Barley-sorghum craft beer production with *Saccharomyces cerevisiae*, *Torulaspora delbrueckii* and *Metschnikowia pulcherrima* yeast strains

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Abstract

The use of different yeast strains contributes to obtain insights into beer products with diverse sensory characteristics. In this study, three yeast species of different genera were selected to evaluate their fermentation performance and sensory profile for barley-sorghum beer production. Barley-sorghum wort was produced with 12.5°P and fermented with *Saccharomyces cerevisiae*, *Torulaspora delbrueckii* and *Metschnikowia pulcherrima* yeast strains. Differences were observed in terms of fermentation time and ability to ferment maltose. *S. cerevisiae* attenuated initial maltose concentration within 72 h, while *M. pulcherrima* and *T. delbrueckii* performed fermentation within 120 and 192 h, respectively. Both yeast strains simultaneously produced 11% and 23% lower ethanol concentrations, compared to *S. cerevisiae* with 37.9 g/L. Wort fermented with *T. delbrueckii* showed residual maltose concentration of 19.7 ± 4.1 g/L, resulting in significantly enhanced beer sweetness. *S. cerevisiae* produced significantly increased levels of higher alcohols, and obtained the highest scores for the sensory attribute body perception. Beer produced with *T. delbrueckii* contained significantly lower fermentative 2,3-butanediol and 2-methyl-1-butanol volatiles; this beer also showed reduced body perception. Beer conditioned with *T. delbrueckii* was significantly preferred over *M. pulcherrima*. Besides *S. cerevisiae* with high fermentative power, *T. delbrueckii* and *M. pulcherrima* were found to have reduced maltose fermenting abilities and provide significantly different sensory attributes to barley-sorghum beers.

Keywords Craft beer · Non-*Saccharomyces* · Fermentative volatiles · Sensory attributes

Introduction

The popularity of craft beer is of growing interest in several countries and provides alternatives to mainstream beer production. In Europe, South America and North America craft beer is now a well-known beverage and one of the growing segments in the beverage sector [1]. Growth in this market segment is associated with the ‘millennial generation’ aged 21–30 which is perceived to be interested in exploring new beer tastes and willing to pay higher prices. Craft beer drinkers are particularly interested in tasting new beers with different flavors rather than the usual well-known commercial brands [2]. Certain untypical flavors in craft beers even have

the potential of being perceived by the consumer as having higher quality compared to commercial beer [3].

There are several options to obtain different sensory profiles in beers to meet customer demands. For instance by diversification of the applied raw materials and adjuncts, adaptation of technical brewing procedures and the choice of fermenting yeast strains [4–6]. In terms of applied raw materials and adjuncts, an Italian survey indicated that there is a certain consumer expectation on the manufacturing procedures of craft beer production. One consumer expectation is the utilization of heirloom grains in the grain bill [7]. Among the heirloom grains used in brewery, *Sorghum bicolor* grain is receiving a high interest with regard to functional food and beverage production [8]. Sorghum also has a long tradition in being used for the production of fermented beverages in African countries [9]. Sorghum beer has furthermore been described as one of the most delicate beers from a sensory point of view with a complex but moderate taste [10]. Based on consumer expectations and the sensory attributes of sorghum beer, there has developed

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a large interest to use sorghum as raw material or adjunct in craft beer production [4, 11, 12]. The fermentation of wort produced solely from malted sorghum could, however, result in impaired yeast growth and enzymatic activities during fermentation [12]. This can be overcome by initially adjusting the grain bill to a high content of easy to ferment malted barley and a reduced content of sorghum. This makes sorghum an interesting adjunct.

Generally, the choice of wort fermenting yeast strains and beer conditioning is crucial, as the abundance of many aroma-active compounds in beer is directly linked to the yeast strain applied [5, 13]. All brewing yeasts produce relevant aroma components, i.e. higher alcohols and esters. The levels of each of these compound found in beer depend not only on the fermentation conditions but also on the yeast strain [12]. The goal of the use of specific yeasts is to increase fermentation efficiency, to develop new beer characteristics, and especially to enhance the sensory complexity of the final beer produced [14]. Endeavors to obtain beers with more complex sensory characteristics have led experts to investigate non-conventional yeasts [12]. In winemaking, there has been a re-evaluation of the role of non-*Saccharomyces* yeast with the aim to enhance the aromatic profile of the final product [15]. The use of non-*Saccharomyces* yeasts in oenology is still a fairly new concept in brewing and opens possibilities to develop significantly different sensory characteristics in beer compared to traditional *Saccharomyces cerevisiae* yeast strains [16].

