THE IMPACT OF USED DIFFERENT COLORED RAW MATERIALS ON COLOUR OF PRODUCED BEER

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Abstract
The aim of this article is to analyse the impact of the colour of the main raw materials used for beer production on the colour of brewed beer. The colour of beer is an important user standard whereby the consumer evaluates the beverage first, before the smell and taste are applied. The process of beer brewing using two mash process was provided in the experimental brewery in the Department University of Life Sciences Prague (the beer brand "Suchdolsky Jenik"). Laboratory trials were focused on the study of influence of the colour of malt, hops and brewer's yeast. These raw materials were tested by spectrophotometric measurements according to the colours CIELAB system by the Spectrophotometer CM-600d Konica Minoltaand Spectrophotometer HACH Lange DR 500. The effect of four different types of malts and malt grist (Pilsner Malt, Munich Malt, Caramel Malt and Colouring Malt), Saazer Variety of hops on colour of produced beer was analysed.

Key words: *brewhouse; hops; malt; spectrophotometer; yeast.*

INTRODUCTION
The beer is very old cultural drink, our knowledge of beer production fades into the dim an distant past. This time is probably linked to the settling of the hunter-gatherers and the beginning of grain cultivation, around 12 000 years ago. Colour of beer is an integral and important part of its degustation. When beer is poured into a clear glass, the colour is the first thing the prospective beer drinker will notice. Colour invariably conjures up expectations, usually subliminal, of the flavour experience ahead. A bright golden beer may lead one to expect refreshment and to recall sunny days spent in beer gardens, whereas a reddish–black beer with a thick brown head may evoke expectations of malty roasted flavours and thoughts of sitting in front of a roaring fireplace. Because colour works so powerfully upon the mind, chefs, winemakers, and brewers alike will pay very close attention to achieving the right hues for their creations. It is ironic, therefore, that colour can be an unreliable indicator of flavour. This is because colour exists more in the mind than in reality; technically, colour is the mere reflection or refraction of light as it strikes an object, solid, liquid, or gaseous. Our eyes register the wavelengths of light they receive, and the brain translates these into the colours we see. In beer, colour is determined in various ways. The most significant source of beer colour is pigments in the grain. The malt used in the brewhouse is kilned; the longer the drying process and the higher the drying temperature, the darker will be the grist for the mash and the more opaque will be the beer made from it. In very simple way the measurement of beer colour will be done visually by colour comparison with standardised colour discs (*Kunze, 2010*). Samples and colour discs are adjusted in a comparator until the same colour is obtained. In the case of dark beer measurement is often necessary to dilute it by liquid with known dilution factor (K). This method can be influenced by different factors (*Basařová et al., 2010*): type of lighting, angel of observation, the thickness of the liquid layer, haze of the liquid, design of the apparatus, optic properties of coloured glass. The Lovibond "52" system for the measurement of colour in beer was invented in 1893 by Joseph W. Lovibond in Greenwich, England. It involved the visual comparison of standardized colours, in the form of coloured glass discs, with samples of beer. This was superseded in 1950 when L.R. Bishop proposed the use of a revised set of slides. Bishop's revised system was adopted as the EBC standard in 1951 and the standard slides were manufactured by Tintometer Co, UK, as they are to this day. On the Lovibond scale, a pale golden lager might have a colour of 2˚ or 3˚, a pale ale 10˚–13˚, a brown ale or dark lager 17˚–20˚, all the way through to the near black of imperial stout at 70˚.

SRM

The Standard Reference Method (SRM) is a unit for measuring beer colour in the US. The European Brewery Convention (EBC) is a similar unit used in Europe. Finding SRM is a laboratory procedure based on measuring the light that passes through a small sample of beer. The beer to be tested is put into a 1 centimetre square cuvette made of glass. Deep blue light (430 nm) is shown through the cuvette. The entering light has a known intensity and the intensity of the exiting light can be measured. SRM is proportional to the physics quantity called Absorption = (Intensity in / Intensity out). Darker coloured beers appear dark because they absorb a larger proportion of the light passing through them. They also have a higher SRM due to higher absorption. The palest beers have an SRM around 1 or 2. Beers that appear totally black have SRM values of 40 or higher, but all beers with SRM greater than about 40 will look very similar.

