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Chemical and sensory profile of lager beers hopped with Czech bitter varieties Boomerang and Gaia

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Abstract

Characterising the sensory profiles of beers made from new hop varieties is of considerable importance for their application in brewing. New Czech bitter varieties Boomerang and Gaia were tested in three-year pilot brews (200 l) of 12% single-hopped pale lager, produced in kettle and kettle+dry-hopped variants. The hop-derived aroma and bitterness profile of the beers was evaluated using a comprehensive descriptive method. Hop-related volatiles in beer were determined by GC/MS-MS method. Both of these bitter varieties showed a pleasant bitterness profile even in dry-hopped beers. The overall impression of the beers from the varieties tested was favourable, at the level of the control beer (Saaz). The profile of hop derived volatiles and aroma in beers from Gaia and Boomerang varieties were different. The results show the potential of Boomerang for both single kettle-hopped beers and dry-hopped lagers due to its interesting aroma profile (spicy, herbal, floral). The Gaia variety can be used in a similar way, with a preference for dry hopping to give a well-balanced hop-derived aroma profile. Both varieties have shown considerable potential for the production of new beer brands, and their drought tolerance may also help their widespread cultivation.

Keywords: hop varieties; Boomerang; Gaia; dry hopping; sensory profile of beer; hop volatiles

1 Introduction

Hops are undoubtedly a brewing raw material necessary to create or complete the sensory character of beers of all styles and the specific character of beer brands. Approximately 150 hop varieties have been bred and registered worldwide, with more being added every year (Patzak and Henychová, 2018). Hop breeding in the Czech Republic has a long tradition, and currently 28 Czech varieties are registered by the Central Institute for Supervising and Testing in Agriculture (CISTA), including the traditional Saaz (CISTA, 2024).

Breeding objectives are aimed at different uses, whether for high α-acids content, basic bittering of beer or typical hop aroma, including new varieties of "flavour hops" and, more recently, drought resistance of varieties in the context of climate change (Olšovská et al., 2023). Traditional aromatic hop varieties have maintained their place in the market, but changes in consumer preferences and the need for innovation and the development of new beer brands have led to the breeding and use of new varieties with interesting flavour and bitter profiles.

The brewing value of hops depends mainly on the content and composition of bitter acids and essential oils formed in the lupulin glands of the hop cones (*Humulus lupulus* L.). Hop resins (bitter acids) give the beer its bitterness, while volatile substances from the hop essential oil group provide aroma and flavour (Almaguer et al., 2014).

Bitterness is one of the main attributes used to assess the sensory quality of beer and it includes several aspects of bitter perception, intensity, quality (pleasantness) together with the rate of bitterness fading after drinking

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(Mikyška et al., 2015). These aspects also depend on the beer matrix (He et al., 2014). The majority of beer bitterness comes from iso-α-acids (Oladokun et al., 2015; Almaguer et al., 2014; Jaskula et al., 2009). Oxidised bitter acids, humulinones and hulupones also contribute to bitterness, especially during dry-hopping (Krofta et al., 2019; Algazzali and Shellhammer, 2016; Dušek et al., 2014; Krofta et al., 2013b), and some polyphenols also exhibit bitter or bitterness-modifying properties (Oladokun et al., 2016; Goiris et al., 2014).

The specific aroma that hops impart to beer depends on many factors. Hop volatiles, essential oils, consist of several hundred compounds, over 450 have been identified in the aroma-rich volatile fraction of hops and over 1,000 may exist (Roberts, 2004). Hop volatiles are divided into three chemical classes: hydrocarbons (about 70%), oxidised compounds (about 30%) and sulphurous compounds. The monoterpene hydrocarbon β-myrcene usually forms the largest proportion of hop volatiles, irrespective of the variety. In addition, the sesquiterpenes α-humulene, β-caryophyllene and, in some hop varieties, β-farnesene are other common main constituents of the hydrocarbon group. The group of oxidised compounds consists of a complex mixture of alcohols (linalool, geraniol), esters and ketones. Other oxidised terpenoids include acids, aldehydes and epoxides (Biendl et al., 2014). Volatiles in hops typically represent 0.5–3.0% of the weight of dried cones (Dresel et al., 2016). Overall, the aroma of hops is due to a synergistic mixture of individual compounds rather than the effect of a single compound (Dietz et al., 2020).

Most of the components of hop essential oils undergo significant changes during wort boiling. Thermal/oxidative conversion of the essential oils takes place and large losses occur. Only a few polar terpenoid compounds, such as linalool, geraniol and humulene epoxides, can partially survive this process; these compounds impart the hop flavour to the final beer (Rettberg et al., 2018; Praet et al., 2016; Fritsch and Schieberle, 2003). During the main fermentation, biotransformation of essential oil components by yeasts takes place (Takoi et al., 2017; Praet et al., 2012) and sorption of some essential oils, especially myrcene, to yeast cells occurs (Haslbeck et al., 2017). During dry hopping, essential oil components are extracted into a low alcohol beer solution and partially sorbed or modified by the yeasts present (Forster and Gahr, 2013; Praet et al., 2012).