In recent years, growth of non-*Saccharomyces* yeasts has been observed in spontaneous or fermentation processes inoculated with *S. cerevisiae*, suggesting a great contribution of these yeasts to the flavor and quality of alcoholic beverages [15, 17, 18]. Despite an increased variety of yeast strains used in the brewery, the performance of non-*Saccharomyces* yeasts has mainly been investigated in wine making. For instance, several oenology studies focused on aroma profile contribution by *Torulaspora delbrueckii* [19–21] and *Metschnikowia pulcherrima* [22, 23] yeast strains. *T. delbrueckii* has been successfully selected to increase fruity aroma compounds such as β -phenylethanol ('rose' flavor), 1-propanol, isobutanol, amyl alcohol ('solvent brandy' aroma) and ethyl acetate [24–26]. *M. pulcherrima* was found to alter the aromatic bouquet in wine by producing enhanced levels of ethyl propanoate, 2-methylpropyl acetate, 2-methylbutyl acetate, ethyl decanoate and 2-phenylethyl acetate [18, 23, 27]. The ability of both non-*Saccharomyces* yeasts to significantly change the perceived flavor in wines makes them an interesting target in the context of craft beer production.

Regarding the application of *T. delbrueckii* yeast strains in brewing processes, only a few studies have been carried out. King and Dickinson [28] reported that *T. delbrueckii* is able to transform hop terpenoids and significantly influences

the aroma profile of the beer produced. Tataridis et al. [20] focused on wheat beer production by inoculation with *T. delbrueckii*, facilitating more intensity and complexity to the product. Michel et al. [29], focused on ten *T. delbrueckii* yeast strains, providing highly different fruity, floral and wort attributes to the final beer. Canonico et al. [15] evaluated defined analytical and aromatic differences in beer when produced in pure and mixed cultures with selected *T. delbrueckii* strain. Wort fermentation with *M. pulcherrima* strains has not been reported so far. With the advances in beer production worldwide, new challenges arise each year in the search for novel approaches to developing distinctive beverages with attractive sensory and nutritional characteristics. Considering the diversification and consumer expectation in craft beer production, appropriate approaches should be selected to investigate heirloom adjuncts in combination with non-*Saccharomyces* yeast strains. To the best of my knowledge, the use of non-*Saccharomyces* yeast strains for beer production with sorghum adjuncts has not been investigated so far.

The aim of the study was to evaluate volatile profiles of barley beer with sorghum adjuncts pitched with different yeast strains (*S. cerevisiae*, *T. delbrueckii*, *M. pulcherrima*) by instrumental and sensory analysis. It further evaluated the wort fermentation ability of the yeasts.

Materials and methods

Experimental setup

This study focused on barley beer production with sorghum adjuncts inoculated with three selected yeast strains: *Saccharomyces cerevisiae* var. *diastaticus* (SafAle WB-06, Fermentis, France), *Torulaspora delbrueckii* (Biodiva TD 291, Lallemand, France) and *Metschnikowia pulcherrima* (Flavia MP 346, Lallemand, France). All yeast strains were applied because of their specific features. *S. cerevisiae* strain SafAle WB-06 is described to provide a fruity and phenolic character in wheat beers [20, 30]. *T. delbrueckii* was used because of low volatile acidity production and aroma enhancement features [19]. *M. pulcherrima* strains are frequently applied in wine production and known to contribute to aroma and color attributes during fermentation [31]. All yeast strains were applied after standardized wort production and their fermentation performance examined in triplicates.