SRM = 12.7 x D x A_430, where D is a dilution coefficient equal to volume sample / volume beer, equal to one for an undiluted sample and equal to two for a sample diluted 1:1 with water. A_430 is the absorption through the cuvette at 430 nm. The multiplier 12.7 was chosen to make SRM values similar to Lovibond values. The two scales are very similar for pale coloured beers, but diverge substantially for darker coloured beers. Our visual experience is based on light at many wavelengths, but SRM data is only produced from one wavelength. Therefore, SRM cannot fully describe apparent colour, but it does a reasonable job of describing most beers with one number. Variations between red-tinted and yellow-tinted browns in the middle of the scale are a particularly noticeable weakness of the SRM method.

European Brewery Convention

European Brewery Convention (EBC) is an organisation representing European breweries. EBC is also the name for a method of measuring beer colour codified by this organization. The EBC colour value is measured in a way that is essentially the same the way SRM is measured. The two values are exact multiples of each other. EBC = 1.97 x SRM. Both are based on absorption of 430 nm light through a sample of beer in cuvette 1 x 1 cm.

The number of EBC units will be calculated by EBC = 25 x D x A(430), where D is a dilution coefficient equal to volume sample / volume beer, equal to one for an undiluted sample and equal to two for a sample diluted 1:1 with water. A_430 is the absorption through the cuvette at 430 nm. SRM differs only by using a multiplier of 12.7 instead of 25. An earlier version of the EBC scale was based on light with a wavelength of 530 nm. EBC shares the simplicity and limitations of SRM.

Normal beer colour colours are following (*Olšovská et al., 2017*): Pilsner beer 5.0-12.0 EBC, Pale full gravity beers 7.0-15.0 EBC, Dark full gravity beers 30.0-40.0 EBC, Export pale beers 7.0-15.0 EBC, Export dark beers 45.0-100.0 EBC, Märzen, pale type 9.0-15.0 EBC, Bock beer, pale type 8.0-15.0 EBC. Malt Colour Units (MCU) is an easy way for brewers to calculate the amount of colour expected in a given recipe. This is especially useful for recipes that you are making for the first time. Unfortunately, the relationship between the calculated value MCU and directly measured values of colour (visual inspection, SRM, and EBC) is not straightforward. There are many formulas that attempt to provide a conversion between MCU and SRM. The issue of beer colour in some scientific articles is also addressed. Mostly traditional brewing methods are using official European Brewery Convection (EBC) analysis, e.g. Benard, 2000; Seaton & Cantrell, 1993. The problems of beer colour is also given some attention in some scientific articles. Smedley, 1995 uses CIELAB's colour space to demonstrate how the beer colour differences can be used commercially.

MATERIALS AND METHODS

The laboratory measurements were carried out at the Faculty of Engineering CULS Prague. The process of beer production using two mash process was provided in the experimental small scale brewery in the Department of Technological Equipment of Buildings of Faculty of Engineering at the Czech University of Life Sciences Prague (the beer brand "Suchdolsky Jenik").

Some research were focused on the experimental brewery construction and beer production (*Chládek, 2007; Chládek et al., 2013*). This microbrewery (founded 2006) is equipped with brewhouse, which consists of two stainless steel (SS) vessels. One is a wort kettle with agitator blade, heated by steam (temperature 130°C, pressure 0,3 MPa), second one is lauter tun, with raking and cutting unit, equipped with SS false bottom. The volume of one brew is 10 hl (1,000 litres), two mash process was used. The wort is clarified in whirlpool, cooled down in two section heat exchanger using tap water and glycol, aerated pitched by the yeast W96, fermented and aged in cylindroconical vessels (20 hl) cooled down by circulation of glycol, than without any filtration or pasteurisation beer is filled in glass bottles 0,5 l and kegs 30 l and 50 l and sold in University Shop. Supplier of floor Pilsner malt is Brewery Ferdinand located in town Benešov, variety of hops is Saaz, supplied by Hops Institute in the town Saaz, partly from University Hops Garden, belonging to the University Brewery. The yeast No W96 was supplied by the Laboratory propagation station of the brewery Krušovice (Member of Heineken Group). Both brewery and hops Garden were under supervision operated by students. For each brew (10 hl water) were used 200 kg of malt, 3 kg of hops and 10 litters of aerated yeast W96. For darker colour of brewed beer was per brew of any kind of beer added 4 kg of Colouring malt grist. The effect of four different types of malts and malt grist (Pilsner Malt, Bavarian malt, Caramel malt and Colouring malt), Saazer Variety of hops on colour of produced beer was analysed. Laboratory trials were focused on the study of influence of the colour of malt, hops and brewer's yeast. These ingredients were tested by spectrophotometric measurements according to the colours CIELAB system by the Spectrophotometer CM-600d Konica Minolta. The colour attributes L* value (lightness), redness (a* values) and yellowness (b* values) were measured five times of each sample, first in its original intact state and subsequently also after milling in the hammer mill. The colours attributes of hops and brewer's yeast were measured as well. The average values of all measured results were calculated. The colours of tested malt and produced beer were compared with the official European Brewery Convection (EBC) scale used for the beer evaluation and found good agreement. For the measurement using method of EBC was used spectrophotometer HACH Lange DR 5000 wavelengths range 190 – 1,100 nm.

