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Evaluation of visual characteristics of beer using the computer vision method

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Abstract

Introduction. The aim of this study was to monitor the colour and stability of foam of different types of beer (light and dark beer) using a non-destructive method - computer vision and digital image analysis.

Materials and methods. Beer colour and beer foam stability of different beer types (declared as dark and light beer type) were measured using computer vision method. Beer foam stability, expressed as change in foam height over time, is modelled using an exponential decay model. Measurement of foam decay generally involves measuring beer drainage or the decreasing height of the head.

Results and discussion. The dark beer was less bitter (16.75 IBU), with higher polyphenol content (181.80 EBC), compared to the light beer style (bitterness was 26.50 IBU, total polyphenol content 103.50 EBC). Alcohol content was mostly below 5% (4.82% for the pale beer and 4.90% for the dark beer), and pH was 4.39 for the pale beer and 4.43 for the dark beer. Beer colour was expressed in the CIE$L^*a^*b^*$ colour system, with darker beers having lower values for lightness ($L^* = 28.7$), higher values for $a^* = 10.4$, and lower values for $b^* = 4.4$. In contrast, light beers were brighter ($L^* = 65.5$), with lower values of $a^* = 7.7$ and higher values of $b^* = 4.4$. Dark beers had higher EBC, lower L^*, and higher a^* values than pale beers due to the use of colouring malts that were kilned and roasted at a higher temperature at which Maillard reaction products were formed. The change in beer foam over time is a combination of liquid removal and bubble decay. The dark style of beer showed much more stable foam than the light beer. Beer foam height was statistically different ($p< 0.05$) between light and dark beer, with dark beer samples having higher initial foam height (66.1 mm) compared to light beer (48.7 mm). Dark beer samples had lower values of rate constant (0.0091 s^{-1}) and higher values of foam half-life time (76.1 s), implying that dark beer had more stable foam than light beer. In contrast, light beer samples had higher values of the rate constant (0.0110 s^{-1}) and lower values of the foam half-life time (63.2 s). The applied mathematical model (exponential decay model) was found to be suitable for predicting the change in foam decay rate and foam stability of light and dark beer samples. Moreover, the values of foam height of dry and wet part of foam were well predicted by the exponential decay model.

Conclusions. Computer vision has been shown to be a suitable, objective, reproducible, and reliable method for measuring the colour and stability of beer foam (total foam, wet foam, and dry foam) for light and dark beer varieties.

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Introduction

Among the important parameters of beer quality are the colour of beer, its clarity, bitterness and the volume fraction of alcohol. The colour and clarity of beer are expected to be constant after production and during storage and sale [1]. According to the colour of beer, we divide it into light, red, dark and black. The colour of beer conveys an important message to the consumer, so the darker colour of beer suggests a stronger taste and aroma, a higher percentage of alcohol and a richer fullness of beer, while the lighter colours of beer are just the opposite. [1,2] There are several methods for measuring beer colour like the Lovibond comparison system method, the spectrophotometric method, the tristimulus colorimetric method and the computer vision method [3].

The quality of the foam influences the overall perception of the consumer to a great extent. Therefore, the control of foam behaviour is essential. The physical properties responsible for beer foam behaviour are: foam or head formation, foam collapse, foam drainage, or head retention, bubble collapse, and bubble cling, lacing, or foam adhesion. [2,4]

Numerous methods and procedures have been proposed to determine foam characteristics. Some of them are based on the rate of the drainage of liquid from the foam, like the Blom or Rudin method. The Blom method [5] is based on the rate of liquid drainage from the foam, where the rate of drainage is described as first order kinetic. After a short lag period, the logarithm of the weight of the foam is proportional to time. The Rudin tube method [6] uses a long tube of small diameter with the CO_2 injection for foam formation in the degassed samples. Some methods are based on the measurement of foam collapse, where the foam is measured by focusing a microscope onto the foam surface [3]. The most popular method to measure foam collapse is the NIBEM foam stability tester where foam collapse is measured with a conductivity probe, which follows the upper foam level as a function of time. The time elapse from 1 – 4 cm below the top of the glass is measured every cm and taken as a measure for foam behaviour. Other methods are based on the measurement of the conductivity of a foam or methods based on determining bubble-size distribution in aqueous foams. In general, it is possible to categorize foam measurement analysis methods by means of foam generation into two groups. [7]

