4
20/Stout	11.81	3.65	5.23	4.35	4.36	7.88	67.7	24.2	4.2

Table 2. *Cont.*

Sample/Style	OE (°P)	AE (°P)	RE (°P)	ABV (mL/100 mL)	pH	Haze (EBC)	Color (EBC)	Bitterness (IBU)	CO_2 (gL^{-1})
21/Stout	13.61	4.38	6.17	4.99	4.14	3.89	65.6	26.6	4.2
22/Stout	14.64	3.85	5.93	5.86	4.17	6.64	63.9	40.1	5.4
23/Porter	11.00	1.83	3.60	4.84	4.35	2.76	69.8	41.0	4.0
24/Porter	13.77	4.76	6.50	4.88	4.50	5.88	58.6	27.1	5.3
25/Brown porter	12.62	5.19	6.63	4.00	4.16	1.56	86.5	20.1	5.4
26/Heffeweizen	12.33	2.67	4.53	5.15	4.14	1.75	18.0	13.6	4.6

OE—original extract; AE—apparent extract; RE—real extract; ABV—alcohol by volume.

Sample 1/Spicy herb ale fits within the reported bitterness (5–40 IBU) and ABV (2.5–12) for this style [8]. This is a traditional beer brewed with low hops content, using certain herbs and spices or honey to make it more aromatic and appealing [8]. Griutbeer is another style that represents a traditionally produced ale, usually without using any hops, resulting in 0 IBU. Different herbs, roots and spices can be added to it, but sample 2/Griutbeer was made by adding anise and some hops to it, resulting in 20.9 IBU. The alcohol content is a bit higher than reported by [9].

Only three lager beers were subjected to analysis. They were all within the recommended limits for lager style [3].

Pale ales were also within the limits recommended by [3].

Koelsch-style beer was a within the recommended values (6–12 EBC) for color, 6.2 EBC, and alcohol by volume was 4.16%, where the recommended value is 4.8–5.3% [3].

Samples 11 and 12 belong to the blond ale style. Recommended values for this style are original gravity 11.2–13.3 °Plato, apparent extract 2.1–4.1 °Plato, alcohol by volume 4.1–5.1%, bitterness 15–25 IBU, and color 6–14 EBC. Sample 11 was found to be within the limits, but showed discrepancies regarding color and bitterness. These parameters were higher than recommended by [3] for this style.

Samples 13 and 14/amber ales were generally within the recommended limits for this style. However, sample 14 had a somewhat higher bitterness (54 IBU) than recommended (25–45 IBU).

Brown ale (sample 15) had appropriate bitterness (33 IBU) compared to the recommended value (30–45).

Three samples were Indian pale ale style. All samples had higher color than recommended for this style (6–12 EBC).

Stouts showed somewhat lower bitterness than recommended (30–60) by [3], with only one sample within the limits, sample 22.

Porters showed relatively higher values for bitterness and color.

Sample 26/Heffeweizen was within the recommended limits.

Haze measured in all samples was a bit higher due to lack of filtration. Crafted beers are commonly more or less hazy. However, lager- or Koelsch-style beers are intended to be haze-free, desirably brilliant, with haze under 1 EBC unit since, according to the EBC scale, hazy beers are above 1 EBC unit. Physical–chemical properties are important for quality maintenance. Knowing them can give an insight into certain production errors. However, some physical–chemical properties, such as color, are hard to detect by sensory analysis. Differences in color can be subtle or not visible to the human eye, thus the quantification of this property in EBC units is useful for quality maintenance.

Table 3 shows the analysis of 11 volatile compounds in investigated beers. Some of these compounds are crucial or indicative for a certain beer style, e.g., isoamyl acetate, which is characteristic for wheat beers, providing them with a banana-like aroma.

Acetaldehyde (ACE) provides a sour or tart green apple flavor to beer, almost similar to dry cider [6]. Commonly, this off-flavor can be prevented by aerating the wort prior adding the yeast, avoiding exposure to oxygen during fermentation (not lift fermenter lid), and do not bottle or keg beer too early [10]. Commonly, the threshold for ACE varies between 10 and 20 mgL^{-1}. Beyond this concentration, the above-mentioned off-flavors are pronounced [11]. ACE concentrations were different between samples, with sample 13/amber ale having the highest concentration of this compound (16.04 mgL^{-1}). Higher levels of ACE can contribute to a longer fermentation where yeast cells autolyze/die out [12]. However, in all samples, the concentrations of ACE were below the threshold and thus not detectable by panelists.