Sensory perceptions of hop-derived volatiles in beer are commonly described as floral, citrus, fruity, spicy or herbal. Terpene alcohols such as linalool and geraniol are important components of the floral character of hop essential oils and beer. The contribution of hop essential oils is particularly pronounced in dry hopping. The typical hop flavour and aroma of kettle-hopped beers is mainly formed by oxidised sesquiterpenes (Praet et al., 2016). It is known that the aroma of raw hops is often not comparable to the hop aroma in the final beer (Dietz et al., 2021; Hanke et al., 2015; Praet et al., 2012) and therefore hop varieties are tested and compared with each other in brewing experiments (Van Simaeys et al., 2022; Vollmer et al., 2019; Hanke et al., 2015; Forster and Gahr, 2014; Kishimoto et al., 2006).

The Research Institute of Brewing and Malting (RIBM) has a long tradition of testing the brewing properties of new Czech varieties. In cooperation with breeders, mainly from the Hop Research Institute, the fine aromatic varieties Saaz Brilliant, Saaz Comfort, Saaz Shine and Saaz Special have been evaluated in the past (Mikyška et al., 2021, 2021a) and subsequently recommended by the RIBM for the production of Czech beer according to the PGI České pivo (European Committee, 2008). The first Czech flavour hop variety Kazbek (Krofta et al., 2019) and seven other new varieties of this type (Mikyška et al., 2022) or the bitter/pharmaceutical variety Vital with a high desmethylxanthohumol content were also presented (Krofta et al., 2013, 2013a). This article presents the results of three years of pilot brewing trials with the promising Czech bitter varieties of Boomerng and Gaia.

2 Materials and methods

2.1 Experimental brews

Three-year brewing trials (2 hl) of single hopped beers were carried out in the experimental brewhouse (Kaspar-Shulz, Germany) of the Research Institute of Brewing and Malting (RIBM). 12% all malt wort was produced by the double decoction method from commercial pilsner malt of the Bojos barley variety. The mash solids were separated from the sweet wort using a lauter tun, keeping the volume of the sweet wort constant.

The beers were hopped with P90 pellets of the Gaia and Boomerang varieties. One sample each was taken from the 2021 and 2023 harvests. The samples were supplied by the Hop Research Institute (HRI), and the control beer was hopped with Saaz pellets. Kettle hopping to a target bitterness of around 30 IBU was carried out in three batches, 30% at the start, 50% after 30 minutes and 20% 15 minutes before the end of the 80 minute dynamic pressure boil.

The wort was clarified in a whirlpool, cooled to a fermentation temperature of 10 °C and fermented in cylindrical-conical tanks with lager yeast strain RIBM 95 for 5 days at a maximum temperature of 12 °C. Maturation in lager tanks lasted for three weeks at a temperature of

1–2 °C. Five days before the end of the maturation period, 50 litres of beer were taken and dry-hopped using a static method with a dose of 3 g of hop pellets per 1 litre placed in a finely woven net.

The beers were filtered using a deep-bed filter plate consisting of cellulose, kieselguhr and perlite, then packaged in 500 ml glass bottles and finally pasteurised in an immersion pasteuriser. The beer was handled in a carbon dioxide atmosphere throughout the filtration and bottling process.

2.2 Analyses

Bitter acids, α- and β-acids and xanthohumol in hop pellets were analysed by liquid chromatography using the standardised isocratic EBC 7.7 method and total polyphenols by the EBC 7.14 method (EBC-Analytica, 2024). Hop volatiles were determined by GC-MS as previously described (Krofta et al., 2024). Beer analyses were carried out according to EBC methods (EBC-Analytica, 2024), using the following methods: 9.4 Original, real and apparent extract and original gravity of beer, 9.2.6 Alcohol in beer by near infrared spectroscopy, 9.35 pH of beer, 9.6 Colour of beer: spectrophotometric method, 9.8 Bitterness of beer, 9.11 Total polyphenols in beer by spectrophotometry. 7.8 Iso-α-, α- and β-acids in hops and isomerised hop extracts by HPLC were used to determine α-acids and iso-α-acids in beer. Hop-related volatiles in beer were determined by the GC-MS method previously described (Mikyška et al., 2018) with minor modifications.