The first group generates the foam using “natural” pouring techniques (Constant method, the foam collapse time by Yasui, the cylinder pour test by Vundla) [8,9]. The second group is artificial methods, which assess the foam stability using beer that is not carbonated. These foams are generated by gassing through porous frits, (Ross and Clark and Rudin) [6,10], passing through nozzles (Steinfurth Foam Stability Tester and Lg Foam tester (MEBAK)) [11], or by employing other methods such as shaking [12,13] or flashing (NIBEM) [8].

Most of the standard methods for measuring beer foam stability are based on measurements of the weight or volume of the liquid collapsed from the foam [5,6,14,15] and they have several limitations (Foam is generated in an atypical way, so the resulting foam are different from those of foam produced by typical beer-pouring methods; Liquid drainage is only one of the factors related to foam stability). Evans *et al.* [16] concluded that the ideal foam measurement method would be to assess beer foam quality with a combination of digital camera and image analysis software.

Given the need for objective instrumental measurements of colour in the coloured and almost translucent samples, the purpose of this paper was to find the method that can simultaneously determine the colours of both light and dark beer. In this study the same mathematical model (exponential decay model) was applied to model of the wet and dry parts of beer foam. Furthermore, the same method was applied for the purpose of determining the foam stability of these two different types of beer. So far, there has been no research on the stability kinetics of beer foam, which would include both dark and light beer style. The beer model was improved by separating the wet part of the beer foam from the dry part of the foam, and by distinguishing between the contribution of drainage and condensation to the beer foam collapse. The basic concept was to develop a customer-oriented approach, so that values are measured in a consumer-use situation.

The aim of this study was to monitor the colour and stability of the foam of different types of beer (light and dark beer) using a non-destructive method – computer vision and digital image analysis.

Materials and methods

Materials

For this study, two bottled lager beer style sample sourced from Osječka pivovara d.d. (Osijek, Croatia) were used one declared as dark beer and the other as light beer. Six bottles per beer sample from two different batches (purchased in 2018 and 2019) were used for all the analyses. All measured parameters were made in four replicates, and average values were used for data analysis.

Physical-chemical analyses

Beer alcohol content was measured on an Alcolyzer (Anton Paar GmbH, Austria). Standard beer analyses and determination of colour, bitterness, total polyphenols and pH were carried out according to EBC methods 9.6, 9.8, 9.11 and 9.35 (Analytica-EBC®, 2010) [17]. Standard method for foam stability evaluation were conducted according to the MEBAK method 2.18.2 (MEBAK®, 2012) [11], using the NIBEM-TPH foam stability tester with the Inpack 2000 Sampling Device, type ISD (Haffmans, Holland).

Analysis of beer colour with computer vision

Figure 1. Cylindrical pilsner beer glass [18]

The colour stability of beer samples was evaluated with tristimulus analysis by using computer vision. The computer vision method is implemented in several steps: image acquisition, image analysis and extracting the features of interest.

Image acquisition. To acquire an image of beer sample, a digital camera was used (Canon EOS 1100D). Before shooting, the camera was calibrated with a Datacolor SpyderCHECKR™ calibration plate. Before the experiment, the beer samples were degassed, so that gas bubbles did not affect the colour measurements. Beer samples were held at 6 °C, and analyses were performed at ambient temperature

(□20 °C). Before analysis, the beer samples were degassed by gently stirring with a magnetic stirrer and the sample was filtered through a 0.45 µm membrane filter. A 100 ml of each beer sample was poured into a cylindrical pilsner beer glass, and placed inside the photographing chamber at a distance of 50 cm from the camera lens. The 24-bit coloured images was captured in TIFF format and sRGB colour model. The cylindrical pilsner beer glass used in the analysis is shown in **Figure 1**. The photographing chamber was illuminated by four LED lamps with a diffuser located on the outside.