Wort production

The specific wort employed for the fermentation experiments was produced on a 120 L pilot-scale brewing plant (Carl GmbH Destillations- und Brauereitechnik, Germany). Wort target extract of 12.5°P was set based on an extract

ratio of 80% (w/w) from barley malt (Weyermann Pilsner Malz, Weyermann GmbH, Germany) and 20% (w/w) from sorghum flakes (Altdorfer Mühle GmbH, Germany). Determination of fermentable substances was performed as described by Pohl and Senn [32]. The determination of the fermentable substance in grain is defined as the sum of glucose and maltose content released in the production process and converted to ethanol by *S. cerevisiae*. The fermentable substance was determined with 59.6% for barley malt and 69.1% for sorghum. Grain bill and strike water were determined according to Kunze [33] and Thesseling et al. [34]. Mashing was performed at 57 °C with 100.7 L striking water, 10.8 kg barley malt and 2.3 kg sorghum flakes and the temperature kept for 20 min. For gelatinization and enzymatic starch conversion, mash was heated to 63 °C (60 min). Saccharification was performed at 72 °C (15 min) and wort finally heated to 76 °C (10 min) to reduce enzymatic activity. Subsequently, wort was lautered and boiled (60 min). The wort was boiled with the addition of 11.6 g Hallertauer hop (Magnung, Brau-Partner, K. Kling, Germany) at the beginning and again after 30 min wort boiling until reaching target extract with wort density (DMA 35, Anton Paar, Austria) of 1.0486 g/L.

Fermentation

Triplicates of 30L wort were pitched with 0.5 g/L *S. cerevisiae*, 0.8 g/L *T. delbrueckii* and 0.3 g/L *M. pulcherrima*, respectively, and fermented in beer-kegs at 20 °C. 150 ml samples were taken on a 24 h base until reaching extract value of 5°P. Subsequently, beer was transferred to pressure vessels, equipped with 3×10^5 Pa pressure-regulating air-vents, and stored at 10 °C for 28 days. Fermentation samples were 0.45 µm membrane filtered and analyzed for maltose, glucose, fructose and ethanol concentrations by high-performance liquid chromatography (HPLC), using a 7.8 × 300 mm Rezex RPM-Monosaccharide Pb + 2 Ion exclusion column (Phenomenex, Aschaffenburg, Germany), with refractive index detector (Shodex RI-101, Thermo Fisher, Waltham USA) and sulphuric acid (0.005 N) eluent at 0.6 mL/min flow rate.

Instrumental beer analysis

After fermentation, a headspace gas chromatograph (GC-2010 Plus, Shimadzu Scientific Instruments, Kyoto, Japan), equipped with a flame ionization detector (FID) and Rtx-Volatiles column (Restek Corp., Bellefonte, USA), was used to quantify 16 volatile compounds in the finalized beers. 0.45 µm membrane filtered beer samples were GC analyzed for 1-butanol, 1-propanol, 2-butanol, 2,3-butanediol, 2-methyl-1-butanol, 2-phenylethyl alcohol, 2-phenylethyl acetate, 3-methyl-1-butanol, acetaldehyde, acetoin, diacetyl,

ethyl acetate, ethyl lactate, isoamyl acetate, isobutanol and methanol. GC standards were three-point calibrated ($R^2 > 0.99$). Limit of quantification was 0.5 mg/L.

Sensory beer analysis

The sensory analysis was split into sensory profile analysis and beer difference tests. Sensory profile analysis tests were carried out according to ISO 6564: 1985 [35] and ISO 4121: 2003 [36]. A panel of twelve judges (seven male, five female) evaluated different attributes in the tasting chart on hedonic 6-point-scale. Every tasting station was equipped with three freshly poured tasting glasses and a glass of water. The samples were anonymized by coding, according to the yeast strain inoculated. The attributes were classified into three groups: appearance, smell and taste. Judges scored each attribute from 0 to 5 with 5 being the highest value and 0 being the lowest. For appearance attributes, foam consistency was determined referring to bubble sizes, with lowest value expressing very light, large bubbles, and highest value in case of small bubbles and a creamy appearance; foam persistency was determined by low and high duration, depending on the duration of the foam; foam color was rated in a range of intense white (lowest value) and brown (highest value); effervescence was rated depending on the intensity of the CO₂ flow in the beer matrix, with the lowest value referring to a low intensity and the highest value referring to a high intensity; clarity was determined referring to the range of transparency with opaque receiving the highest value on a sliding scale. The panel was asked to smell the headspace of the beer to rate malt, yeast, caramel, banana and hop attributes with the lowest value being an absent or slight odor and the highest value an intense odor. For taste parameters, beers were examined for bitterness, sweetness, acidity, body, astringency and aftertaste, with a range of mild or absent tastes receiving the lowest value and a strong or intense taste the highest value. A radar chart was elaborated showing the average values for each beer type.

