Chemical and sensory profiles of beers from barley varieties registered in the Czech Republic

ALEXANDR MIKYŠKA – VRATISLAV PSOTA

Summary

Though detailed analysis of malt provides information on its suitability for processing in the brewery, unequivocal relationship between the quality characteristics of the malt and the sensory properties of the beer is not clear. Pilot brewing tests with twelve malting barley varieties registered in the Czech Republic with detailed chemical and sensory analysis were repeated for four years. The results showed some specific characteristics of the varieties and contributed to the knowledge of the relations between the quality features of the malt and the sensory quality of the Czech lager beer and, moreover, the interaction of individual basic descriptors of beer taste. The colour of beers and the polyphenols are affected by decoction mashing, the prediction of beer values from malt analysis is limited. Based on the overall sensory impression, only the best-rated beers (Laudis 550, Bojos and Francin) from the worst-rated KWS Irina variety were distinguished. The harvest year-dependent proteins in barley significantly influenced the malt and beer quality. The varieties were partially distinguished by a principal component analysis of the basic sensory descriptors, but the important factor was the harvest year.

Keywords

barley varieties; malt; beer; sensory quality

Barley varieties submitted for examination for registration in the Czech Republic as malting ones are tested by the Research Institute of Brewing and Malting (RIBM, Praha, Czech Republic) in terms of malt quality. Description of all registered varieties and their malting values are published annually in the Barley Yearbook [1]. Test results of new varieties are published in cooperation of RIBM and Central Institute for Supervising and Testing in Agriculture of the Czech Republic (CISTA, Brno, Czech Republic) [2]. Although detailed malt analysis provides information on characteristics regarding their applicability in beer brewing and on the possibility of reaching a certain level of quality parameters of beer, there is no clear relationship between the quality features of malt and the final quality of beer, in particular its sensory properties. This is generally accepted and, recently, nano-scale brewing tests provided clear evidence that barley genotype as well as its cultivation site significantly contribute to many sensory descriptors. However, the authors of this study state that larger volumes of beer are needed to evaluate these traits [3].

When comparing the established varieties and evaluating the promising varieties, it is therefore appropriate to add brewing trials to the malting tests. The commercial success of the malting barley variety depends on its acceptance by the breweries in replacing the current varieties with a new variety while maintaining the quality standards of the brewery or for improving the sensory characteristics of the beer. Brewing trials of new varieties on a pilot scale make it possible to detect merits or shortcomings in brewing properties of the varieties in advance of operational deployment and to compare the new raw material with established varieties. This step in the chain breeders – malthouses – breweries that provides timely information on brewing properties of new varieties can save time and resources.

In 2014 (harvest 2013), RIBM launched pi-

Alexandr Mikyška, Research Institute of Brewing and Malting, Lípová 15, 12000 Praha 2, Czech Republic.
Vratislav Psota, Research Institute of Brewing and Malting, Mostecká 7, 61400 Brno, Czech Republic.

Correspondence author:
Alexandr Mikyška, e-mail: mikyska@beerresearch.cz

lot brewing trials with varieties registered in the Czech Republic. This article summarizes the results of pilot malting and brewing trials of twelve barley varieties that were tested during at least three years, to take into account the effect of the harvest year.

MATERIALS AND METHODS

Malt

Grains of spring malting barley varieties Blaník, Bojos, Francin, Kangoo, KWS Irina, Laudis 550, Malz, Petrus, Sebastian, Sunshine, Vendela and Xanadu were obtained annually (harvests 2013 to 2016) from experimental stations of CISTA. Malts were prepared in a laboratory malting device (KWM Uničov, Czech Republic) according to the methodology of Mitteleuropäische Brautechnische Analysenkommission (MEBAK) [4] (1.5.3 Micromalting) in the following conditions: 72 h steeping at 14 °C with CO_2 exhaustion, steeping periods on 1st day 5 h, on 2nd day 4 h and on 3rd day 3 h. Germination time was 72 h at 14 °C. Predrying 12 h at 55 °C, kilning 4 h at 80 °C.

Brewing trials

Fifty liter batches of brews of 11% pale lager beer were brewed in an experimental brewery (Pacovské strojírny, Pacov, Czech Republic). A single decoction mashing procedure was used. The brews were lautered to the constant malt extract in the wort. The lautering rate was measured as the average wort flow rate over the entire operation, lautering and sparging.

Hopping (hop CO_2 extract and Saaz hop pellets 1 : 1) was in three doses, 30 % at the beginning, 50 % after 30 min, and 20 % of hops 10 min before the end of the 80 min wort boiling. The hot break was separated in a whirlpool.

Fermentation was in cylindrical conical tanks (CCT) using lager yeasts, strain RIBM95. Fermentation started at 10 °C, the maximum temperature was 12 °C ± 0.1 °C. The beer was chilled to 5–6 °C and transferred to "lager" CCT. The maturation took three weeks at 1–2 °C. The beer was filtered through a plate filter, bottled and pasteurized.

Malt and beer analysis

The malts were analysed according to the European Brewery Convention (EBC) Analysis Committee methodology [5], using the following methods: 4.3.1 Total nitrogen of malt: Kjeldahl method; 4.5.1 Extract of malt: Congress mash; 4.7.2 Colour of malt: Visual method; 4.9.1 Soluble nitrogen of malt: Kjeldahl method; 4.10 Free amino nitrogen of malt by spectrophotometry; 4.11.1 Fermentability, final attenuation of laboratory wort from malt; 4.12 Diastatic power of malt; 4.15 Friability, glassy corns and unmodified grains of malt by friabilimeter; 4.16.2 High molecular weight β-glucan content of malt: Fluorometric method; 8.12.9 Total polyphenols in beer by spectrophotometry.

Further, methodology of MEBAK [4] was used, with the methods 3.1.4.2.7 Malt: pH and 3.1.4.11 Mashing method according to Hartong-Kretschmer RE 45 °C (relative extract at 45 °C). Arabinoxylans were determined by Douglas method [6].

Wort and beer analyses were carried out according to EBC methodology [5], using the following methods: 8.3 Wort extract; 9.35 pH; 9.6 Colour; 9.7 Final attenuation; 9.2.1 Original extract of beer; 8.12.9 Total polyphenols; 9.10 Free amino nitrogen; 9.8 Bitterness.

Foam stability was determined by the MEBAK 2.18.2 method [7], using NIBEM Foam Stability Tester (Haffmans, Venlo, the Netherlands) that measures the time during which the foam drops by 30 mm (expressed as seconds per millimetre).

Sensory analysis was carried out using the EBC method 13.10 Sensory analysis (description analysis) [5] by a RIBM panel of trained assessors. Basic descriptors, namely, carbonation, palate fullness, bitterness, astringency, sourness and sweetness (ascending scale 0–5; imperceptible – very strong) were taken into the account. Overall impression, the general assessment of the sample, considering the appropriateness of the all attributes present, including off-flavours, their intensities and the unidentifiable background flavour, were accessed in a descending scale 1–9 (excellent – inappropriate).

The variability of experimental data was represented by standard deviation. The data were processed by two-factor analysis of variance (ANOVA) and by the principal component analysis (PCA).

RESULTS AND DISCUSSION

Malts

Results of the malt analyses showed both differences between the varieties in the particular parameters and the influence of the harvest year (Tab. 1).

The malt extract ranged from 81.9 % (Vendela) to 85.3 % (Malz). The fermentability of laboratory worts, ranged from Bojos and Francin (79.3 %) to Vendela (83.3 %). The 2015 harvest exhibited a trend towards a higher attenuation degree

Tab. 1. Results of malt analysis.