Image analysis. After photographing, the colour of the samples was determined using the digital image analysis method. A digital image processing software, ImageJ™ (Wayne Rasband, National Institute of Health, Maryland, USA), was used to analyse the images obtained during colour tests. The results of colour measurement were expressed as values of red (R), green (G) and blue (B) in the RGB colour system. The obtained colour values were converted to the *CIEL**a*b* colour model.

Analysis of foam collapse rate and foam stability using the computer vision

Analysis of beer foam was performed using the computer vison method in three steps: foam generation, measurement of foam height and foam collapse time, and calculation of foam stability value.

Before analysis beer samples were held at 6 °C, and analyses were performed at ambient temperature (20 ±1 °C). Foam is generated by natural pouring using the adopted method reported by Yasui [9], where a volume of 100 ml of beer was poured freehand into a 400 mL cylindrical pilsner beer glass from a precisely defined height. The angle between the bottle and the glass was adjusted to ensure that the beer struck the bottom of the glass and was poured as a steady stream for the duration of the pour.

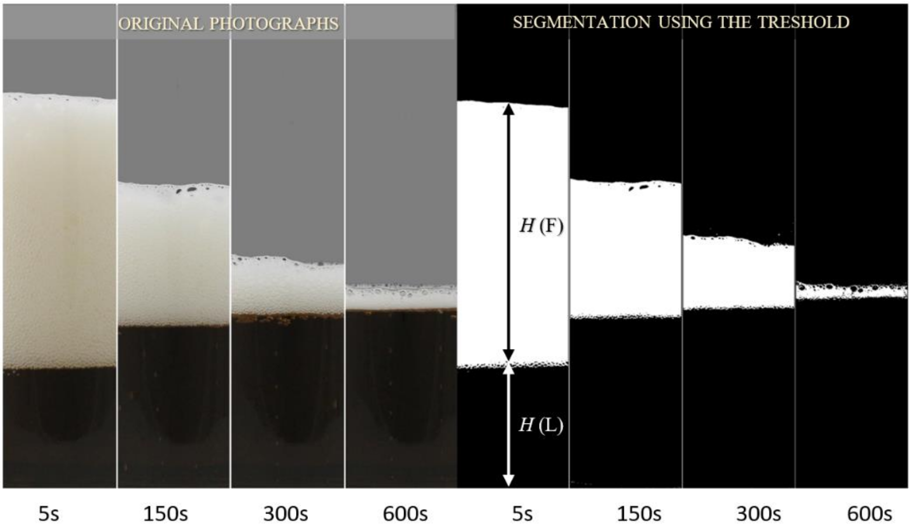


Figure 2. Beer foam collapse determined using the image analysis method [19]

The profile of the beer in a glass was recorded by a CCD-camera every 5 s for 10 min (600 s) period. After the image of foam profile was captured, photographs were subjected to digital image analysis, and the percentage of foam layer was measured using a computer software program ImageJ™. The 24-bit coloured foam images captured during tests were converted into an 8-bit format (Figure 2). After that, the images were converted to binary images using a procedure called thresholding and then the height of foam was calculated [20].

The beer height measurements were taken from the inside bottom of the glass to the beer/foam interface. The foam measurements were calculated according to Equation 1- 2 [21]. The values for both the liquid and wet part of the foam were used for further mathematical modelling procedure.

$$H_t(DFP) = H_t(F) + H_t(L) - H_{max}(L) \tag{1}$$

$$H_t(WFP) = H_t(F) - H_t(DFP) \tag{2}$$

where:

H_t (DFP) – height of the dry part of the foam after a certain time t,
H_t (WFP) – height of the wet part of the foam after a certain time t,
H_t (F) – foam height after a certain time t,
H_t (L) – height of the liquid after a certain time t,
H_{max} (L) – maximum height of the liquid, at time t = 600s.

Several parameters were extracted from the images: foam height, liquid height (beer beneath foam), and some parameters were calculated (foam collapse rate and foam half-life). The results of the image analysis showed the change in the height of the foam column, over time (Figure 3).