To evaluate sensorial differences between the obtained products, the statistic one-tailed triangle test [37] was applied on all three beer types. Sensorial tests were carried out by a group of 32 food scientists and students. Each panelist conducted three triangle tests, identifying the nonpair sample in trial setups of *S. cerevisiae* versus *T. delbrueckii*, *T. delbrueckii* versus *M. pulcherrima* and *S. cerevisiae* versus *M. pulcherrima*. All samples were encoded and evaluated in 50 mL shares.

Statistical analysis

Data of triplicates are presented in means and standard deviation. Differences between beer types were examined by one-way analysis of variance (ANOVA) with Tukey post-hoc

test on a significance level of $p < 0.05$. Identification of significant data correlation was performed with the Pearson test. Principal component analysis (PCA) was carried out to highlight differences between the obtained results. Triangle tests were statistically evaluated by one-tailed X^2 tests. Calculations were performed by statistical analysis software SPSS 25 (IBM Corp., Armonk, USA). Graphs were constructed by SPSS and Excel (Microsoft Office 2010, Microsoft Corporation, USA).

Results and Discussion

The main quality characteristics of beer are appearance, aroma, flavor and mouthfeel [38]. Quality beer production depends on yeast fermentation efficiency and on the characteristic flavors and aroma provided by the yeasts [6]. In this study, three different yeast species were evaluated for fermentation parameters and beer aroma.

Wort densities at the beginning of the fermentation experiments were similar and equal wort densities were achieved with 12.5°P. The produced wort showed initial maltose, glucose and fructose concentrations of 45.4 ± 0.9 g/L, 10.0 ± 1.8 g/L and 2.1 ± 0.6 g/L, respectively. According to these results, similar wort characteristics were achieved, which is essential to perform comparable fermentation experiments with different yeast strains.

Yeast strains showed significantly different fermentation efficiencies (Fig. 1). All yeast strains were able to reduce the apparent extract to $< 5.0^\circ\text{P}$, described by Branyik et al. [39] as limited or stopped fermentation process. The fermentation time to achieve the final extract ranged from 72 to 192 h. Literature suggests that fermentation performance is limited by the ability of yeasts to transport maltose into the cell [40]. In our study, yeasts showed different abilities to metabolize maltose. *S. cerevisiae* reduced the available maltose within 72 h to 3.3 ± 0.1 g/L, *M. pulcherrima* metabolized maltose mainly between 72–120 h to 7.9 ± 3.7 g/L and *T. delbrueckii* degraded maltose within 192 h to residual maltose concentration of 19.7 ± 4.1 g/L. In accordance to our results, Canonico et al. [15] also investigated fermentation performances of eight *T. delbrueckii* strains and showed their main fermentation activity to be within 192 h. As expected, *S. cerevisiae* indicated efficient maltose fermentation performance. The fermentation with *M. pulcherrima* and *T. delbrueckii* yeast strains showed significant correlations between maltose and extract reduction ($r \geq 0.92$, $p = 0.000$) and significant correlations between maltose and ethanol concentrations ($r \leq -0.92$, $p = 0.000$). This indicated that the maltose fermentation ability had a major influence on fermentation performance.

Reduced maltose fermentation abilities have already been investigated in multiple yeast strains. In terms of *T.*

Fig. 1 Yeast strain dependent fermentation performance of sugar and ethanol metabolism. SC *S. cerevisiae*, TD *T. delbrueckii*, MP *M. pulcherrima*. Fermentation was conducted in triplicates

delbrueckii, Callejo et al. [41] described a reduced maltose fermentation ability. Tataridis et al. [20] stated a 30% reduced maltose fermentation rate compared to *S. cerevisiae* WB-06 strain. Our investigation indicated extended fermentation rate differences and incomplete maltose attenuation by yeast strain *T. delbrueckii* Biodiva TD 291. There is, however, a high variability of maltose fermentation ability within different *T. delbrueckii* strains [29]. Canonico et al. [15] even showed that only eight cultures out of the 28 *T. delbrueckii* strains were able to ferment maltose. And more specific, Toh et al. [42] identified two *T. delbrueckii* Biodiva strains to be unable to metabolize maltose. In our investigation yeast strain Biodiva TD 291 showed contradictory results. This states a strong yeast strain dependency in terms of maltose fermentation ability within *T. delbrueckii*.