	Harvest	Blaník	Bojos	Francin	Kangoo	KWS Irina	Laudis 550	Malz	Petrus	Sebastian	Sunshine	Vendela	Xanadu	*R*	*SD*
Extract in dry matter [%]	2013	84.0	84.1	81.9	82.6		83.5	85.6	82.4	83.4	83.3	81.5	82.2	83.1	1.1
	2014	83.2	83.6	81.5	82.7	82.1	82.8	84.6	82.8	83.6	83.4	82.6	84.3	83.1	0.8
	2015	83.2	83.5	82.5	83.3	82.0	83.4	85.3	83.7	84.0	83.4	81.5	81.5	83.1	1.0
	2016		84.7	82.1	81.8	82.9	83.0	85.7	84.9	81.5	83.1	81.9	83.3	83.2	1.3
Limit attenuation [%]	2013	81.5	79.0	79.0	82.2		80.9	81.2	81.1	81.4	83.5	82.7	78.8	81.0	1.5
	2014	80.7	78.6	79.0	83.0	81.4	80.6	80.4	80.9	82.6	82.3	82.4	81.5	81.1	1.3
	2015	80.2	81.1	81.0	83.0	82.8	82.7	82.5	83.1	82.6	83.9	83.7	81.1	82.3	1.1
	2016		80.3	79.2	82.1	81.7	79.4	81.7	81.8	80.3	82.6	84.3	82.1	81.4	1.4
Diastatic power	2013	394	386	350	470		312	329	388	318	383	399	345	370	44
	2014	364	301	379	412	358	310	306	373	339	366	392	327	352	34
	2015	214	298	325	454	274	286	278	423	404	446	279	382	339	76
	2016		312	380	482	332	285	304	419	425	473	436	422	388	66
Kolbach index [%]	2013	40.3	37.8	42.3	46.2		38.7	42.5	38.6	38.6	45.9	43.6	41.3	41.4	2.8
	2014	39.5	41.5	44.3	42.2	38.0	39.9	42.8	40.1	43.2	51.1	46.0	42.8	42.6	3.3
	2015	37.9	48.1	46.3	46.1	45.8	49.5	51.3	49.2	44.6	47.5	47.5	39.9	46.1	3.7
	2016		49.2	43.8	45.6	44.9	47.8	52.9	48.6	41.9	50.1	53.5	47.5	47.8	3.4
Relative extract 45 °C [%]	2013	37.6	31.6	40.4	42.2		34.2	35.6	34.4	36.1	39.0	36.7	43.3	37.4	3.4
	2014	35.0	36.2	39.9	37.9	40.4	35.3	40.9	36.4	38.8	48.8	37.3	42.8	39.1	3.7
	2015	31.5	41.5	43.9	43.3	42.0	42.6	42.4	41.6	41.9	45.3	37.8	42.7	41.4	3.4
	2016		42.9	38.5	43.4	39.3	41.0	44.9	43.9	37.0	44.6	43.5	51.5	42.8	3.7
Nitrogen compounds [%]	2013	10.5	11.3	11.2	10.8		10.7	10.3	10.7	9.4	10.3	10.2	11.7	10.6	0.6
	2014	9.7	10.1	11.1	10.0	11.8	10.4	10.2	9.9	8.9	10.4	9.9	9.8	10.2	0.7
	2015	9.7	9.3	10.0	10.0	9.3	9.4	9.1	9.6	9.2	9.9	8.1	10.7	9.5	0.6
	2016		9.7	10.0	11.1	9.4	10.1	9.4	9.8	10.1	10.3	8.2	10.6	9.9	0.7
Soluble nitrogen [$mg \cdot l^{-1}$]	2013	674	684	755	799		661	701	661	578	755	708	772	704	60
	2014	686	748	882	760	798	737	776	712	685	960	818	749	776	77
	2015	651	802	826	825	766	833	836	842	729	846	691	763	784	62
	2016		856	782	913	756	863	887	847	757	920	788	905	843	59
Free amino nitrogen [$mg \cdot l^{-1}$]	2013														
	2014	144	159	178	137	155	158	163	147	149	182	168	151	158	13
	2015	138	193	167	185	162	201	124	160	145	177	161	156	164	22
	2016		172	139	200	155	170	182	167	134	178	168	186	168	19
Colour	2013	2.5	2.2	2.7	2.8		2.4	2.2	2.9	2.7	2.6	2.6	3.2	2.6	0.3
	2014	3.5	2.7	3.3	3.3	3.0	2.7	2.6	3.5	2.9	3.8	3.4	3.4	3.2	0.4
	2015	2.7	2.7	2.8	2.8	3.1	2.8	2.8	2.9	2.7	2.7	3.1	3.2	2.9	0.2
	2016		2.8	2.7	3.9	3.5	2.7	3.2	2.7	2.8	3.2	3.2	3.2	3.1	0.4
pH	2013	5.89	6.00	5.90	5.96		5.99	5.97	5.93	5.99	5.98	5.95	5.93	5.95	0.04
	2014	5.97	6.00	5.92	6.04	6.00	6.03	5.97	6.00	6.01	5.94	6.02	6.03	5.99	0.04
	2015	5.98	5.95	5.94	6.01	6.00	5.98	5.93	5.93	6.01	5.99	6.02	6.03	5.98	0.03
	2016		5.90	5.94	5.97	6.03	5.89	5.91	5.97	5.99	5.99	5.98	5.97	5.96	0.04

Tab. 1. *continued*

	Harvest	Blanik	Bojos	Francin	Kangoo	KWS Irina	Laudis 550	Malz	Petrus	Sebastian	Sunshine	Vendela	Xanadu	*R*	*SD*
Friability [%]	2013	86.1	90.1	81.8	92.6		93.0	91.3	84.8	87.1	96.4	94.9	68.1	87.8	7.6
	2014	81.4	85.1	86.0	87.4	74.3	84.1	88.8	86.6	86.2	94.0	94.8	81.3	85.8	5.3
	2015	82.6	91.8	83.3	89.0	94.2	94.9	95.5	90.8	86.0	97.3	98.2	85.4	90.8	5.2
	2016		93.7	90.1	90.0	87.9	95.8	99.4	87.6	76.2	98.3	99.2	88.9	91.6	6.5
β-Glucans [mg·l-1]	2013	231	127	204	123		129	192	195	266	40	49	210	161	69
	2014	431	242	103	173	392	243	259	254	186	62	61	232	220	110
	2015	504	118	220	182	121	85	125	102	325	32	79	190	174	124
	2016		126	156	126	322	119	125	237	366	81	77	205	176	91
Arabinoxylans [mg·l-1]	2013														
	2014	634	651	726	1030	534	670	621	741	706	750	792	688	712	116
	2015	582	541	643	793	481	593	899	708	514	699	670	508	636	120
	2016		894	831	798	700	855	1190	966	798	416	811	691	814	181
Total polyphenols [mg·l-1]	2013	52.8	51.3	53.7	70.5		51.9	59.0	70.3	82.2	68.6	78.9	52.6	62.9	11.0
	2014	71.0	56.0	69.0	64.0	62.0	61.0	63.0	75.0	71.0	68.0	73.0	56.0	65.8	6.1
	2015	69.0	61.3	62.9	60.5	85.9	70.7	86.8	81.4	70.1	84.1	77.9	59.2	72.5	9.9
	2016		83.0	76.0	61.0	65.0	73.0	80.0	83.0	77.0	51.0	64.0	53.0	69.6	11.0

Diastatic power is expressed in Windisch-Kolbach units as the amount of maltose released from starch by malt enzymes under the conditions of the method [5]. Colour is expressed in EBC units according to Analytica-EBC methodology as the wort absorbance value at a wavelength of 430 nm multiplied by 25 [5]. *R* – average, *SD* – standard deviation.

(82.3 %) compared to the other three harvests (81.0–81.4 %).

The average diastatic power of all malts was 362 Windisch-Kolbach units (WK; the amount of maltose released from starch by malt enzymes under the conditions of the method) and showed a considerable varietal dependence. All malts were above the minimum required for Czech lagers (220 WK).

The level of nitrogen compounds in malts harvested in 2013 (10.6 %) and 2014 (10.2 %) was higher than in 2015 (9.5 %) and 2016 (9.9 %), while the soluble nitrogen and proteolytic modification increased, the Kolbach index in first two years (41.4 % and 42.6 %) was lower than in 2015 and 2016 (46.1 % and 47.8 %). The level of nitrogen compounds significantly affects most other technological properties of malt [8], which was reflected in this experiment.