Ethyl-acetate (EAC) results in considerable off-flavors, such as fruity, ester-like, or rum-like off-flavors. This compound is a by-product of fermentation [6]. The flavor threshold for ethyl-acetate in lager beer is <5 mgL^{-1} [1], but is generally reported to be up to 30–50 mgL^{-1} [12]. EAC was quantified in all samples below the sensory threshold. Special beer, such as samples 1/Spicy herb ale and 2/Gruitbeer had EAC concentrations above 20 mgL^{-1} (35.36 and 23.65 mgL^{-1}). This could probably be attributed to the fact that different herbs were added to this beer, which could have contributed to the fruity flavors. All lagers in this case had over 10 mgL^{-1}, with sample 5/Lager having 20.43 mgL^{-1}. Pale ales had EAC concentrations well below the threshold, with the highest concentration being determined in sample 7/Pale ale (15.58 mgL^{-1}). Sample 11/Blond ale also had a low level of this compound (9.76 mgL^{-1}). Between blond, amber and brown ales (samples 11–15), sample 13/Amber ale had the highest concentration of EAC, 22.26 mgL^{-1}. Indian pale ales exhibited somewhat higher values for this compound, being above 30 mgL^{-1} in samples 17 and 18, while sample 19 showed values below 10 mgL^{-1}. Stouts and porters (samples 20–25) had relatively low concentrations of EAC, mostly below 10 kgL^{-1}. However, in samples 20 and 24, higher levels of EAC were detected, reaching 19.7 and 27.21 mgL^{-1}.

Propanol is a higher alcohol, also denoted as fusel alcohol. Such alcohols are important flavor contributors, and their concentration in beer is commonly affected by the used yeast strain and fermentation temperature. Ales are known to have four times higher concentrations of propanol than lagers [15], and the sensory threshold for this component is designated as 800 mgL^{-1} [13,16,17]. N-propanol was highest in sample 18/Indian pale ale, resulting in 51.89 mgL^{-1}. However, all samples had n-propanol well below the sensory threshold.

Isobutanol is designated as higher alcohol as well. According to Engan, the sensory threshold ranges 100–175 mgL^{-1} [18]. Isobutanol, as with other higher alcohols (n-propanol, isobutanol, 2-methylbutanol (amyl alcohol), and 3-methylbutanol (isoamyl alcohol)), appears at concentrations near or above the designated sensory thresholds. Generally, they contribute to beer flavor by intensifying the alcoholic/solvent-like aroma and taste resulting in a corresponding warming effect on the palate [19]. The highest concentration was found in sample 2/Gruitbeer, reaching 109.91 mgL^{-1}. This is the only sample that had the concentration of this compound above the designated threshold. However, since it barely exceeded the threshold, and Gruitbeer is rich in many other aromas, this was not recognized as an off-flavor. Isobutanol levels in other samples were well below the threshold.

3—methylbutanol (or isoamyl alcohol) is commonly recognized as malty, bitter, alcoholic or solvent-like [6]. The threshold for amyl alcohols is 70 mgL^{-1} [13]. The increased levels of this compound in beer are related to higher fermentation temperatures, commonly for all higher alcohols [6]. 3—methylbutanol is a very important higher-alcohol compound regarding beer flavor and subsequently drinkability. Namely, if isoamyl alcohol concentration increases, it affects drinkability, due to making the beer flavor heavier. It has an undesirable effect on beer quality in concentrations that exceed 20% of the total amount of n-propanol, isobutyl alcohol and isoamyl alcohol [17]. Again, the only sample that showed value above 100 mhL^{-1} appeared to be sample 2/Gruitbeer, with 108.6 mgL^{-1}.

Belonging to higher alcohols as well, 2-phenylethanol levels in beer are also correlated to fermentation pace. It is described with roses, sweetish, perfumed aromas [6], Its threshold is 125 mgL^{-1}. None of the samples exceeded this threshold.

Table 3. Results of volatile component analyses of investigated beers.