The method of evaluation of the test sieving data

This method is described by Chládek et al. (2018). The data obtained from the sieve analysis is relatively difficult to evaluate in a reproducible way. Therefore, a graphical interpretation of the data is often used as it helps in more easily imagining the analytical form of the function (which describes the granulometric composition of the sample). From the analytical form of the function, it is possible to obtain the essential characteristics of the bulk materials. There are important characteristics such as, 'the coefficient of polydispersity' and the mean statistical size of the particle $\bar{x}$ which determines the precision of milling.

RESULTS AND DISCUSSION

Main results from measuring are shown in the Table 1.

Tab. 1 Colour range coordinates (L*, a* and b* mean values with SD) of tested hops, brewer's yeast, malts, malts grist and EBC values of produced beer

Raw material	Parameter			
	L* ± SD	a*± SD	b* ± SD	EBC units
Hops	47.67 ± 0.57	1.64 ± 0.13	13.34 ± 0.27	-
Brewer's yeast	65.63 ± 0.04	5.40 ± 0.02	21.43 ± 0.14	-
Colouring malt	39.68 ± 0.23	3.23 ± 0.10	3.84 ± 0.17	-
Col. malt grist	41.29 ± 0.51	3.69 ± 0.09	4.68 ± 0.14	-
Pilsner malt	59.99 ± 0.24	4.64 ± 0.09	17.83 ± 0.11	-
Pilsner malt grist	75.50 ± 1.11	2.27 ± 0.25	11.48 ± 0.76	-
Pilsner malt beer	-	-	-	5.9
Munich malt	59.81 ± 0.93	3.47 ± 0.14	12.17 ± 0.04	-
Munich malt grist	69.97 ± 1.02	3.22 ± 0.23	13.30 ± 0.51	-
Munich malt beer	-	-	-	12.5
Caramel malt	54.74 ± 1.09	7.11 ± 0.29	18.96 ± 0.76	-
Caramel malt grist	55.62 ± 0.31	6.98 ± 0.48	16.85 ± 0.38	-
Caramel malt beer	-	-	-	27.5

SD – Standard deviation

In Table No 2 are shown measured results of light beer, for its production was used Pilsner malt only. According EBC System the average value of beer was appr. 8 unit of EBC. To compare with colour of pilsner malt grist is the increase in colour of brewed beer nearly three times, the reason for colour increase are, of course, Maillard reactions (chemical reaction between an amino acids and a reducing sugar, usually requiring the addition of heat, similary as browning).

Tab. 2 Parameters of Light beer

Light beer									
Pilsen malt (200 kg)					Pilsner malt grist (200 kg)				light beer**
EBC		CIELAB System			EBC	CIELAB System			EBC
No	Colour	L*	a*	b*	Colour	L*	a*	b*	Colour
1	2.90	59.99	4.64	17.83	2.90	75.50	4.64	17.83	8.10
2	2.80	59.32	4.84	17.92	2.80	75.60	4.84	17.92	7.50
3	3.00	58.00	4.74	17.88	3.10	75.40	4.74	17.88	8.30
4	2.70	61.20	4.65	17.69	2.70	75.60	4.65	17.69	8.50
5	2.80	59.20	4.64	17.95	2.80	75.40	4.64	17.95	8.40
6	2.90	59.10	4.66	17.66	2.90	75.20	4.66	17.66	7.40
7	2.90	59.10	4.59	17.88	2.90	75.20	4.59	17.88	7.70
8	2.90	49.30	4.40	17.84	2.90	76.10	4.40	17.84	7.90
9	2.50	62.30	4.65	17.82	3.00	75.20	4.65	17.82	7.80
10	2.60	57.20	4.63	17.83	3.10	75.80	4.63	17.83	8.20
Mean	2.80	58.47	4.64	17.83	2.91	75.50	4.64	17.83	7.98
SD	0.16	3.53	0.11	0.09	0.13	0.29	0.11	0.09	0.38
CV	5.58	6.04	2.39	0.52	4.42	0.38	2.39	0.52	4.76

Brewed beer was not possible in System **CIELAB System measured
SD – Standard deviation; CV – coefficient of variation

In the Table 3 are shown measured results of semi-dark beer, for its production were used next to Pilsner malt, Munich malt and Caramunich malt.. According EBC System the average value of beer was appr. 8 unit of EBC. To compare with colour of pilsner -, Munich- nad Caramunich grist is the increase in colour of brewed beer nearly 6 times (for pilsner grist due to its weight).