A permanent panel of 12 trained RIBM evaluators assessed the beers using quantitative descriptive methods. In addition to the basic sensory profile, hop-related aroma notes (hoppy/fresh hops, citrus, floral, herbal, fruity, resinous, spicy and grassy) were rated on a scale from 0 (not perceptible) to 5 (very strong). Beer bitterness was assessed using a modified procedure of the comprehensive evaluation of beer bitterness (Mikyška et al., 2015). The intensity of bitter sensation after drinking, after 15 s (maximum) and after 40 s (lingering) was recorded on a scale from 0 (not perceptible) to 5 (very strong), and the character (pleasantness) of bitterness on a scale from 1 (fine, pleasant) to 5 (very harsh, clinging). In the subsequent session the panellists were gender balanced non-smokers between the ages of 25 and 50.

3 Results and discussion

3.1 Hop samples

The content and composition of the brewing-relevant components of hops, i.e bitter acids, essential oils and polyphenols depend primarily on the genetic basis, the hop variety (Krofta et al., 2024; Mikyška et al., 2022a; Almaguer et al., 2014). In addition, a number of studies have shown that the biosynthesis of secondary metabolites in hops is also significantly influenced by the soil, climate and weather conditions of the growing area (Krofta et al., 2024; Rutto et al., 2021; Rodolfi et al., 2019).

The composition of secondary metabolites, bitter acids, essential oils and polyphenols in hop samples for brewing trials, shown in Table 1 was consistent with the characteristics of the varieties tested (Nesvadba et al., 2022). The α-acids content of the bitter varieties Boomerang and Gaia was 10.5% and 12.2% respectively, while the control Saaz had 2.6%. The α/β-acid ratio of Boomerang and Gaia was about 1.8. The new genotypes have a significantly higher total essential oil and xanthohumol content than the aromatic varieties. β-Farnesene, a specific marker of traditional Saaz, was also present in the essential oil of both cultivars. It is worth noting that the lower proportion of cohumulone in the α-acids of Gaia (25.3%) and to a lesser extent Boomerang (28.1%) compared to Agnus (30–35%). Aromatic varieties typically have a cohumulone content of 20–25%, while bitter varieties, particularly those from the American genetic range, have a cohumulone content of 40–50%. According to some authors, higher levels of cohumulone result in a harsher, less pleasant bitterness in beer (Basařová et al., 2017), while other authors (Shellhammer et al., 2004) found no differences.

Gaia was gained from Agnus and a male plant originating from the Yeoman hop variety coming from England together with breeding materials of Czech and foreign hop varieties. Boomerang was developed by selection from hybrid descendants originating from a multiple hybridization of Agnus, Magnum and Premiant as well as semi-finished breeding materials with Saaz, Sládek, Northern Brewer and Fuggle in their origin (Nesvadba et al., 2023).

The variety of Agnus shows a very good drought tolerance, long-term stability of α-acids levels and yield per hectare (Krofta et al., 2024a). The two bitter varieties tested also have a very good stability in α-acids content based on 13 years of monitoring (Nesvadba et al., 2023).

3.2 Kettle hopped beer

The bitterness as well as the hop-derived aroma of the beer depend on the hop variety, the dosage and the distribution of hop doses during the boil. Hopping to the three doses used in these experiments ensures both the manifestation of bittering ability, sufficient α-acids isomerisation (Jaskula et al., 2009) and polyphenol extraction (Mikyška and Dušek, 2019), and the manifestation of oxidised and native (3rd hop dose) hop essential oils.

In kettle-hopped beers, oxidised fraction of essential oils, terpene alcohols in hops (Dietz et al., 2020) and other oxidation products formed during boiling are very likely involved (Praet et al., 2016), but even small amounts of terpene hydrocarbons can affect the flavour profile of beer due to synergistic effects (Dietz et al., 2020).

Table 1 *Content and composition of hop secondary metabolites in the hops*

Parameter	Unit	SAZ	BOO	GAA
α-Acids	% w	2.59 ± 0.54	10.48 ± 0.74	12.18 ± 0.43
Cohumulone	% rel.	19.5 ± 4.1	28.1 ± 1.6	25.3 ± 3.2
β-Acids	% w	3.67 ± 0.41	6.08 ± 0.19	6.48 ± 0.65
Alpha/beta ratio		0.7 ± 0.1	1.7 ± 0.1	1.9 ± 0.2
Total polyphenols	%w	5.68 ± 0.54	3.39 ± 0.70	3.16 ± 0.61
Xanthohumol	%w	0.42 ± 0.05	0.84 ± 0.22	0.89 ± 0.21
Total hop oils	%w	0.49 ± 0.28	1.86 ± 0.42	1.36 ± 0.22
Myrcene	% rel.	21.90 ± 5.50	19.70 ± 3.60	15.60 ± 0.60
Linalool	% rel.	0.22 ± 0.01	1.12 ± 0.14	0.40 ± 0.09
Geraniol	% rel.	0.24 ± 0.04	0.20 ± 0.01	0.32 ± 0.06
β-Caryophylene	% rel.	9.84 ± 0.30	12.94 ± 0.05	11.90 ± 0.50
trans-β-Farnesene	% rel.	17.74 ± 3.65	2.50 ± 0.81	6.16 ± 0.95
α-Humulene	% rel.	21.95 ± 0.35	21.10 ± 2.45	9.92 ± 5.08
Selinens	% rel.	2.81 ± 0.02	3.90 ± 2.36	17.85 ± 3.00