Threshold Value [11–21]	Acetaldehyde mgL^{-1}	Ethyl Acetate mgL^{-1}	n—Propanol mgL^{-1}	Isobutanol mgL^{-1}	3—Methylbutanol mgL^{-1}	2—Phenylethanol mgL^{-1}	Isoamyl Acetate mgL^{-1}	2—Phenylethyl Acetate mgL^{-1}	Dimethylsulphide µgL^{-1}	2,3—Butanedione µgL^{-1}	2,3—Pentanedione µgL^{-1}
	10–20	**30–50**	**800**	**100–175**	**70**	**125**	**1.2**	**3.8**	**30**	**0.15**	**1000**
1/Spicy herb ale	3.37	35.36	38.94	68.9	38.14	66.2	1.93	2.04	16.54	87.50	26.50
2/Gruitbeer	7.03	23.65	29.29	109.91	108.6	104.84	1.02	0.42	12.18	48.50	16.00
3/Lager	2.37	10.95	13.26	17.67	54.99	48.9	0.59	0.47	19.34	9.00	22.00
4/Lager	0.98	16.37	22.04	26.51	44.57	33.65	0.24	0.21	30.98	23.00	24.00
5/Lager	3.30	20.43	7.14	8.78	32.89	29.34	1.66	0.78	43.00	47.00	25.00
6/Pale ale	1.86	6.9	22.56	84.52	39.91	68.4	0.23	0.44	43.08	140.00	32.00
7/Pale ale	2.39	15.58	28.59	47.95	50.92	31.21	0.43	0.13	73.46	45.00	10.00
8/Pale ale	0.85	10.90	20.10	10.13	22.21	25.21	0.34	0.01	58.61	27.00	30.00
9/Pale ale	2.04	8.22	27.97	18.50	43.18	45.27	0.52	0.23	23.75	67.00	15.00
10/Koelsch style	0.47	11.10	19.88	18.87	24.85	26.37	0.37	0.14	70.36	24.00	27.00
11/Blond ale	3.12	9.76	20.21	36.01	47.56	45.79	0.38	0.14	56.11	27.00	30.00
12/Blond ale	1.82	3.93	20.58	36.72	40.15	49.27	0.07	0.06	29.92	13.00	6.00
13/Amber ale	16.04	22.26	37.04	35.34	36.87	33.28	0.62	0.33	62.91	55.00	10.00
14/Amber ale	4.43	13.69	20.87	62.09	69.31	80.40	0.73	0.49	52.53	25.00	15.00
15/Brown ale	1.20	12.93	21.12	37.10	39.54	36.82	0.46	0.20	39.65	55.00	30.00
16/Indian pale ale	4.27	13.57	36.51	51.00	54.18	39.15	0.19	0.05	85.23	59.00	14.00
17/Indian pale ale	7.81	30.74	35.54	28.01	37.20	25.70	0.65	0.23	46.81	48.00	11.00
18/Indian pale ale	2.38	37.13	51.89	36.11	29.27	39.56	0.11	0.05	35.41	25.00	7.00
19/Indian pale ale	4.40	8.97	22.91	32.86	39.71	44.34	0.20	0.11	31.33	26.00	28.00
20/Stout	4.46	19.70	25.46	35.48	52.05	57.53	1.48	1.04	24.97	59.00	26.00
21/Stout	0.26	5.68	29.85	70.63	55.91	49.97	0.12	0.07	26.06	50.00	13.00
22/Stout	1.63	7.88	32.79	37.05	66.04	42.31	0.31	0.16	12.49	72.00	21.00
23/Porter	2.06	9.68	25.96	39.20	49.96	38.35	0.49	0.20	26.54	111.00	29.00
24/Porter	0.93	27.21	28.37	44.48	50.78	43.83	1.86	0.96	21.32	84.00	18.00
25/Brown porter	2.59	5.66	22.56	75.05	53.57	70.19	0.31	0.40	27.28	166.00	65.00
26/Heffeweizen	0.99	28.79	19.87	65.59	84.48	62.61	3.95	1.87	21.10	31.00	28.00

Isoamyl acetate gives a characteristic banana-like, fruity, apple or pear flavor. It is a result of yeast activity and common to wheat beers [6], and has a threshold of 1.2 mgL^{-1}. Values obtained in our research were mainly below this threshold, except in samples 1/Spicy herb ale (1.93 mgL^{-1}), 5/Lager (1.66 mgL^{-1}), 20/Stout (1.48 mgL^{-1}) and 24/Porter (1.86 mgL^{-1}). The highest concentration was found in sample 26/Hefeweizen, amounting to 3.95 mgL^{-1}, as is appropriate.