The free amino nitrogen (FAN) concentration of the wort ranged between 141 mg·l^{-1} and 179 mg·l^{-1}. Low FAN concentrations (below 160 mg·l^{-1}) were determined in Bojos, Malz, Petrus, KWS Irina and Sebastian.

Degradation of starch endosperm cell walls given by friability (average 89.0 %) was higher in 2015 and 2016 harvests and it was variety-dependent. The prescribed minimum for malts for Czech lagers is 75 %. Similar to friability, the concentration of β-glucan in the laboratory wort (average 183 mg·l^{-1}) was variety-dependent. The β-glucan concentration in the wort was dependent on friability ($r = -0.741$).

The pH values of the laboratory worts were in a narrow range of 5.93 to 6.01. The colour was in the 2013 and 2015 harvests (2.6 and 2.9 EBC units; wort absorbance value at a wavelength of 430 nm multiplied by 25) lower than in the 2014 and 2016 harvests (3.2 and 3.1 EBC), Bojos and Malz tended to lower values.

The total polyphenols concentration in worts ranged from 55.2 mg·l^{-1} (Xanadu) to 77.4 mg·l^{-1} (Petrus).

Brewing trials

The results of brewing trials are discussed in the context of basic quality criteria with regard to the production of Czech (Pilsner) pale lager beers. The values should be: colour of 8–16 EBC, the difference between apparent and limit attenuation from 1.0 % to 9.0 %, bitterness from 20 to 45 bitter units (BU; represents a concentration of *iso*-alpha bitter acids in beer [5]), pH 4.1–4.8 and total polyphenols concentration from 130 mg·l^{-1} to 230 mg·l^{-1}.

Wort lautering

The speed of first wort lautering and sparging represents a monitored technological parameter of the malt processability in the brewhouse. The average flow rate, throughout the entire operation, of Malz, Blaník, Laudis 550, Petrus and Sunshine brews was below the set average (Fig. 1), significant was the difference between the worst (Blaník, Malz) and the best varieties (KWS Irina). The lautering rate level for 2013 malts was significantly lower than for malts from other three years. The malts from 2013 had the lowest proteolytic modification.

Negative effects on lautering are attributed to non-starch polysaccharides, β-glucans and arabinoxylans, and also to substances of a protein nature [9–11]. The lautering rate correlated with Kolbach index and soluble nitrogen of malt (r = 0.333 and r = 0.498, respectively). In this study, the lautering rate had no conclusive link to non-starch polysaccharides, although some malts had a β-glucan concentration well above the limit of 200 mg·l^{-1} [12]. However, the β-glucan concentration varies during the brewing process according to malt processing technology, so the correlation between malt and beer is small [13]. The low mash-in temperature and decoction mashing reduce the β-glucan concentration in the wort [14, 15].

Our results indicated a lower lautering rate of Blaník (high β-glucan) and Malz, by 20% lower than that of the best-flowing Francin and Sebastian varieties.

Physico-chemical profiles

The results of the analysis of sweet worts, hopped worts and beers are summarized in Tab. 2–4.

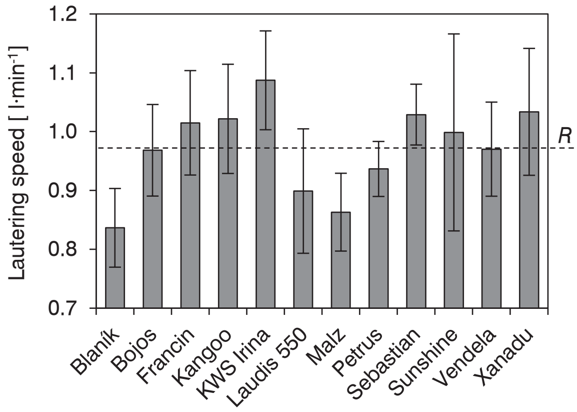

Fig. 1. Speed of lautering of experimental worts.

R – average.

Colour

Colour is one of the basic sensory attributes of beer. Its value is a part of the the beer's style and of the given beer brand. Colour of malts Bojos, Malz and Sebastian was below the average value for the entire set of malts (2.94 EBC). The colour of the decoction wort corresponded only partially to the malt colour (r = 0.617, n = 46). Thus, especially for Blaník and, to a lesser extent, for Petrus, Francin and Sebastian, the colour value of the decoction wort was lower than those of malt and lower than the average of the whole set (6.07 EBC; Fig. 2). Colour substances in sweet and hopped wort are formed by thermal action, oxidation of polyphenols, Maillard reaction (reaction of amino acids and reducing sugars) and caramelization [15]. The reaction rate increases with temperature. Due to mash boiling and longer mashing time, decoction worts have a higher colour value com-

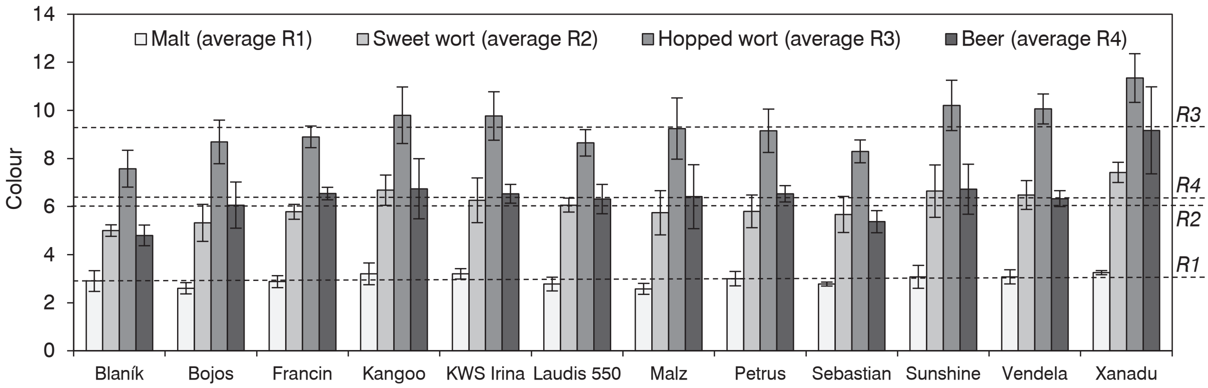

Fig. 2. Comparison of colour of malt, sweet wort, hopped wort and beer.

Tab. 2. Results of experimental sweet wort analysis.

	Harvest	Blaník	Bojos	Francin	Kangoo	KWS Irina	Laudis 550	Malz	Petrus	Sebastian	Sunshine	Vendela	Xanadu	*R*	*SD*
Colour	2013	5.3	4.0	5.3	6.0		5.9	4.2	5.6	4.9	5.4	6.3	7.2	5.5	0.9
	2014	5.0	5.8	6.1	7.2	5.1	6.5	6.2	4.9	6.8	8.1	5.6	7.4	6.2	1.0
	2015	4.7	5.6	5.7	6.1	6.3	6.1	5.9	6.8	5.1	5.8	7.2	8.1	6.1	0.9
	2016		5.9	6.0	7.4	7.4	5.7	6.6	5.9	5.9	7.2	6.8	7.0	6.5	0.6
pH	2013	5.76	5.81	5.74	5.75		5.90	5.78	5.73	5.78	5.81	5.78	5.73	5.78	0.05
	2014	5.91	5.80	5.75	5.80	5.58	5.90	5.75	5.82	5.86	5.93	5.57	6.02	5.81	0.13
	2015	5.68	5.60	5.50	5.94	5.99	5.72	5.79	5.75	5.92	5.91	5.73	6.31	5.82	0.20
	2016		5.98	6.11	6.04	6.12	6.04	5.89	5.93	6.02	5.98	6.02	5.94	6.01	0.07
Total polyphenols [mg·l-1]	2013	138	157	165	195		153	168	179	212	195	203	172	176	22
	2014	150	166	178	141	146	185	196	180	193	205	195	197	178	21
	2015	148	182	186	178	246	179	205	219	207	225	235	178	199	27
	2016		176	171	176	216	162	229	206	172	183	245	189	193	26
Free amino nitrogen [mg·l-1]	2013	164	170	247	214		187	180	227	156	200	242	208	200	30
	2014	190	194	218	197	210	249	201	179	145	254	237	202	206	29
	2015	151	209	189	198	195	213	203	216	180	219	201	214	199	18
	2016		232	191	262	186	225	251	225	195	246	214	237	224	24

Colour is expressed in EBC units according to Analytica-EBC methodology as the wort absorbance value at a wavelength of 430 nm multiplied by 25 [5]. *R* – average, *SD* – standard deviation.