Metschnikowia pulcherrima showed enhanced maltose fermentation ability over *T. delbrueckii* but a reduced maltose fermentation ability compared to *S. cerevisiae*. A

biochemical study on *M. pulcherrima* yeast strains also indicated a reduced maltose fermentation ability [27]. However, more detailed data on maltose fermentation performances of *M. pulcherrima* strains have so far not been published. In our investigation *M. pulcherrima* indicated a fast maltose degradation within 48 h after monosaccharides were depleted. The uptake and utilization of alternative sugars after monosaccharide depletion is a characteristic phenomenon in yeast cells due to carbon catabolite repression of metabolic pathways [43]. Results indicated a delayed but efficient maltose fermentation ability of *M. pulcherrima* Flavia MP 346 strain.

Saccharomyces cerevisiae produced the highest amount of ethanol with 37.9 ± 0.5 g/L. In combination with maltose fermentation ability, this evidenced a high fermentative power of *S. cerevisiae* compared to the other yeast strains. *M. pulcherrima* and *T. delbrueckii* yielded ethanol values of 33.7 ± 0.5 g/L and 29.2 ± 3.2 g/L, respectively. The fermentation parameters showed significant correlation of ethanol concentrations and apparent extract in all yeast strains ($r \leq -0.99$, $p = 0.000$) and confirms the possibility to apply simple extract analysis as an indicator of the fermentation process. In accordance to Parapouli et al. [27], stating ethanol tolerance in *M. pulcherrima* strains up to 7% (v/v), all yeast strains demonstrated tolerance against the evaluated ethanol concentrations.

Formation of average fermentative volatile concentrations by three yeast strains can be seen in Table 1. Many volatile compounds showed pronounced differences between yeast strains. Since the wort composition was similar prior to fermentation, the produced levels of fermentative volatiles were influenced by the pitched yeast. Consequently, all

fermentative volatiles contribute to the overall organoleptic properties of the end product.

Higher alcohols are important flavor and aroma compounds and are the most abundant compounds in beer. Below a certain threshold, these ‘fusel alcohols’ add complexity to beer and enhance its pleasant, refreshing and floral character [44]. In terms of higher alcohols, 2,3-butanediol was the most abundant higher alcohol. *T. delbrueckii* beer contained significantly lower 2,3-butanediol concentrations. It has a relatively high flavor threshold and, therefore, a limited effect on the overall beer flavor [45]. *S. cerevisiae* beer contained significantly higher concentrations of 3-methyl-1-butanol, 2-phenylethyl alcohol, 1-propanol and 2-methyl-1-butanol. 3-methyl-1-butanol, 1-propanol and 2-methyl-1-butanol are aliphatic alcohols that contribute to the ‘alcoholic’ or ‘solvent’ aroma and a warm mouthfeel of beer [46]. 2-methyl-1-butanol and 3-methyl-1-butanol cause fruity flavors in threshold concentrations of 50 mg/L and 1 mg/L respectively. 1-propanol may additionally cause a ‘rough’ flavor and harshness of beer [47]. However, none of the beers reached the perception threshold for this compound with 4.5 g/L [6]. *M. pulcherrima* additionally had significantly higher isobutanol concentration, having similar flavor perception attributes as 1-propanol and a perception threshold of 200 mg/L [45, 47].

Esters are important aroma compounds as they have low perception thresholds and define the fruity and floral character of the beer [6, 47]. From the esters analyzed, ethyl acetate concentrations were significantly higher in beer produced with *M. pulcherrima* compared to *T. delbrueckii*. Ethyl acetate represents approximately one third of all esters in beers contributing to a fruity and solvent-like aroma at a perception threshold concentration of 30 mg/L [46, 47]. The concentration of isoamyl acetate was significantly lower in *M. pulcherrima* beer, being perhaps the most important ester due to its very low flavor threshold [5] and is associated with a characteristic banana aroma [46].