2—phenyletil acetate is an ester as well. It is characterized by an aroma that resembles roses or honey, and is often described as tasting like raspberry or guava. Commonly, it is recognized when exceeding the threshold of 3.8 mgL^{-1} [13,16,17]. All samples showed lower levels than the reported threshold.

Dimethylsulphide (DMS) is a compound that comes from malt as a raw material, and is commonly removed during the boiling stage by simply evaporating. It is described as tasting like cooked cabbage, sweet corn or cooked vegetables [20], while some authors [21] report that DMS gives beer even blackcurrant-like flavor. Higher values mean that the boiling time was shortened, not allowing DMS to evaporate. The designated threshold for DMS in beer is 30 μgL^{-1} [22]. Some authors rely on the fact that the usual values found in beers vary from 14 to 144 μgL^{-1} and greatly depend on the beer style [23]. It appears that almost 50% of the samples, 12 of them, had higher DMS levels. DMS concentrations went up to 85 μgL^{-1} (Sample 16/Indian pale ale). Samples 7/Pale ale and 10/Koelsch style had over 70 μgL^{-1}. These concentrations are high, and must have been noted by the sensory panel in the evaluation samples.

2,3—butanedione or diacetyl flavor (vicinal diketone) is commonly described as a buttery, creamy, or butterscotch flavor [6]. DIA is a very important compound in beer flavor profile, and is generally regarded as unwanted in finished beer. It is common in lagers, which have a threshold of 0.15 mgL^{-1} [22]. Some authors reported the taste threshold for diacetyl in lager beer is 0.1—0.2 mgL^{-1} [24–26], but Kluba et al. [27] and Saison et al. [28] stated that values as low as 14–61 μgL^{-1} may cause off-flavors in beer production. Since lager beers are light, when compared to ales, the emerging diacetyl flavor is designated as a production error. Some ale beers can withstand higher diacetyl concentrations of up to 1.0 mgL^{-1} [29], which is noted in many samples and beer styles in this research. All samples showed significantly lower values than the threshold, except sample 25/Brown porter, in which 166 μgL^{-1} of this compound was detected.

2,3—pentanedione is also a vicinal diketone. Similarly to the forementioned compound, it is described as buttery, cloying, honey or creamy-like in flavor. Its threshold is 10 times higher than for diacetyl, reaching up to 1 mgL^{-1} [30]. According to this research, all samples showed lower values than the designated threshold.

Table 4 shows the results of sensory evaluation of investigated beers. They were evaluated by the panelists, who evaluated the overall sensation, which included carbonization, mouthfeel, bitterness, off-flavors, smell, taste and astringency. The best score was assigned to sample 26/Hefeweizen. Considering the physical–chemical analysis and volatile compounds, this beer was top in all categories and deserved highest score. Second-best, with 96 points, were beers 1 and 2, the spicy herb ale and gruitbeer. According to sensory evaluation, they showed excellent traits which were in accordance with physical–chemical analysis. Even though Koelsch-style beer had higher concentrations of DMS (Table 3), none of the panelists remarked this, which means that overall quality of the beer was excellent and this compound was masked with prevailing compounds, which resulted in well-balanced beer scoring 96 points. Samples 14/Amber ale and 21/Stout scored 95. Similarly, sample 14 also had higher levels of DMS, but this went unrecognized by the panelists, probably due to the full body and aromas originating from dark/roasted malt. Regarding the errors evident via physical–chemical analysis, these beers received the highest scores, since the overall sensation during sensory analysis excluded them as best.

Table 4. Results of sensory evaluation of investigated beers.