Tab. 3. Results of experimental hopped wort analysis.

	Harvest	Blaník	Bojos	Francin	Kangoo	KWS Irina	Laudis 550	Malz	Petrus	Sebastian	Sunshine	Vendela	Xanadu	*R*	*SD*
Colour	2013	8.3	7.5	8.7	9.5		8.3	7.6	9.0	7.6	9.1	9.8	11.1	8.8	1.1
	2014	8.0	8.7	8.8	8.3	8.4	8.0	9.3	7.9	8.4	11.2	9.2	10.4	8.9	1.0
	2015	6.5	8.5	8.5	9.7	10.1	9.3	8.9	10.4	8.2	9.2	10.2	13.0	9.4	1.5
	2016		10.0	9.7	11.6	10.8	9.1	11.1	9.3	9.0	11.3	11.0	10.9	10.3	0.9
pH	2013	5.61	5.65	5.56	5.63		5.79	5.65	5.57	5.63	5.69	5.64	5.60	5.64	0.06
	2014	5.77	5.69	5.63	5.65	5.58	5.81	5.66	5.68	5.76	5.76	5.47	5.76	5.69	0.09
	2015	5.54	5.47	5.37	5.83	5.84	5.56	5.67	5.62	5.75	5.76	5.59	6.17	5.68	0.20
	2016		5.8	5.9	5.9	5.9	5.9	5.8	5.8	5.9	5.8	5.9	5.8	5.8	0.1
Total polyphenols [mg·l-1]	2013	213	222	271	278		248	283	255	307	281	294	270	266	28
	2014	237	221	233	232	253	235	265	260	253	245	225	249	242	13
	2015	189	226	245	243	293	239	277	275	279	275	304	225	256	32
	2016		247	225	235	279	218	290	265	227	244	308	249	253	28

Tab. 3. *continued*

	Harvest	Blaník	Bojos	Francin	Kangoo	KWS Irina	Laudis 550	Malz	Petrus	Sebastian	Sunshine	Vendela	Xanadu	*R*	*SD*
Free amino nitrogen [mg·l^{-1}]	2013	180	172	234	215		178	180	205	162	191	241	207	197	25
	2014	178	209	214	196	203	160	203	186	152	265	237	211	201	30
	2015	154	216	195	207	206	224	213	229	185	226	209	222	207	20
	2016		243	196	264	187	230	256	229	199	249	220	241	229	24
Limit attenuation [%]	2013	81.9	78.1	80.9	84.3		81.6	81.9	79.7	82.6	81.7	83.0	77.1	81.2	2.0
	2014	82.6	79.2	77.2	79.2	75.7	82.8	78.5	76.2	79.5	86.0	80.8	86.4	80.3	3.4
	2015	82.5	86.0	84.4	86.3	86.8	85.1	86.9	85.8	85.9	88.9	90.5	87.1	86.4	1.9
	2016		82.3	82.4	85.2	85.4	86.4	89.4	85.9	85.7	87.5	91.8	87.1	86.3	2.6

Colour is expressed in EBC units according to Analytica-EBC methodology as the wort absorbance value at a wavelength of 430 nm multiplied by 25 [5]. *R* – average, *SD* – standard deviation.

Tab. 4. Results of the chemical analysis of experimental beers.

	Harvest	Blaník	Bojos	Francin	Kangoo	KWS Irina	Laudis 550	Malz	Petrus	Sebastian	Sunshine	Vendela	Xanadu	*R*	*SD*
Colour	2013	4.8	4.6	6.5	6.3		5.3	4.7	6.6	4.7	5.5	6.t1	7.3	5.7	0.9
	2014	5.3	6.4	6.8	5.5	6.7	7.0	6.8	6.0	5.6	7.2	6.1	9.3	6.5	1.0
	2015	4.3	6.1	6.1	6.4	6.0	6.4	5.9	6.9	5.4	6.0	6.2	12.1	6.5	1.8
	2016		7.2	6.8	8.8	6.9	6.5	8.3	6.6	5.9	8.2	6.9	8.0	7.3	0.9
pH	2013	4.55	4.55	4.42	4.44		4.56	4.46	4.47	4.48	4.53	4.48	4.60	4.50	0.05
	2014	4.45	4.66	4.59	4.42	4.40	4.34	4.33	4.27	4.41	4.49	4.35	4.53	4.44	0.11
	2015	4.24	4.28	4.51	4.51	4.58	4.26	4.26	4.31	4.43	4.55	4.24	4.85	4.42	0.18
	2016		4.50	4.63	4.77	4.57	4.63	4.52	4.57	4.39	4.58	4.55	4.52	4.57	0.09
Total polyphenols [mg·l^{-1}]	2013	163	165	214	219		182	190	211	223	219	235	210	203	23
	2014	173	139	187	143	185	159	183	188	173	178	185	142	170	18
	2015	148	167	173	168	197	155	172	203	184	181	217	167	178	19
	2016		177	165	184	172	162	209	154	176	197	224	202	184	21
Foam stability [s·mm^{-1}]	2013	9.50	8.90	9.87	8.57		9.30	9.17	9.70	8.77	8.87	8.10	8.80	9.05	0.50
	2014	9.47	9.17	9.90	8.33	8.93	10.97	8.93	9.30	9.33	9.70	8.13	9.73	9.33	0.71
	2015	9.30	8.60	9.23	9.47	8.20	8.80	8.13	7.87	9.67	10.07	7.97	10.00	8.94	0.76
	2016		7.87	8.30	7.23	7.83	7.13	7.47	8.20	6.93	7.13	6.77	7.33	7.47	0.49
Apparent attenuation [%]	2013	70.9	74.5	67.9	75.7		73.5	72.4	70.0	74.8	73.6	78.6	68.9	72.8	3.0
	2014	81.3	79.3	76.0	79.1	77.6	78.1	76.9	76.9	75.9	82.7	83.0	80.6	79.0	2.4
	2015	76.2	78.9	75.7	81.5	80.4	86.5	85.0	84.5	76.9	82.0	89.3	80.3	81.4	4.1
	2016		83.8	80.7	82.0	79.6	82.4	85.6	82.8	79.9	81.5	84.0	81.9	82.2	1.7

Colour is expressed in EBC units according to Analytica-EBC methodology as the wort absorbance value at a wavelength of 430 nm multiplied by 25 [5]. *R* – average, *SD* – standard deviation.

Tab. 5. Results of the sensory evaluation of experimental beers.