Modelling the change in foam column height over time

The method is based on the simultaneous measurement of the level of the foam-liquid interface and the foam height as a function of time. The height of the foam, the height of the wet part of foam and dry part of the foam, rate constant and foam half-life time (or head retention value) was thus obtained. The exponential decay model was used to predict the foam stability of different types of beer. Foam collapse follows an Exponential Decay Law (EDL) [5], where the foam height at time can be expressed as the following function of time (or first-order reaction model):

$$H_t = H_0 \times e^{-kt} \tag{3}$$

$$t_{1/2} = \frac{ln\,(2)}{k} \tag{4}$$

where:

H_0 – initial height of the foam at time t=0,
H_t – height of the foam after a certain time t,
k – rate constant (s^{-1}),
t – time (s),
$t_{1/2}$ – foam half-life time (s) or Head Retention Value (HRV).

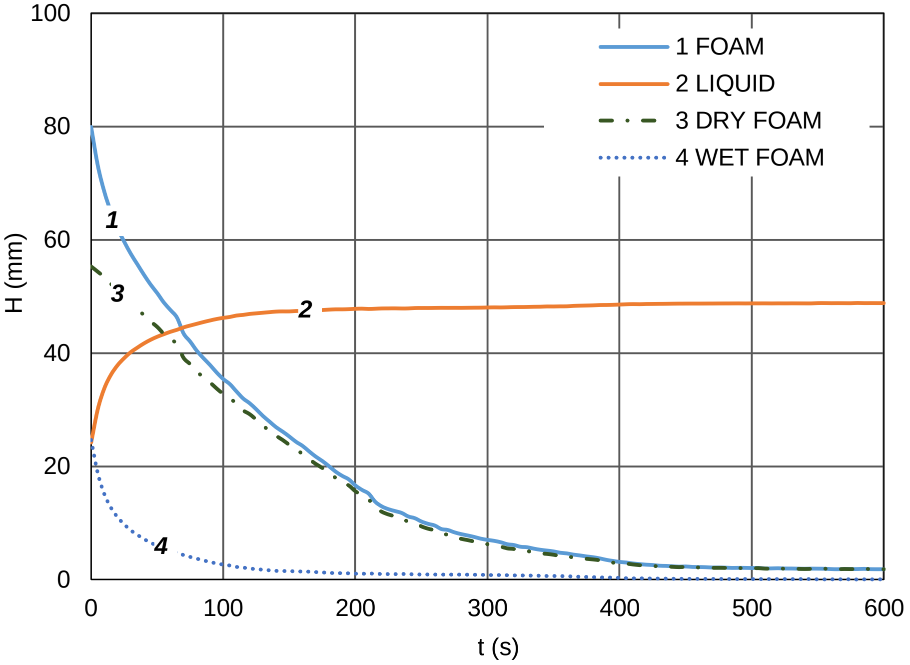


Figure 3. Dynamics of beer foam stability measured using digital image analysis

The beer model was improved by separating the wet part of the beer foam from the dry part of the foam, and by distinguishing between the contribution of drainage and condensation to the beer foam collapse. In this study the same mathematical model (exponential decay model) was applied to model the wet and dry parts of the beer foam [21].

The XLSTAT plugin in MS Excel was used to process the experimental data, and the model parameters were calculated using regression analysis. The success of the approximation of experimental data by mathematical models was evaluated on the basis of several statistical criteria:

$$\text{Coefficient of determination, } R^2 \qquad (5)$$

$$\text{Mean square error, } RMSE = \sqrt{\frac{1}{N}\cdot\sum_{\mathrm{i}=1}^{N}\left(H_{t_{pre,i}} - H_{t_{eks,i}}\right)^2} \qquad (6)$$

Statistical analysis

Data were expressed as means ± standard. Analysis of variance (ANOVA) was performed using the XLSTAT add-in within the MS Excel program (Addinsoft, NewYork, USA). Differences were considered to be significant at validity of α = 0.95.

Results and discussion

Quality indicators such as foam stability, alcohol content, pH value, bitterness, polyphenols content and colour are important for consumers and reveal much about the beer type. The results of the physical–chemical analyses are shown in Table 2.