SAZ – Saaz; BOO – Boomerang; GAA – Gaia

The values of the basic chemical analysis of the beers (Table 2) document the balance of the brews. The original extract, attenuation, alcohol, colour and bitterness values of the experimental and control beers were not significantly different. The experimental beers had a lower content of total polyphenols than the control beers, depending on the type of variety. The control beers had, on average, a lower iso-α-acids value measured by HPLC method and a higher bitter unit value. The bitterness value can also be influenced by the oxidation products of α- and β-acids, humulinones and hulupones, and polyphenols, all substances that exhibit or modify sensory bitterness (Oladokun et al., 2016). The sensory bitterness of the experimental and control beers was not different (see Table 4).

The values of selected essential oils in beer are given in Table 3. The hop volatiles undergo many changes during the brewing process. In the course of wort boiling, these

Table 2 *Basic analytical parameters of kettle hopped and kettle+dry hopped beers*

		Kettle-hopped			Kettle+dry-hopped		
Parameter	**Unit**	**SAZ**	**BOO**	**GAA**	**SAZ**	**BOO**	**GAA**
Original Extract	% w	11.17 ± 0.2	11.07 ± 0.3	11.23 ± 0.3	11.23 ± 0.2	11.07 ± 0.3	11.27 ± 0.3
Apparent attenuation	%	73.7 ± 0.7	75.8 ± 1.0	75.1 ± 2.8	72.4 ± 1.1	75.5 ± 1.3	74.8 ± 2.9
Alcohol	% w	3.40 ± 0.1	3.47 ± 0.1	3.50 ± 0.2	3.36 ± 0.1	3.45 ± 0.1	3.50 ± 0.3
Colour	EBC	7.6 ± 0.4	7.8 ± 0.2	8.0 ± 0.6	7.9 ± 0.5	8.0 ± 0.2	8.0 ± 0.6
Total polyphenols	mg/l	210 ± 21.0	146 ± 10.0	154 ± 2.0	239 ± 13.0	157 ± 10.0	160 ± 4.0
α-Acids	mg/l	0.91 ± 0.4	1.13 ± 0.4	0.90 ± 0.6	1.86 ± 0.5	1.45 ± 0.6	1.58 ± 0.8
iso-α-Acids	mg/l	31.3 ± 2.1	34.9 ± 2.0	32.7 ± 0.9	29.4 ± 1.7	33.0 ± 1.5	30.7 ± 2.4
Bitterness	IBU	34.0 ± 2.8	31.7 ± 1.2	32.0 ± 1.4	35.7 ± 3.3	30.7 ± 3.3	34.7 ± 0.9
pH		4.64 ± 0.1	4.43 ± 0.2	4.58 ± 0.0	4.76 ± 0.1	4.48 ± 0.2	4.61 ± 0.1

SAZ – Saaz; BOO – Boomerang; GAA – Gaia compounds are exposed to strong evaporation and heavy oxidative conditions. Subsequently, flavour compounds are affected by yeast fermentation, adsorption to yeast cells, reduction, hydrolysis, esterification and biotransformation (Haslbeck et al., 2017; Takoi et al., 2014; Praet et al., 2012). Among the significant terpene hydrocarbons, differences between the tested varieties were observed for myrcene and limonene, with higher values in beers from the Gaia variety. The sensory profile of kettle-hopped beers is mainly composed of oxidised terpenes (Praet et al., 2016). Among the group of hop terpene alcohols, which are very important for the sensory profile of beer, significantly higher levels of linalool and geraniol were found in the beers from the Boomerang cultivar. Methyl geranate was higher in both tested varieties compared to the control beer.