Regarding the contents of 2-butanol, acetoin, diacetyl and ethyl lactate, the concentrations of these compounds were below the limit of quantification in all three experiments. In general, the three yeast strains produced significantly different fermentative volatiles compositions with significantly lower total higher alcohol and total ester concentrations in beer produced with *T. delbrueckii*. This result is contradictory to a study on wine fermentation, where *T. delbrueckii* yeast strains produced noticeably higher concentrations of higher alcohols, esters and phenolic aldehydes as well as other molecules [20]. The reduced formation of fermentative volatiles in our study might be an effect of limited maltose fermentation ability which could influence the formation of by-products such as higher alcohols and esters [39, 46, 47].

Despite different abundancies of fermentative volatiles, it has to be mentioned that the presence of different higher

Table 1 Concentration of volatile compounds in the beer produced by the three yeast strains (mg/L)

	<i>S. cerevisiae</i>	<i>T. delbrueckii</i>	<i>M. pulcherrima</i>
2,3-Butanediol	839.5 ± 14.5^a	665.6 ± 26.0^b	966.3 ± 53.7^a
3-Methyl-1-butanol	109.6 ± 2.2^a	51.4 ± 5.9^b	53.4 ± 6.6^b
2-Phenylethyl alcohol	60.8 ± 3.1^a	42.0 ± 0.8^b	39.9 ± 5.0^b
1-Propanol	53.3 ± 0.4^a	32.8 ± 3.1^b	16.3 ± 1.0^c
2-Methyl-1-butanol	34.7 ± 0.7^a	20.5 ± 1.1^b	27.9 ± 2.6^c
Isobutanol	26.8 ± 0.5^a	22.7 ± 1.3^a	32.9 ± 2.9^b
Methanol	6.7 ± 1.5^a	4.7 ± 0.3^a	4.8 ± 0.4^a
1-Butanol	4.0 ± 0.2^a	3.9 ± 0.2^a	3.8 ± 0.1^a
Ethyl acetate	31.9 ± 0.5^{ab}	29.7 ± 5.4^a	39.3 ± 3.7^b
Isoamyl acetate	3.2 ± 0^a	2.9 ± 0.3^a	2.3 ± 0.1^b
2-Phenylethyl acetate	1.0 ± 0.1^a	1.0 ± 0.1^a	0.8 ± 0.1^b
Acetaldehyde	9.3 ± 2.6^a	13.9 ± 2.9^a	8.5 ± 1.3^a

Data are means $\pm$ standard deviations

Data with different superscript letters within each row are significantly different (Tukey tests: $p < 0.05$)

alcohols and esters can have a synergistic effect on the individual flavors, which means that they can also have a positive effect on beer flavor, below their individual perception threshold concentrations. For instance, volatile esters are common trace compounds in beer but are extremely important for flavor profile. They have desirable attributes at low concentrations but lead to undesirable attributes at high concentrations [48–50]. Moreover, most esters are present at concentrations around their perception threshold values which implies that minor changes in concentration may have dramatic effects on beer flavor [45, 51, 52].

PCA was performed to highlight differences between the obtained yeast strains, based on the quantified fermentative volatiles. The first two principal components explained 84% of the data variance. The first principal component (PC1) covered 56.3% of the data variance and PC2 additional 27.8%. The three yeast strains could be differentiated in three main groups (Fig. 2). *S. cerevisiae* group was located on the positive axis side of PC1 in proximity to 1-propanol,

3-methyl-1-butanol, 2-methyl-1-butanol, 2-phenylethyl alcohol, methanol and isoamyl acetate. Beer pitched with *S. cerevisiae* strains exhibited the highest production of higher alcohols, which is resembled by the positive axis side of PC1. *M. pulcherrima* group is located at the negative axis side of PC1 and PC2, while *T. delbrueckii* is related to the positive axis side of PC2. *M. pulcherrima* yeasts produced the highest concentrations of ethyl acetate (39.3 ± 3.7 mg/L), indicated by proximate relation in the graph.