	Harvest	Blaník	Bojos	Francin	Kangoo	KWS Irina	Laudis 550	Malz	Petrus	Sebastian	Sunshine	Vendela	Xanadu	*R*	*SD*
Carbonation	2013	2.8	2.8	3.0	2.9		2.6	2.6	3.0	2.6	2.3	2.9	2.6	2.7	0.2
	2014	1.8	2.3	2.4	2.3	2.4	2.5	2.6	2.4	2.5	2.3	2.5	2.4	2.4	0.2
	2015	2.7	2.6	2.5	2.1	2.5	2.4	2.3	2.3	1.3	1.5	2.4	1.7	2.2	0.4
	2016		1.9	2.0	2.2	1.9	2.1	1.8	2.5	1.5	1.7	2.1	2.1	2.0	0.2
	R	2.4	2.4	2.5	2.4	2.3	2.4	2.3	2.6	2.0	2.0	2.5	2.2		
	SD	0.5	0.3	0.4	0.3	0.3	0.2	0.3	0.3	0.6	0.4	0.3	0.3		
Palate fullness	2013	2.5	2.7	2.4	2.8		2.1	2.5	2.4	2.5	2.8	2.8	2.8	2.6	0.2
	2014	2.5	2.1	2.1	2.0	2.3	2.6	2.0	1.9	2.4	2.2	2.3	2.1	2.2	0.2
	2015	1.7	1.9	1.9	2.7	2.0	2.3	1.9	1.9	2.2	2.4	2.1	2.2	2.1	0.3
	2016		2.3	2.4	2.5	2.7	2.5	2.1	2.5	2.4	2.6	2.4	2.0	2.4	0.2
	R	2.3	2.2	2.2	2.5	2.3	2.4	2.1	2.2	2.4	2.5	2.4	2.3		
	SD	0.4	0.3	0.2	0.3	0.3	0.2	0.2	0.3	0.1	0.2	0.3	0.3		
Bitterness	2013	2.7	2.6	2.7	2.4		2.4	2.5	2.8	2.6	2.5	2.5	2.8	2.6	0.1
	2014	2.0	2.1	2.1	2.3	2.1	2.6	1.9	2.0	2.3	2.6	2.4	2.5	2.2	0.2
	2015	1.7	1.7	2.0	1.8	2.0	1.8	1.8	1.7	1.2	1.6	1.7	2.0	1.8	0.2
	2016		1.9	1.7	2.3	2.1	1.9	1.8	1.9	2.1	2.2	1.7	1.9	2.0	0.2
	R	2.2	2.1	2.1	2.2	2.1	2.2	2.0	2.1	2.0	2.2	2.1	2.3		
	SD	0.4	0.3	0.3	0.3	0.0	0.3	0.3	0.4	0.5	0.4	0.4	0.4		
Astringency	2013	1.2	1.1	1.3	1.0		1.0	1.1	0.8	1.3	1.3	1.0	1.5	1.1	0.2
	2014	1.4	1.3	1.4	1.1	2.1	1.7	1.3	2.2	1.6	1.7	1.7	1.2	1.6	0.3
	2015	1.2	0.9	1.1	1.4	1.5	1.5	1.2	1.2	1.3	1.5	1.2	1.4	1.3	0.2
	2016		1.3	1.5	1.4	1.4	1.4	1.4	1.6	1.4	1.3	1.4	1.3	1.4	0.1
	R	1.2	1.2	1.3	1.2	1.7	1.4	1.2	1.5	1.4	1.4	1.3	1.4		
	SD	0.1	0.2	0.2	0.2	0.3	0.3	0.1	0.5	0.1	0.2	0.2	0.1		
Sourness	2013	1.2	1.6	1.6	1.6		1.0	1.6	1.6	1.8	1.3	2.1	1.2	1.5	0.3
	2014	1.4	1.9	1.9	1.5	1.7	2.0	2.1	1.9	1.3	2.0	1.9	1.7	1.8	0.2
	2015	2.1	1.9	1.8	2.2	2.2	1.8	1.9	1.8	2.0	1.6	2.2	1.9	2.0	0.2
	2016		1.9	1.8	1.6	1.7	1.8	2.0	1.9	1.5	1.6	1.9	1.4	1.7	0.2
	R	1.6	1.8	1.8	1.7	1.9	1.7	1.9	1.8	1.7	1.6	2.0	1.6		
	SD	0.4	0.1	0.1	0.3	0.2	0.4	0.2	0.1	0.3	0.3	0.1	0.3		

Tab. 5. *continued*

	Harvest	Blaník	Bojos	Francin	Kangoo	KWS Irina	Laudis 550	Malz	Petrus	Sebastian	Sunshine	Vendela	Xanadu	*R*	*SD*
Sweetness	2013	1.7	1.6	1.9	1.6		1.4	1.4	1.3	2.3	2.6	1.9	2.0	1.8	0.4
	2014	1.9	1.9	1.6	1.8	1.9	1.4	1.6	1.8	2.3	1.8	1.7	2.1	1.8	0.2
	2015	1.5	1.4	1.4	2.2	2.2	1.5	1.7	1.4	2.1	2.0	1.4	2.0	1.7	0.3
	2016		1.3	1.4	1.6	1.8	1.4	1.2	1.6	1.8	2.1	1.3	1.5	1.5	0.2
	R	1.7	1.6	1.6	1.8	2.0	1.4	1.5	1.5	2.1	2.1	1.6	1.9		
	SD	0.2	0.2	0.2	0.2	0.2	0.0	0.2	0.2	0.2	0.3	0.2	0.2		
Overall impression	2013	4.1	3.9	3.9	4.2		4.0	3.4	4.4	4.9	4.6	4.3	3.6	4.1	0.4
	2014	4.8	5.0	4.8	4.7	5.8	4.7	5.6	5.4	5.8	5.6	5.3	5.2	5.2	0.4
	2015	5.1	4.6	4.5	5.0	5.1	4.6	4.4	4.2	5.0	4.1	4.8	5.6	4.8	0.4
	2016		4.4	4.6	4.5	4.9	3.9	4.6	4.1	3.6	3.7	4.7	4.7	4.3	0.4
	R	4.7	4.5	4.5	4.6	5.3	4.3	4.5	4.5	4.8	4.5	4.8	4.8		
	SD	0.4	0.4	0.3	0.3	0.4	0.4	0.8	0.5	0.8	0.7	0.4	0.8		

Descriptors: ascending scale 0–5 (0 – none, 5 – very strong). Overall impression: descending scale 1–9 (1 – excellent, 9 – inappropriate). *R* – average, *SD* – standard deviation.

pared to infusion worts. The colour value of the decoction wort correlated with FAN in the wort ($r = 0.454$, $n = 46$) and with the soluble nitrogen in malt ($r = 0.390$) at a $P = 0.01$.

During wort boiling, the colour value increases due to both the heat load and the reactions of hop substances [15]. The average colour value of hopped wort was 9.31 EBC. The differences in the sweet worts were maintained in the hopped wort, the colour values of the sweet and hopped worts strongly correlated ($r = 0.811$). During fermentation and maturation of beer, the colour value decreased, changes were proportional to the wort colour (wort/beer: $r = 0.836$) and the average beer colour (6.24 EBC) was close to the decoction sweet wort colour. The colour values of sweet worts correlated with the colour values of beers ($r = 0.726$). The relationship between malt and beer ($r = 0.445$) was significantly weaker. The colour prediction of the beer produced by decoction mashing based on malt colour is thus inaccurate. The colour values of beers ranged from 4.8 EBC to 9.6 EBC, the lowest were Blaník (4.8 EBC) and Sebastian (5.4 EBC), markedly higher was Kangoo (9.6 EBC; Fig. 2, Tab. 5). It is obvious that for barley varieties lower in malt modification, lower beer colour values can be expected.

The colour of beer depends, in addition to malt, on the technical and technological conditions of its processing in the brewing process. Lower heat load and lower oxygen exposure at mashing and wort boiling reduce the resulting beer colour.

pH

The pH value of malt and beer is relevant in several respects. The activity of saccharolytic and proteolytic enzymes in mashing is significantly affected by pH of the malt. Usual pH of laboratory wort from Pilsner malt is 5.6–6.0. For starch conversion, the optimum pH value of mash is 5.3. The decrease in pH during fermentation and maturation of beer promotes clarification and natural colloidal beer stability. Protein-polyphenol complexes have an isoelectric point, and thus the lowest solubility, in the acidic pH range. The pH value of the beer itself also participates in organoleptic sensation. The Czech pale lagers have a slightly higher pH than similar foreign beers [16].