The sensory profile of hop-derived aroma notes in beer (Figure 1) shows a significant hoppy aroma in all the beers, and differences between the varieties, with the Boomerang

Table 3 *Composition of hop volatiles in kettle hopped and kettle+dry hopped beers (µg/l)*

	Kettle-hopped			Kettle+dry-hopped			Odor	Sensory detection treshold (µg/l beer)
	SAZ	BOO	GAA	SAZ	BOO	GAA		
α-+β-Pinene	<1,00 ±	<1,00 ±	<1,00 ±	<1,00 ±	<1,00 ±	<1,00 ±	orange peel, pine, resinous, woody	2.5; 62; 140
Myrcene	22.5 ± 17.5	32.5 ± 25.5	42.2 ± 20.8	119.0 ± 94.0	351.0 ± 107.0	420.8 ± 53.0	herbal, resinous, spicy, metal	10; 30; 200; 1000
Limonene	76.5 ± 11.0	11.0 ± 3.0	55.8 ± 13.2	63.0 ± 9.1	68.4 ± 21.0	96.2 ± 25.8	citrus, orange- like	n/a
Linalool	171.9 ± 32.1	399.3 ± 33.7	201.5 ± 14.5	589.2 ± 112.8	1205.3 ± 112.3	726.1 ± 168.1	floral, fruity, citrus, rosewood, aniseed, terpenic, after roses, hoppy	0.14, 1; 8; 9; 15; 27; 80
β-Caryophylene	73.2 ± 54.8	83.5 ± 66.5	90.5 ± 74.5	57.5 ± 38.5	124.0 ± 106.0	75.0 ± 62.0	spices, woody, floral, love	16, 160; 230; 450
4-Terpineol	7.0 ± 0.5	6.0 ± 1.4	5.2 ± 2.2	10.0 ± 0.9	11.3 ± 0.2	7.0 ± 3.7		n/a
trans-β-Farnesene	14.8 ± 7.4	13.4 ± 5.6	13.6 ± 3.4	15.5 ± 7.5	16.3 ± 4.7	15.8 ± 4.2	woody, citrus, sweet	550; 2000
α-Humulene	3.7 ± 2.3	3.9 ± 3.0	3.5 ± 2.7	5.2 ± 2.8	9.0 ± 1.1	5.0 ± 1.8	balsamic	450; 747; 800
Methyl geranate	25.4 ± 3.0	91.9 ± 28.0	112.9 ± 14.0	19.9 ± 10.0	115.9 ± 34.0	231.9 ± 45.0		22
α-Terpineol	24.9 ± 4.1	36.4 ± 0.7	27.7 ± 6.0	39.4 ± 12.2	52.4 ± 1.2	42.2 ± 10.4	floral, citrus, woody, iney, terpenic	300; 1000; 2000
Geranyl acetate	13.3 ± 6.0	13.1 ± 2.0	9.2 ± 1.0	13.7 ± 2.0	13.6 ± 5.0	9.6 ± 3.0	floral, roses	9; 460
Nerol	48.4 ± 28.5	37.6 ± 18.4	18.4 ± 13.4	48.1 ± 32.6	42.9 ± 21.2	35.1 ± 3.2	floral, roses, lemon	4; 36; 500
Geraniol	172.1 ± 27.0	285.7 ± 41.0	143.2 ± 22.0	220.6 ± 48.0	502.1 ± 112.0	448.4 ± 124.0	floral, roses, lemon	4; 36; 500

SAZ – Saaz; BOO – Boomerang; GAA – Gaia

Table 4 *Descriptive sensory analysis of kettle hopped and kettle+dry hopped beers*

	Kettle-hopped			Kettle+dry-hopped		
Parameter	SAZ	BOO	GAA	SAZ	BOO	GAA
Carbonation	2.40 ± 0.08	2.87 ± 0.18	2.50 ± 0.11	2.60 ± 0.08	2.50 ± 0.15	2.50 ± 0.11
Palate-fulness	2.60 ± 0.04	2.73 ± 0.05	2.73 ± 0.05	2.80 ± 0.07	2.87 ± 0.06	2.77 ± 0.02
Bitterness	1.47 ± 0.10	1.53 ± 0.06	1.43 ± 0.09	1.67 ± 0.02	1.63 ± 0.05	1.63 ± 0.08
Bitterness – culmination	3.27 ± 0.10	3.17 ± 0.06	3.13 ± 0.08	3.23 ± 0.02	3.40 ± 0.15	3.33 ± 0.02
Bitterness-lingering	2.07 ± 0.16	2.13 ± 0.14	2.23 ± 0.23	2.07 ± 0.08	2.33 ± 0.21	2.23 ± 0.12
Bitterness-character	2.73 ± 0.12	2.50 ± 0.04	2.47 ± 0.10	2.67 ± 0.05	2.67 ± 0.06	2.50 ± 0.11
Astringent	1.33 ± 0.10	1.30 ± 0.14	1.27 ± 0.16	1.13 ± 0.06	1.23 ± 0.08	1.30 ± 0.11
Sweet	1.53 ± 0.09	1.50 ± 0.11	1.77 ± 0.15	1.67 ± 0.19	1.53 ± 0.09	1.60 ± 0.04
Sour	1.67 ± 0.06	1.80 ± 0.14	1.67 ± 0.22	1.40 ± 0.07	1.67 ± 0.06	1.53 ± 0.16
Pleasantness of hop aroma	3.20 ± 0.43	3.37 ± 0.41	3.20 ± 0.32	2.60 ± 0.32	2.87 ± 0.39	2.50 ± 0.32
Overall impression	**3.23** ± 0.22	**3.37** ± 0.19	**3.13** ± 0.27	**2.93** ± 0.21	**2.87** ± 0.33	**3.13** ± 0.14