Sample	Appearance	Smell	Off-Smell	Taste	Off-Taste	Mouthfeel	Score
1/Spicy herb ale	10	20	19	19	23	5	96
2/Gruitbeer	9	20	20	17	25	4	96
3/Lager	9	16	17	20	23	5	91
4/Lager	9	17	13	17	20	4	81
5/Lager	8	19	20	17	25	5	94
6/Pale ale	9	19	16	19	18	4	85
7/Pale ale	9	17	16	17	20	5	85
8/Pale ale	10	19	20	17	23	5	94
9/Pale ale	9	20	17	19	20	5	90
10/Koelsch style	10	17	19	20	25	5	96
11/Blond ale	10	20	19	19	23	4	95
12/Blond ale	10	17	16	17	20	5	86
13/Amber ale	9	20	19	17	20	5	90
14/Amber ale	10	20	20	19	23	4	96
15/Brown ale	10	19	19	20	22	4	93
16/Indian pale ale	9	20	19	17	20	4	90
17/Indian pale ale	9	17	19	19	20	4	88
18/Indian pale ale	8	17	15	17	20	4	82
19/Indian pale ale	10	19	17	19	22	5	91
20/Stout	9	19	19	16	23	4	90
21/Stout	10	19	20	19	23	4	95
22/Stout	10	19	20	17	23	5	94
23/Porter	9	20	17	19	22	4	91
24/Porter	10	19	19	17	23	4	92
25/Brown porter	10	17	17	16	23	4	88
26/Heffeweizen	10	20	20	19	25	5	98

Lager beers' scores varied. Some were designated as watery, some were not carbonated enough, but two of them received high scores, 91 and 94. Sample 4/Lager was given 81 points since it had an off-flavor, was too watery and had not enough mouthfeel. Carbonation was also not satisfactory. Even though this sample had only slightly higher DMS levels (30.98 μgL^{-1}), in regard to sample 5/Lager (43.00 μgL^{-1}), it significantly deteriorated the overall sensation in sample 4 (81), while sample 5 received a much better score (94).

Pale ales received relatively high scores, with samples 8 and 9 gaining 90 or more points. Samples 6 and 7 of this category received 85 points.

This is due to the lack of carbonation, mouthfeel and high DMS values (43.08 and 73.46 μgL^{-1}), which evidently significantly affected the evaluation panelists.

Blond ales were scored 86 points (sample 11) and 90 points (sample 12). The somewhat lower score of sample 11 was probably caused by a detected papery flavor, lower carbonation and mouthfeel.

Amber (samples 13 and 14) and brown ale samples (15) received relatively high scores of 90 or more points. Sample 13 had higher values of EAC (>22 mgL^{-1}) and DMS (>62 μgL^{-1}), which probably resulted in lower score points. Head retention was low as well. They also had higher levels of DMS, well above the designated threshold of 30 μgL^{-1} (52.53, 39.65 and 85.23 μgL^{-1}), but this did not affect the sensory analysis.

Indian pale ales (IPA) are usually very aromatic, full of citrus and hoppy aromas, which mask production errors and give them potential to receive the best score. However, in this research, the IPA style did not receive the best score, as two of them received below 90 points. This is probably due to the fact that they all had higher DMS levels, which were not masked by the hoppy aromas. Also, as noted by the panelists, carbonation and mouthfeel were a bit off. Color was also described as not in style, which was later confirmed by the physical–chemical analysis.

Stouts and Porters were generally scored very well, above 90 points. The evaluators only stated that carbonation was a bit low in some samples; regardless, the physical–chemical analysis showed that all samples had CO_2 levels above the prescribed limit.

Brown porter (sample 25) received a slightly lower score (88), probably due to high 2,3—butandione levels (>166 μgL^{-1}) and inappropriate carbonation.

In order to emphasize the differences and/or analogies among beer samples based on the sensory, physical–chemical and volatile compounds analysis, principal component analysis (PCA) was performed. The first two principal components describing 38.06% of the total variability in the dataset were used in a PCA biplot. The biplot (PCA) visualization of sensory analysis and physical–chemical analysis, coupled with volatile compounds content, is shown in Figure 1. It is visible that some samples grouped around the same property, such as OE or pH, or volatile compounds (DMS). They were commonly grouped by the style, but there are some exceptions. Sample 17/Indian pale ale received higher extract levels than the other two samples of IPA, and sample 18 of the same style received the lowest score (82), which is visible from Figure 1. Samples 7 and 8/Pale ale were excluded from their style due to high DMS values and bitterness (sample 8). Koelsch-style was similar to lagers and thus grouped near the lager style. Mouthfeel was negatively correlated with CO_2 and pH. Off-smell and score were negatively correlated with DMS, while sample 26/Heffeweizen showed correlation with clarity, bitterness and smell, but was closely related with the characteristic volatile isoamyl acetate.