The laboratory worts had largely balanced pH values. Decoction worts showed a trend towards lower values for Blaník, Bojos, Francin, Malz, Petrus and Vendela in comparison with other varieties (Fig. 3). The relationship between pH of malts and decoction worts or beers was inconclusive. Values of sweet worts and hopped worts

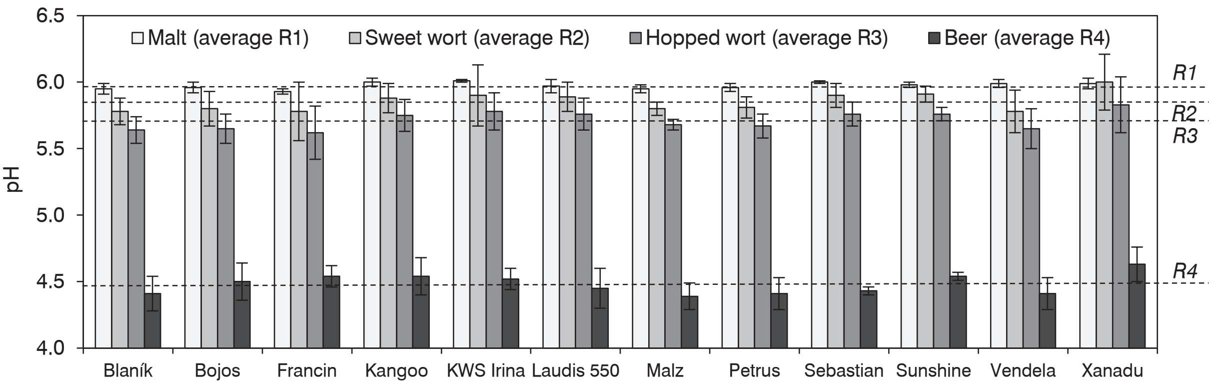

Fig. 3. Comparison of pH value of malt, sweet wort, hopped wort and beer.

strongly correlated (r = 0.970), while the relationship between hopped wort and beer was less pronounced (r = 0.606). The colour of the beers slightly but conclusively correlated with pH of the beers (r = 0.492; P = 0.01). The colour is partly composed of oxidized polyphenolic compounds [15] with a transition between colourless and coloured form being dependent on the ambient pH.

Total polyphenols

High total polyphenols are one of the characteristics of Czech lager. The average concentration of total polyphenols in the malt sample set was 67.8 mg·l^{-1} (Fig. 4). Bojos, Blanik, Laudis 550, Francin, Kangoo and Xanadu were below this average. Polyphenols in barley grains and malt are bound in cell structures along with polysaccharides and proteins. They are located in the cell walls of both the endosperm, especially in the aleurone layer and the malt grain shells, i.e. in the pericarp, testa and lemma, which contain mainly flavonoid substances the carrier of which is the hordein protein [17]. Thus, their concentration in the wort depends on the intensity of mashing and the sparging of spent grains.

Concentration of total polyphenols in malt correlated with proteolytic and cytolytic modification, Kolbach index and friability (r = 0.377, r = 0.356; P = 0.05). For decoction wort, this relation was closer (r = 0.532, r = 0.431, P = 0.01). Total polyphenols in laboratory and decoction sweet worts correlated (r = 0.519).

The concentration of total polyphenols increased between sweet wort and hopped wort by about 25 % (from 188 mg·l^{-1} to 254 mg·l^{-1}). During fermentation and maturation, it dropped to the concentration close to that of the sweet wort (beer average 182 mg·l^{-1}) as a result of the precipitation of the tannin-protein complexes in

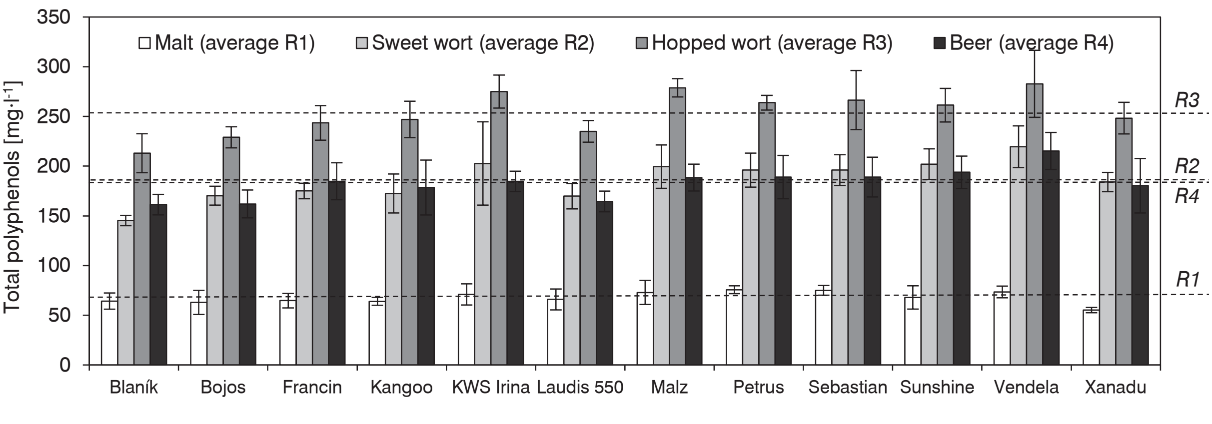

Fig. 4. Comparison of total polyphenols concentration for malt, sweet wort, hopped wort and beer.

beer. The relationship between sweet wort and hopped wort (r = 0.747) and hopped wort and beer (r = 0.735) were strong whereas the relationship between the extremes, malt and beer, was weak (r = 0.210). However, polyphenols in malt affect their quantity in beer and there was a significant difference in the total polyphenol concentration in beer between the groups Blaník, Bojos and Laudis 550 (160–165 mg·l^{-1}), and between the groups Vendela and Sunshine (195 mg·l^{-1} and 215 mg·l^{-1}). The generally accepted fact is that two thirds of polyphenols in beer come from malt [18, 19]. However, their content in hop products varies widely (0–60 g·kg^{-1}) [20] and, therefore, the level of polyphenols in beer will also depend on the hopping.

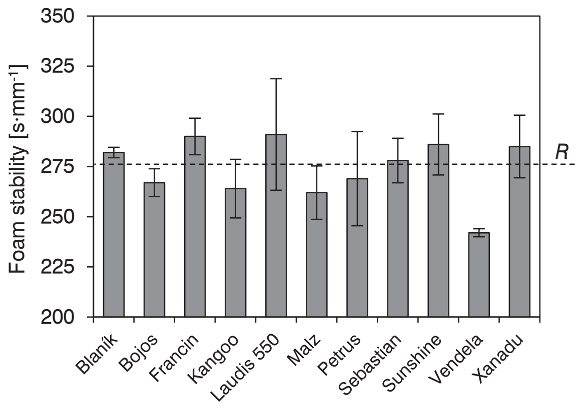

Fig. 5. Comparison of foam stability values of beers.

R – average.

Foam stability

Foaming ability and foam stability are among the key attributes of lager beers. It is generally known that proteins and glycoproteins are foaming agents, while bitter hop substances are foam stabilizers. Surface tension and hence foam stability is reduced by lipids, fatty acids, higher alcohols and esters. The stability of the foam is thus a result of factors with favourable and negative effects, i.e. substances contained in beer [21–25].

The foam stability was in the range of 8.00–11.00 s·mm^{-1} (Fig. 5). Hence, all beers under study were in the category of well-foaming beers (7.33–8.33 s·mm^{-1}) [7]). In varietal averages, all beers, except of Vendela, were excellent foaming beers (above 8.33 s·mm^{-1}). The results for Vendela were significantly lower than those of Francin, Sebastian, Sunshine and Xanadu. Foam stability correlated inversely with proteolytic modification, Kolbach index (r = –0.570). In the harvests of 2015 and 2016, a number of barleys tended to high proteolytically modified malts, which was reflected by the foam stability being lower in these years.

Sensory profiles

In this study, the sensory quality of beers was evaluated mainly from the perspective of barley varieties. The varietal averages given below related to the variety's results over the entire four-harvest period under review. The overall sensory impression score in the whole set of 34 beers ranged from 3.6 to 5.8 points of a nine-point scale (1 – best, 9 – worst; Tab. 5) The average quality in individual years was different, the year 2014 differing from the following years (2013 – 4.1; 2014 – 5.2; 2015 – 4.7; 2016 – 4.3 points). Varietal averages ranged from 4.3 (Laudis 550) to 5.3 (KWS Irina). Bojos, Francin, Laudis 550, Malz and Sunshine tended to better results, distinguished being only top-rated beers (Laudis 550, Bojos and Francin) from the worst-rated KWS Irina.