Descriptors 0 (no perception) – 5 (very strong); Pleasantness of hop aroma 1–5 (descending scale); Overall impression 1–9 (descending scale)
SAZ – Saaz; BOO – Boomerang; GAA – Gaia

variety dominated by spicy, herbal and woody notes and the Gaia variety by herbal, floral and sweet notes. Except for fruity notes, the profile of Boomerang beers matched the aroma profile of hops (Nesvadba et al., 2023). In Gaia beers, herbal aroma was significant in addition to the basic notes detected in hops (spicy, fruity, floral). The composition of the hop-derived aroma notes of the tested varieties differed from the profile of the control beer.

The bitterness of the beers was assessed comprehensively by rating the perception of bitterness after drinking, the bitterness peak, the bitterness lingering and the bitterness character of the beers on a five-point scale from 1-very weak (mild) to 5-very strong (harsh). In terms of bitterness profile, the three-year results show no significant differences between the varieties tested (Table 4). The pleasantness of the hop aroma in the beer from the tested hops and the control beer were rated similarly on average, with slightly lower scores for the beers from the Boomerang variety. The average overall impression of the beers on a nine-point descending scale – Boomerang 3.36, Gaia 3.14 – was very good and comparable to the control beer (3.23) (Table 4).

3.3 Kettle+dry hopped beer

The resulting sensory effect of dry hopping of beers depends on a number of raw material and technological factors, hop variety, hop dose, time of hop contact with beer, hop application method (batch or continuous), technological operation (application to young beer, filtered beer) and last but not least, the type of beer and the matrix of sensory active substances derived and not derived from hops in the initial beer before dry hopping (Mikyška et al., 2024; Bandelt Riess et al., 2020; von Heynitz et al., 2020; Hauser et al.,2019; Algazzali and Shellhammer, 2016; Steenackers et al., 2015).

Addition of hop cones or pellets to beer can cause changes in the basic analytical parameters depending on the dose applied. Increases in pH, beer colour, loss of iso-α-acids by sorption to the solid hop matrix have been reported, but the bitterness value may be slightly increased by interference of extracted α-acids, oxidation products of bitter acids (humulinones and hulupones) and some hop polyphenols (Mikyška et al, 2024; Hauser et al., 2019, 2019a; Coccuza et al., 2019; Hahn et al., 2018; Algazzali and Shellhammer, 2016). The results of the chemical analysis of the dry-hopped beers from these trials (Table 2) are consistent with the above findings. Compared to the original kettle-hopped beer, there was a slight trend towards an increase in pH (0.02–0.13), total polyphenols (5–29 mg/l), α-acids (0.3–1.0 mg/l) and bitterness (2–5 IBU) on average and depending on the variety. Changes in iso-α-acid concentration were inconclusive and are generally addressed to decrease due to sorption to the solid hop matrix during dry hopping.

The sensory bitterness profile of the dry-hopped beers showed a trend towards a very slight (0.1–0.2 points) increase in bitterness culmination, lingering, a harsher bitterness character and a reduction in astringency (except for the Gaia hops) compared to the kettle-hopped beers. The sourness of all beers decreased (Table 4).

In dry-hopping, sensory effects are mainly due to essential oils extracted from hops, while hop resin derivatives and polyphenolic compounds may have a non-negligible influence on the intensity and bitterness profile (Mikyška et al., 2018; Algazzali and Shellhammer, 2016; Oladokun et al., 2016). In our study, we used batch procedure with a contact time of 5 days before the end of the lager and dosing by hop weight (3 g/l) to characterise and compare new varieties, which has proven successful in many cases for the development of specific dry-hopped beer recipes. Dosing by hop weight is common in brewing practice is consistent with the chosen objective of the experiments, characterisation and comparison of the tested varieties.

In dry hopping, unlike the significant thermal transformation and boil-off of hop volatiles, essential oil components are extracted into a slightly alcoholic beer solution and partially sorbed or altered by the yeasts present (Hauser et al., 2019; Takoi et al., 2016; Forster and Gahr 2013; Praet et al., 2012). The transfer rates of specific hop-derived volatiles depend on their octanol-water partition coefficients (log KOW), which is a measure of the hydrophobicity of the compound (Haslbeck et al., 2018).