Tab. 3 Parameters of Semi-dark beer

Semi-dark beer													
	Pilsner malt grist (110 kg)				Munich malt grist (60 kg)				Caramunich malt (30 kg)				Beer**
	EBC	CIELAB Systém			EBC	CIELAB Systém			EBC	CIELAB Systém			EBC
No	Colour	L*	a*	b*	Colour	L*	a*	b*	Colour	L*	a*	b*	Colour
1	2.90	75.5	2.27	11.48	23.5	69.7	3.42	13.3	130	55.72	7.12	16.85	38.00
2	2.60	75.6	2.13	11.6	23.9	69.9	3.12	13.7	130	55.72	7.12	16.40	36.00
3	2.80	75.4	2.18	12.00	23.1	69.9	3.36	12.8	130	55.72	7.12	16.25	37.00
4	2.67	75.6	2.16	11.49	22.1	70.4	3.28	13.5	130	55.72	7.12	16.50	37.00
5	2.71	75.4	2.14	11.56	22.8	69.4	3.38	12.5	130	55.72	7.12	16.30	37.00
6	2.81	75.2	2.30	12.00	23.2	69.8	3.41	14.1	140	54.74	7.11	17.20	37.00
7	2.76	75.2	2.44	17.88	22.8	69.9	2.98	13.1	130	54.74	7.11	17.50	38.00
8	3.17	75.3	2.11	17.84	22.6	68.9	2.80	13.3	130	54.74	7.11	17.20	39.00
9	3.36	75.9	2.18	17.82	22.8	70.4	3.22	13.1	130	54.74	7.11	16.90	41.00
10	3.07	71.3	2.79	17.83	23.2	70.2	3.22	13.4	130	54.74	7.11	17.20	39.00
Mean	2.89	75.04	2.27	14.15	23.0	69.9	3.22	13.3	131	55.23	7.12	16.83	34.45
SD	0.24	1.33	0.20	3.19	0.49	0.46	0.20	0.45	3.16	0.52	0.01	0.44	11.51
CV	8.30	1.70	9.17	22.50	2.17	0.65	6.29	3.38	2.41	0.94	0.07	2.64	33.40

Brewed beer was not possible in System **CIELAB System measured, SD – Standard deviation; CV – coefficient of variation

Tab. 4 Dark Beer

Dark beer																	
Pilsner malt grist (100 kg)					Munich malt grist (50 kg)				Caramunich malt (30 kg)				CARAFA malt grist (30 kg)				Beer
	EBC	CIELAB Systém			EBC	CIELAB Systém			EBC	CIELAB Systém			EBC	CIELAB Systém			EBC
No	Colour	L*	a*	b*	Colour	L*	a*	b*	Colour	L*	a*	b*	Colour	L*	a*	b*	Colour
1	2.9	75.5	4.64	17.83	23.5	69.7	3.42	13.3	130	55.7	7.12	16.9	1350	41.29	3.69	4.68	62.0
2	2.8	75.6	4.84	17.92	23.9	69.9	3.12	13.7	130	55.7	7.12	16.4	1350	41.39	3.59	4.28	61.0
3	3.1	75.4	4.74	17.88	23.1	69.9	3.36	12.8	130	55.7	7.12	16.3	1350	41.29	3.54	4.93	63.0
4	2.7	75.6	4.65	17.69	22.1	70.4	3.28	13.5	130	55.7	7.12	16.5	1350	40.35	3.79	4.72	61.0
5	2.8	75.4	4.64	17.95	22.8	69.4	3.38	12.5	130	55.7	7.12	16.3	1350	40.75	3.65	4.70	62.0
6	2.9	75.2	4.66	17.66	23.2	69.8	3.41	14.1	140	54.7	7.11	17.2	1350	41.25	3.68	4.62	62.0
7	2.9	75.2	4.59	17.88	22.8	69.9	2.98	13.1	130	54.7	7.11	17.5	1350	41.3	3.71	4.71	61.0
8	2.9	76.1	4.40	17.84	22.6	68.9	2.80	13.3	130	54.7	7.11	17.2	1350	42.05	3.65	4.69	60.0
9	3.0	75.2	4.65	17.82	22.8	70.4	3.22	13.1	130	54.7	7.11	16.9	1350	42.15	3.71	4.75	62.0
10	3.1	75.8	4.63	17.83	23.2	70.2	3.22	13.4	130	54.7	7.11	17.2	1350	41.05	3.75	4.68	61.0
Mean	2.91	75.5	4.64	17.83	23.0	69.9	3.22	13.3	131	55.2	7.12	16.8	1350	41.29	3.68	4.68	61.5
SD	0.13	0.29	0.11	0.09	0.50	0.46	0.2	0.45	3.16	0.52	0.01	0.44	0	0.53	0.07	0.16	0.85
CV	4.42	0.39	2.4	0.52	2.17	0.65	6.29	3.38	2.41	0.94	0.07	2.64	0	1.29	1.99	3.45	1.38