The overall impression consists of the complex effect and balance of the partial components of the aroma and taste, the basic descriptors are carbonation, palate fullness, bitterness, sweetness and sourness. Moreover, the overall impression includes a critical appraisal of off-flavours. The carbonation of beers was fairly balanced in the varietal averages (Tab. 5). Beer carbonation is caused by dissolved carbon dioxide, perceived by tactile receptors activated by the presence of bubbles in the liquid, and also by pain receptors, reacting to the conversion of carbon dioxide to carbonic acid. It can be influenced by pH and colloidal substances in beer [26]. Surprisingly, carbonation did not correlate with carbon dioxide concentration, while the relationship with pH was significant (r = –0.455).

The palate fullness is a marker of Czech pale beers, in particular lagers. Varietal averages did not differ and ranged from 2.1 to 2.5 points on a 0–5 scale (Tab. 5). Francin, Malz and Petrus tended to lower values. The palate fullness correlated with pH (r = 0.505) and sensory bitterness of beers (r = 0.380), thus a synergic effect of malt and hops was likely. Factors influencing the sensory perception of the palate fullness of beer are not fully elucidated. It is generally believed that a higher wort extract and a lower attenuation, i.e. a higher viscosity and unfermented extract, dextrins, sugars and proteins in beer have a beneficial effect [18]. A significant role is attributed to proteins with a molecular weight greater than 10 kDa [27].

The astringency of beers was low, varietal averages ranging from 1.1 (Bojos, Malz, Kangoo) to 1.7 (KWS Irina; scale 0–5; Tab. 5, Fig. 6). The

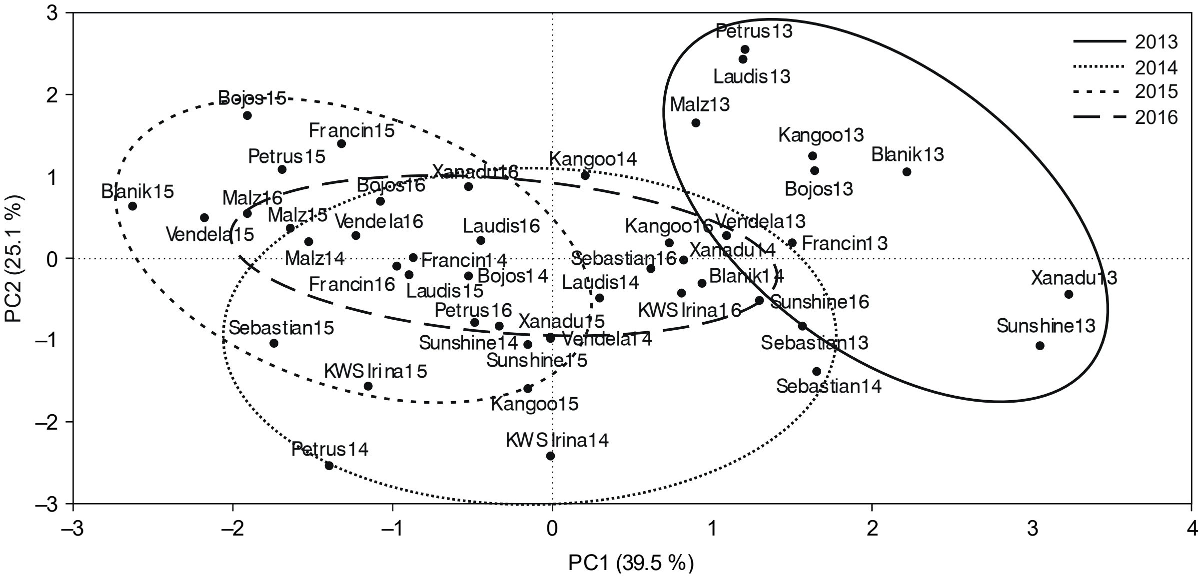

Fig. 6. Principal component analysis of basic sensory descriptors of beers (carbonation, palate-fullness, bitterness, sweetness, sourness).

astringency inversely correlated only with the difference between apparent and limit attenuation (r = –0.417). Higher concentration of unfermented extract could probably reduce the astringency, which is attributed to certain polyphenol substances from malt [28, 29], hops [19] and the alkaloids hordatins derived from malt [30].

The beers sweetness of varieties ranged from 1.5 (Laudis 550, Petrus) to 2.25 (Sebastian, Sushine; scale 0–5). The beers of Laudis 550, Malz and Petrus exhibit a lower sweetness compared to Sebastian, Sunshine, KWS Irina and Xanadu (Tab. 5). The sweetness correlated weakly with palate fullness (r = 0.360) and the carbon dioxide (r = –0.487), carbonation being able to suppress the sweet sensation.

The sourness of beers ranged from 1.6 (Blaník, Laudis 550, Sebastian, Sunshine and Xanadu) to 2.0 points (Vendela; Tab. 5). The perception of sour taste, caused mainly by simple organic acids, depends largely on the overall habitat of beer.

The results of PCA (Fig. 6) show a partial distribution of the varieties but, at the same time, the impact of the harvest year is noticeable, in particular the results of 2013 being different from those of the next three years and this difference formed a considerable part of the variability of the data. The results reflected the fact that only extreme varieties were distinguished in the overall impression.

CONCLUSIONS

The study showed some specific characteristics of barley varieties and contributed to the knowledge on the relations between the qualitative markers of malt and the chemical and sensory profile of lager beer. An important factor is decoction mashing as prediction of beer colour and total polyphenols based on malt analysis is limited. This study shows the significant impact of the harvest year on the quality of the malt prepared by the unified malting process. The analytical profile, saccharolytic, proteolytic and cytolytic modification, and consequent values of soluble nitrogen, limit attenuation, colour and pH, were found to be influenced by the harvest year. This was also reflected by the analytical and sensory profile of beer. In the 2013 to 2016 harvests, there were different weather conditions during vegetation and harvesting [31, 32]. In 2013, despite unfavourable course of the cultivation period, spring barley achieved favourable protein content and favourable average starch content. Harvests 2015 and 2016 were performed under unfavourable weather conditions with frequent showers and storms, which caused barley grains to contain more nitrogenous substances [33]. The overall sensory impression of beers depended on the harvest year. Even so, statistical analysis facilitated partial discrimination of varieties, in particular the top-rated from the worst-rated. In order to reveal the varietal specificity, a long-term evaluation of the varieties in the brewing tests is necessary.

Acknowledgements

This study was supported by the Ministry of Education, Youth and Sports of the Czech Republic, project LO1312. Authors thank Pavel Čejka for PCA of experimental data.