The beers exhibited different sensory profiles when produced with specific yeast strains (Fig. 3). Statistical analysis identified significant differences in visual and taste attributes between the different beers. Clarity was significantly higher in beers produced with *S. cerevisiae* and *M. pulcherrima*, while *T. delbrueckii* showed increased cloudiness. Beers produced by *T. delbrueckii* yeast strains were significantly sweeter, compared to beers produced with *M. pulcherrima*. Authors have validated that wort fermented by yeasts with low maltose fermentation abilities tend to increase the

Fig. 2 PCA with three major groups. SC *S. cerevisiae*, TD *T. delbrueckii*, MP *M. pulcherrima*

Fig. 3 Sensory profile radar chart showing mean values of twelve independent tasters. Different letters in same attribute indicate significant differences ($p < 0.05$). SC *S. cerevisiae*, TD *T. delbrueckii*, MP *M. pulcherrima*

sensory sweetness of the beer, due to its high residual maltose content [41]. It is likely that the reduced maltose attenuation in beer produced with *T. delbrueckii* was responsible for this specific aroma attribute. The body perception of *S. cerevisiae* beers was significantly increased, compared to beers produced by *T. delbrueckii* yeast strain. This might be a result of different levels of higher alcohols in the obtained beers. *S. cerevisiae* beer showed significantly higher alcohol content and was regarded with more intense body perception characteristics. In terms, significantly lower 2,3-butanediol and 2-methyl-1-butanol concentrations in *T. delbrueckii* beer seemed to result in reduced body perception.

Isoamyl acetate levels are important for the perceived intensity of fruity aroma [15]. Despite significantly lower isoamyl acetate concentrations in *M. pulcherrima* beer, the sensorial perception of fruity aroma was similar between the three beer trials. This could be the result of a synergistic effect of different esters [48–50]. *M. pulcherrima* yeasts also produced the highest concentrations of ethyl acetate (39.3 ± 3.7 mg/L), above perception threshold of 30 mg/L [41]. Acidity attributes were, however, identified as similar between all beers.

Comparing all beers in sensorial triangle tests, all three products were identified as significantly different from each other. This indicated that the different yeast strains affected the sensory perception of produced beers. Panelists were additionally asked for the preferred beer sample. Beer produced with *T. delbrueckii* was significantly preferred, compared to beer produced with *M. pulcherrima*. The work of da Costa Jardim et al. [53] advances the understanding of the sensory profile of different styles of craft beers and

consumer preference. They report that beer with enhanced fruity and sweet characteristics and simultaneously reduced bitter attributes had a higher preference among consumers. Reduced preference of *M. pulcherrima* beer might also be in relation to its significantly lower sweetness. Increased sensory complexity of beer produced by *T. delbrueckii* has also been described by Tataridis et al. [20] and could also be preferred in relation to its enhanced sweetness attributes as defined by the radar chart.

Overall, the results showed that all yeast strains were able to produce pleasant and aromatic sensory profiles with specific aroma characteristics.

Conclusion

Although the original wort was similar in all fermentation experiments, beers produced with *S. cerevisiae*, *T. delbrueckii* and *M. pulcherrima* showed notably different fermentation performances and sensory profiles. *S. cerevisiae* indicated high fermentative power and should be preferred in necessity of fast fermentation. Maltose fermentation abilities were positively identified for *M. pulcherrima* and *T. delbrueckii* yeast strains. Both strains were able to reduce apparent extract to $< 5^\circ\text{P}$ and can be applied for craft beer production, in regard to additional fermentation time. Wort fermentation by *S. cerevisiae* strains significantly increased amounts of certain higher alcohols. This resulted in more intense body attributes of beer aroma. Wort fermented with *T. delbrueckii* yeasts resulted in increased residual maltose sugar concentrations and contributed to enhanced sweetness in beer. In comparison to *S. cerevisiae* beer, the results indicated that the overall effects of selected *T. delbrueckii* and *M. pulcherrima* yeast strains are highly positive, leading to pronounced sensory specifics. Beer produced by *T. delbrueckii* was preferred over *M. pulcherrima* and can be recommended for barley-sorghum beer production.

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Compliance with ethical standards

Conflict of interest The author declares that there are no conflicts of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

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