The increase in concentration compared to kettle-hopped beers was present for all essential oil components studied (Table 3), with a very significant, multi-fold increase for the terpene hydrocarbon myrcene, probably due to the application of hops to the beer at the end of maturation with a low yeast count, as this substance is strongly sorbed by yeasts (Haslbeck et al., 2017). The differences between the tested varieties in the essential oil components discussed for kettle-hopped beers were essentially maintained.

In the profile of hop derived aroma notes strengthening of some aroma components occured, i.e. for hoppy/fresh hop, citrus, floral, fruity, grassy, depending on a hop variety, compared to kettle hopped beers (compare Figure 1, Figure 2). The dry-hopped beers from the Boomerang cultivar are dominated by spicy, herbal, floral tones, and the beers from the Gaia cultivar show a well-balanced profile (Figure 2).

Woody aroma notes correlated with linalool, α-terpineol, nerol and geraniol, grassy with myrcene, linalool, 4-terpineol, α-humulene and geraniol (Table 5).

However, the dependencies found may not be causal and generally valid due to synergistic or antagonistic relationships in the sensory perception of individual essential oil components (Dietz et al., 2021; Dietz et al., 2020; Praet et al., 2016; Schmidt and Biendl, 2016; Takoi et al.,2016). Cluster analysis of the aroma profile clearly separated the kettle and kettle+dry-hopped beers. For the kettle-hopped beers, the profile of the Boomerng variety was more consistent with the control beer, whereas for the kettle+dry hopped beers, the profile of the beers hopped with the Gaia variety was closer to the control beer (Figure 3).

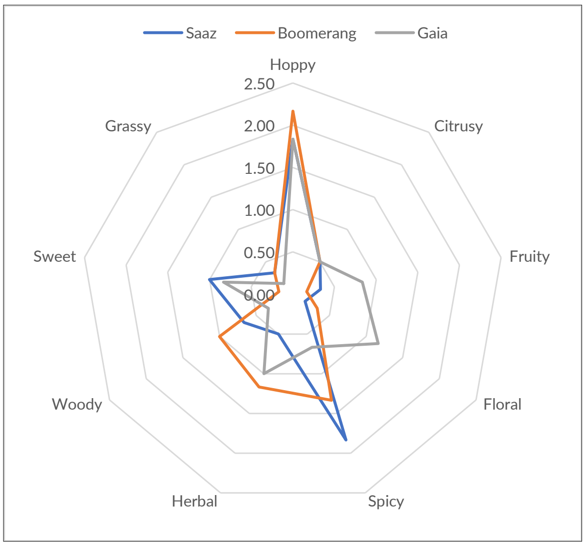

Figure 1 *Hop aroma profile in kettle-hopped beers*

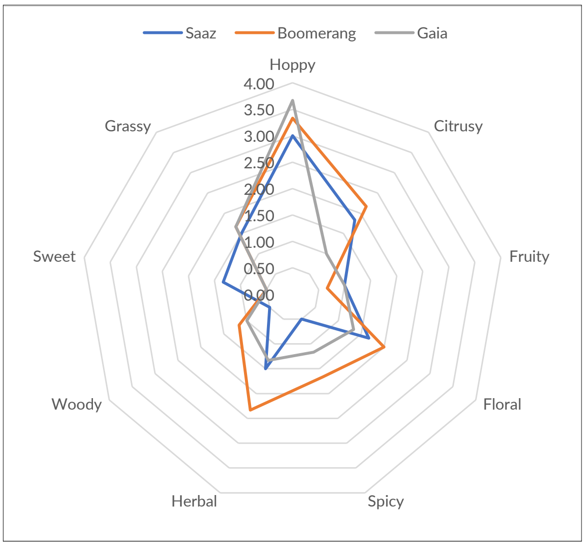

Figure 2 *Hop aroma profile in kettle+ dry-hopped beers*

Table 5 *Correlation matrix of volatiles concentration and hop-related aroma scores in final beers*

Substance	Hoppy	Citrusy	Fruity	Floral	Spicy	Herbal	Woody	Sweet	Grassy
Myrcene	0.86**	0.40	0.48	0.53	0.20	0.54	0.63	-0.37	0.76*
Limonene	0.50	0.28	0.63	0.38	0.09	0.06	-0.01	0.39	0.54
Linalool	0.86**	0.77*	0.33	0.74*	0.26	0.90**	0.75*	-0.36	0.84**
β-Caryophylene	-0.35	0.32	-0.35	-0.04	0.11	0.06	-0.21	0.48	-0.15
4-Terpineol	0.93**	0.80*	0.53	0.81*	0.13	0.83**	0.61	-0.16	0.93**
trans-β-Farnesene	0.33	0.54	0.07	0.14	0.21	0.13	0.12	0.53	0.49
α-Humulene	0.62	0.92**	0.19	0.76*	0.12	0.96**	0.54	-0.12	0.70*
Methyl geranate	0.56	-0.04	0.36	0.27	0.02	0.26	0.46	-0.60	0.36
α-Terpineol	0.75*	0.38	0.30	0.55	0.14	0.70*	0.72*	-0.66	0.61
Geranyl acetate	-0.01	0.44	-0.46	-0.05	0.38	0.25	0.28	0.15	0.14
Nerol	0.70*	0.21	0.03	0.05	0.49	0.22	0.77*	-0.38	0.61
Geraniol	0.84**	0.58	0.18	0.54	0.37	0.77*	0.88**	-0.55	0.77*