REFERENCES

1. Psota, V. – Dvořáčková, O. – Sachambula, L. – Nečas, M. – Musilová, M.: Barley and malt. In: Psota, V. (Ed.): Barley year book 2018. Praha : Výzkumný ústav pivovarský a sladařský, 2018. ISBN: 978-80-86576-79-4.
2. Psota, V. – Dvořáčková, O. – Nečas, M. – Musilová, M.: Barley varieties registered in the Czech Republic after harvest 2017. Kvasny Průmysl, *64*, 2018, pp. 102–110. DOI: 10.18832/kp201817.
3. Herb, D. – Filichkin, T. – Fisk, S. – Helgerson, L. – Hayes, P. – Meints, B. – Jennings, R. – Monsour, R. – Tynan, S. – Vinkemeier, K. – Romagosa, I. – Moscou, M. – Carey, D. – Thiel, R. – Cistue, L. – Martens, C. – Thomas, W.: Effects of barley (*Hordeum vulgare* L.) variety and growing environment on beer flavor. Journal of American Society of Brewing Chemists, *75*, 2017, pp. 345–353. DOI: 10.1094/ASBCJ-2017-4860-01.
4. Raw materials : Collection of brewing analysis methods of the Mitteleuropäische Brautechnische Analysenkommission (MEBAK). Nürnberg : Fachverlag Hans Carl, 2018. ISBN: 978-3-9815960-3-8.
5. Analytica-EBC. Nürnberg : Fachverlag Hans Carl, 2010. ISBN: 978-3-418-00759-5.
6. Douglas, S. G.: A rapid method for the determination of pentosans in wheat flour. Food Chemistry, *7*, 1981, pp. 139–145. DOI: 10.1016/0308-8146(81)90059-5.
7. Wort, beer, beer-based beverages : Collection of brewing analysis methods of the Mitteleuropäische Brautechnische Analysenkommission (MEBAK). Nürnberg : Fachverlag Hans Carl, 2013. ISBN: 978-3-9805814-7-9.
8. Schildbach, R.: Studies of nitrogen content and nitrogen composition of barley, malt and beer. Brewer's Digest, *52*, 1977, pp. 42–49. ISSN: 0006-971X.
9. Jin, Y. L. – Speers, R. A. – Paulson A. T. – Stewart, R. J.: Effects of β-glucans, shearing, and environmental factors on wort filtration performance. Journal of American Society of Brewing Chemists, *62*, 2004, pp. 155–162. DOI: 10.1094/ASBCJ-62-0155.
10. Ford, M. – Evans, E.: The barley and malt factors underlying lautering performance identification and use in barley breeding programs. In: Proceedings of the 28th EBC Congress, Budapest 2001. Nürnberg : Fachverlag Hans Carl, 2001, pp. 111–120. ISBN: 90-70143-21-6.
11. Benismail, N. – Saulmier, L. – Boivin, P. – Allosio-Quarnier, N.: Arabinoxylans and arabinoxylanases from barley to beer. In: Proceedings of the 29th EBC Congress, Dublin 2003. Nürnberg : Fachverlag Hans Carl, 2003, pp. 192–196. ISBN: 90-70143-22-4.
12. Prokeš, J.: Slad. (Malt.) In: Kosař, K. – Procházka, S. (Eds.): Technologie výroby sladu a piva. (Technology of malt and beer production.) Praha : Výzkumný ústav pivovarský a sladařský, 2000. ISBN: 80-902658-6-3. In Czech.
13. Edney, M. J. – La Berge, D. E. – Langrell, D. E.: Relationships among the β-glucan contents of barley, malt, malt congress extract, and beer. Journal of American Society of Brewing Chemists, *56*, 1998, pp. 167–168. DOI: 10.1094/ASBCJ-56-0164.
14. Sacher, B. – Becker, T. – Narziss, L.: Some reflections on mashing - Part 2. Brauwelt International, *34*, 2016, pp. 392–397. ISSN: 0934-9340.
15. Basařová, G. – Šavel, J. – Basař, P. – Lejsek, K.: Pivovarství. Teorie a praxe výroby piva. (Brewing. Theory and practice of beer production.) Praha : Vysoká škola chemicko technologická v Praze, 2010. ISBN: 978-80-7080-734-7. In Czech.
16. Olšovská, J. – Čejka, P. – Sigler, K. – Hönigová, V.: The phenomenon of Czech beer: a review. Czech Journal of Food Sciences, *32*, 2014, pp. 309–319. DOI: 10.17221/455/2013-CJFS.
17. Siebert, K. J.: Haze formation in beverages. LWT - Food Science and Technology, *39*, 2006, pp. 987–994. DOI: 10.1016/j.lwt.2006.02.012.
18. Taylor, B. – Organ, G.: Sensory evaluation. In: Esslinger, H. M. (Ed.): Handbook of brewing: processes, technology, markets. Weinheim : Wiley-VCH, 2009, pp. 675–701. ISBN: 978-3-527-31674-8. DOI: 10.1002/9783527623488.ch29.
19. Almaguer, C. – Schönberger, C. – Gastl, M. – Arendt, E. K. – Becker, T.: *Humulus lupulus* – a story that begs to be told. A review. Journal of the Institute of Brewing, *120*, 2014, pp. 289–314. DOI: 10.1002/jib.160.
20. Mikyška, A. – Vrzal, T. – Dušek, M. – Jurková, M.: Factors affecting the polyphenol compounds and antiradical activity of hops: Long-term study of Czech hop varieties. Kvasny Průmysl, *64*, 2018, pp. 323–330. DOI: 10.18832/kp201839.
21. Šavel, J. – Brož, A.: Měření pěnivosti piva. (Measurement of beer foaming power.) Kvasny Průmysl, *52*, 2006, pp. 314–318. DOI: 10.18832/kp2006026. In Czech.
22. Lusk, L. T. – Goldstein, H. – Ryder, D.: Independent role of beer proteins, melanoidins, and polysaccharides in foam formation. Journal of American Society of Brewing Chemists, *53*, 1995, pp. 93–103. DOI: 10.1094/ASBCJ-53-0093.
23. Kobayashi, N. – Segawa, S. – Umemoto, S. – Kuroda, H. – Kaneda, H. – Mitani, Y. – Watari, J. – Takashio, M.: A new method for evaluating foam-damaging effect by free fatty acids. Journal of American Society of Brewing Chemists, *60*, 2002, pp. 37–41. DOI: 10.1094/ASBCJ-60-0037.
24. Segawa, S. – Yamashita, S. – Mitani, Y. – Takashio, M.: Analysis of detrimental effect on head retention by low-molecular surface-active substances using surface excess. Journal of American Society of Brewing Chemists, *60*, 2002, pp. 31–36. DOI: 10.1094/ASBCJ-60-0031.

25. He, G.-Q. – Wang, Z.-Y. – Liu, Z.-S. – Chen, Q.-H. – Ruan ,H. – Schwarz, P. B.: Relationship of proteinase activity, foam proteins, and head retention in unpasteurized beer. Journal of American Society of Brewing Chemists, *64*, 2006, pp. 33–38. DOI: 10.1094/ASBCJ-64-0033.
26. Clark, R. A. – Hewson, L. – Bealin-Kelly, F. – Hort, J.: The interactions of CO_2, ethanol, hop acids and sweetener on flavour perception in a model beer. Chemosensory Perception, *4*, 2011, pp. 42–54. DOI: 10.1007/s12078-011-9087-3.
27. Langstaff, S. A. – Lewis, M. J.: The mouthfeel of beer – a review. Journal of the Institute of Brewing, *99*, 1993, pp. 31–37. DOI: 10.1002/j.2050-0416.1993.tb01143.x.
28. Narziss, L.: Comments of some taste factors in beer. Brauwelt International, *10*, 1992, pp. 4–11. ISSN: 0934-9340.
29. Narziss, L.: Beer taste and how it is influenced by raw materials and technological factors. Brauwelt International, *16*, 1998, pp. 14–46. ISSN: 0934-9340.
30. Kageyama, N. – Inui, T. – Fukami, H. – Komura, H.: Elucidation of chemical structures of the components responsible to beer aftertaste. Journal of American Society of Brewing Chemists, *69*, 2011, pp. 255–259. DOI: 10.1094/ASBCJ-2011-0901-01.
31. Territorial precipitation. In: Czech hydrometeorological Institute [online]. Praha : Český hydrometeorologický ústav, sine dato [cit. 15 September 2019]. <http://portal.chmi.cz/historicka-data/pocasi/uzemni-srazky?l=en>
32. Territorial air temperature. In: Czech hydrometeorological Institute [online]. Praha : Český hydrometeorologický ústav, sine dato [cit. 10 September 2019]. <http://portal.chmi.cz/historicka-data/pocasi/uzemni-teploty?l=en>
33. Hartman, I.: Malting barley grain quality in the Czech Republic, crop 2016. Kvasny Průmysl, *63*, 2017, pp. 64–69. DOI: 10.18832/kp201709.

Received 21 May 2019; 1st revised 25 September 2019; accepted 11 October 2019; published online 18 November 2019.