Brewed beer was not possible in System **CIELAB System measured,
SD – Standard deviation; CV – coefficient of variation

From the previous experimental activity found, that the impact of yeast and hops was negligible, that's why those raw material were not considered.

The results of lightness L* in the Table 1 indicate that the lightest malt is the Pilsner Malt (L* = 59.99 ± 0.24), which even increased the lightness by the milling to the value of Pilsner Malt grist (L* = 75.50 ± 1.11), which causes the difference ΔL* = 15.51. There are recognised also changes in colour shades, a* and b*. The redness of Pilsner Malt (a* = 4.64 ± 0.09) was reduced by milling to the value of Pilsner Malt grist (a* = 2.27 ± 0.25), which causes the difference Δa* = 2.37. Also the yellowness of Pilsner Malt (b* = 17.83 ± 0.11) was reduced by milling to the value of Pilsner Malt grist (b* = 11.48 ± 0.76), which causes the difference Δb* = 6.35. The colour of beer using Pilsner Malt is the lightest (5.9 EBC units) from tested samples. The results of lightness L* of the Munich malt (L* = 59.81 ± 0.93) is very similar to the Pilsner Malt, but the change of lightness of the Munich Malt grist (L* = 69.97 ± 1.02) is not so high, which causes the difference ΔL* = 10.16. The changes in colour shades, a* and b* are small in comparison with Pilsner malt. The redness of Munich Malt (a* = 3.47 ± 0.14) was reduced by milling to the value of Munich Malt grist (a* = 3.22 ± 0.23), which causes small difference Δa* = 0.25. The yellowness of Munich Malt (b* = 12.17 ± 0.04) was slightly increased by milling to the value of Munich Malt grist (b* = 13.30 ± 0.51), which causes the difference Δb* = 1.13. The use of Munich Malt resulted in colour 12.5 EBC units. The most dark malt is the Caramel Malt with lightness L* = 54.74 ± 1.09. The increment of the lightness of Caramel Malt grist (L* = 55.62 ± 0.31) is very small, which causes the difference only ΔL* = 0.88. The changes in colour shades, a* and b* are small in comparison with Pilsner malt. The redness of Caramel Malt which was the highest from three tested malts (a* = 7.11 ± 0.29) was slightly reduced by milling to the value of Caramel Malt grist (a* = 6.98 ± 0.48), which causes small difference Δa* = 0.13. The yellowness of Caramel Malt, which was also the highest from three tested malts (b* = 18.96 ± 0.76) was reduced by milling to the value of Caramel Malt grist (b* = 16.85 ± 0.38), which causes the difference Δb* = 2.11. The use of Caramel malt resulted in colour 27.5 EBC units. Hops was used the same in all three cases, so its influence in the colour of the beer to be compared cannot be proved. Perhaps it is only possible to state that the colour of the hops shows a fairly slight green colour (a * = - 1.64 ± 0.13). The results of this measurement could be used in the future, for comparison with other types of hops. The same applies to brewer's yeasts that showed a certain shade of redness (a * = 5.40 ± 0.02) and a more significant shade of yellowness (b * = 21.43 ± 0.14).

CONCLUSIONS

The results of this research had shown the leakage of information about relationship between colours of raw materials and brewed beer. From the point of view of quickly growing number of new founded craft breweries and new types of beer (IPA, Ale, Stout etc.) is important to recognize all important parameters including the colours of raw materials for this process.

The results of measurements of different malts presented in this paper can be used with advantage for prediction of colour next brewing beer according demand of future customers. The colour of yeast and hops do not have any impact on brewing beer.

The future research and development in this field of science should be focused on the study of the further research of relationship between properties of used raw materials and quality of brewed beer.

ACKNOWLEDGMENT

This article was financially supported by the Faculty of Engineering of Czech University of Life Sciences Prague (Internal Grant Agency of Faculty of Engineering (IGA TF) – Internal Project No. IGA TF 2019:31170/1312/3121).

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