** significant at P=0.05; ** significant at P=0.01*

The concentration of most hop-related volatiles in the beers, especially in dry-hopped beers, was above the minimum sensory thresholds reported in the literature (Table 3). The intensity of hoppy aroma notes correlated with most terpene alcohols and myrcene. Citrus, floral, herbal and grassy aroma notes correlated with linalool, 4-terpineol and α-humulene, while herbal aroma notes were further influenced by α-terpineol and geraniol.

The overall hop aroma pleasantness score improved by 0.4–0.7 points after dry hopping for all beers including the control beer, and the overall impression score was more favourable except for Gaia. The evaluation of the overall impression is influenced by both the defects and the specific pleasantness of the sensory profile and is to some extent individual. The sensory evaluation has shown that the new bitter varieties can be used to produce very good quality beers, both kettle-hopped and dry-hopped.

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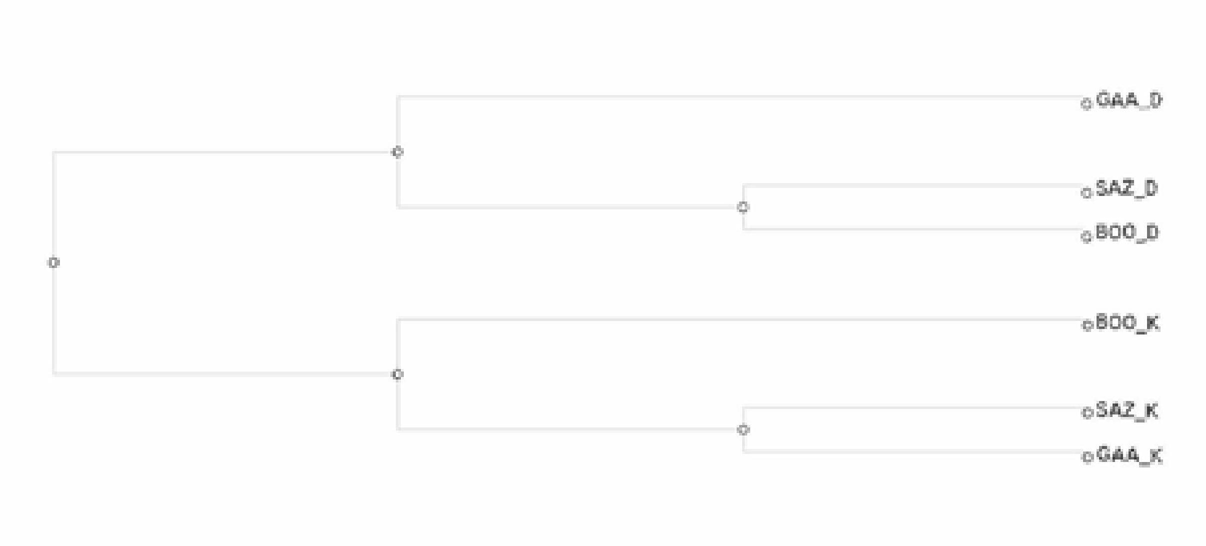

Figure 3 *Results of cluster analysis of hop-derived aroma notes*
SAZ – Saaz; BOO – Boomerang; GAA – Gaia; K – kettle hoped beer; D – kettle + dry hopped beer

4 Conclusion

A three-year pilot-scale trial has demonstrated a very good quality of single-hopped lagers brewed with the new bitter varieties such as Boomerang and Gaia, as well as the individual profile of hop-derived aroma notes that the varieties provide. Boomerang is recommended by its owner, the Hop Research Institute for the first and second hopping of lagers and dry hopping of speciality beers and ales. This work shows the potential of this variety for single variety kettle-hopped beers and also for dry-hopped lagers due to its interesting aroma profile (spicy, herbal, floral). Gaia is recommended for the first and second hopping of lagers. Based on our results, this variety can also be used for dry-hopping single hopped lagers due to a well-balanced hop-derived aroma profile. It is clear that both tested varieties can be used in the recipes of new beer brands with the potential to gain popularity with consumers. In addition, both bitter varieties have a good resistance to drought, which may contribute to their widespread cultivation.

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