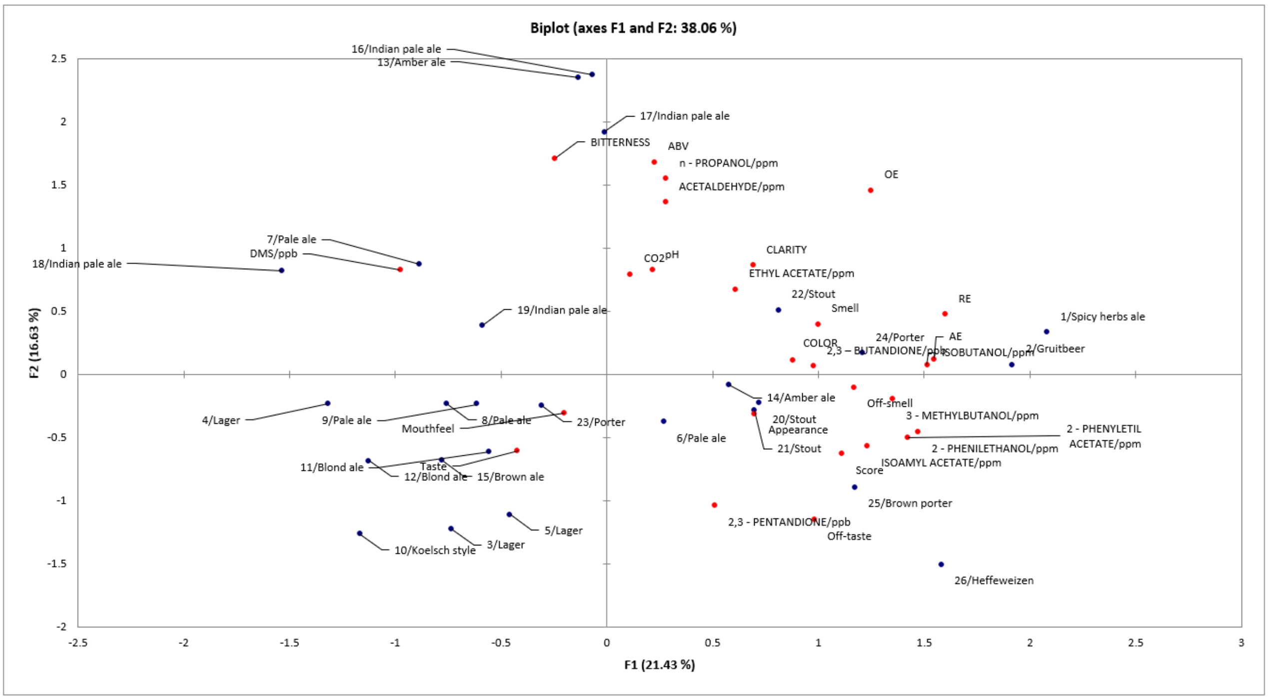

Figure 1. The correlation of sensory analysis and physical–chemical analysis coupled with volatile compound content.

4. Conclusions

The results of this research showed a variety of physical–chemical, chemical and sensory data regarding different beer styles. Some of the beers were evaluated with a lower score, even though they were within the recommended limits regarding the physical–chemical properties or volatile thresholds. Perhaps the best example of this is carbonation, the level of $CO_{2,}$ which was satisfactory in all beers, according to the prescribed legislation, but some beers were evaluated as too carbonated or not carbonated enough. Also, some beers, such as Indian pale ales, showed extract values within the designated limits, but in the sensory evaluation they were scored lower (sample 18) and noted as watery.

On the other hand, some beers that received the best scores had certain production errors which were masked by the overall sensation during evaluation. In conclusion, beer is a complex matrix, consisting of over 800 compounds. In synergy, they can contribute to the off-flavors, but can also add value or mask different off-flavors and deliver a well-balanced beer. It is important to regularly monitor the sensory quality of beer, but also perform physical–chemical analysis, especially coupled with volatile compounds analysis. However, not all, especially small, breweries have the opportunity to provide finances for such extended analysis, thus delivering a variable quality of beer to the consumers.

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