The dark beer style showed much stabile foam than light. Alcohol content was mostly below 5% as well as pH value, which was almost the same for all beer styles (below 4.4). The ethanol content of beer is very important, from both an economic and sensory points of view, as it is used to classify beers in terms of taxes and taste. The dark beer type was less bitter, with higher polyphenolic content and EBC colour value, in comparison to the light beer style (Table 2). Typically, the colour of the beer is due to the malt and other raw materials that were used in the brew house [7] and is largely due to the melanoidins and caramel present in the malt, although further caramelization can take place during wort boiling.

Table 1

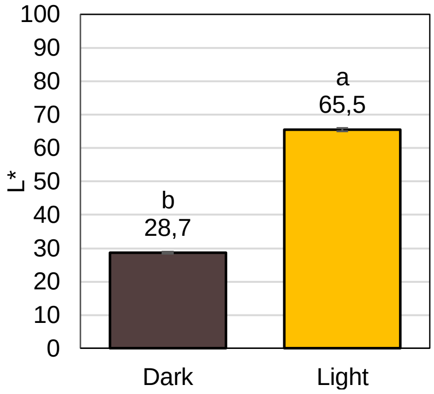
Results of the analysed beer parameters

Beer type	**Foam stability** (min)	**Alcohol v/v** (%)	**pH value**	**Bitterness** (IBU)	**Total Polyphenols** (EBC)	**Colour** (EBC)
Light	7.00 ± 0.08^b	4.82 ± 0.22^a	4.39 ± 0.04^a	26.50 ± 3.00^a	103.50 ± 7.19^b	9.80 ± 2.69^b
Dark	10.00 ± 0.09^a	4.90 ± 0.16^a	4.43 ± 0.08^a	16.75 ± 3.86^b	181.80 ± 6.22^a	72.14 ± 1.71^a

Values are means of four replications ± SD.
Values in the same column with different superscripts (a-b) are significantly different ($p<0.05$)

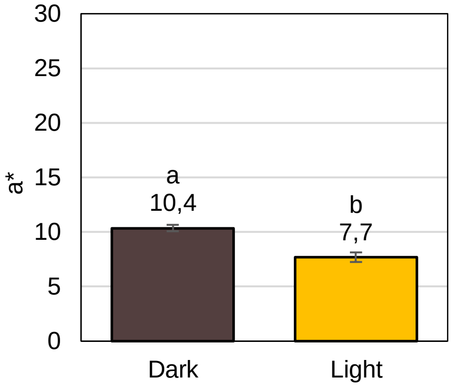
Colour formation occurs in beer during caramelization and Maillard reactions. Caramelization can produce hundreds of different chemical products in different colours, but most of them are brown. Maillard's reactions contribute to the colour of the beer by forming melanoidins during them, which give the beer a darker colour. Also, some products of Maillard's reactions, such as furans, furanosines, pyrroles, and pyrazines affect the colour of beer. The increased concentration of these compounds in beer will cause beers to be darker, while a smaller amount of these compounds yields lighter beers [22]. Furthermore, the colour of beer is influenced by the polyphenols found in barley, and when malt is cooked, polyphenolic components are released, and some new components are formed, and colour is formed as well. During the storage and/or aging of beer, polyphenol oxidation can occur, which is very noticeable in light beers [23]. In darker beers, colour change due to polyphenol oxidation is masked by the colour of coloured and roasted malt. Furthermore, oxidation of the polyphenol can lead to an enhanced protein-polyphenol interaction and the formation of haze of non-biological origin. The colour change of beer due to a polyphenol oxidation is most noticeable in light beers during storage and/or aging of beer [1,24].

Low EBC values denotes (light) pale beer, and higher EBC values describe darker beers. **Figures 4–6** show the colour measurement results of two different beer samples declared as dark and light lager beer. The colour of the samples was measured using the computer vision method and represented as CIE L^*, a^* and b^* values. The lightness (L^*) is achromatic component of CIE colour space in the range 0-100, the higher the L^*, the lighter the sample. The a^* and b^* values are chromatic component of the CIE colour space, and can be between – 127 and + 127. The chromatic component a^* indicates the presence of a green-red colour (smaller *a** means green, and the higher *a* denotes* red colour of sample). The chromatic component *b** indicates the presence of a blue-yellow colour (smaller *b** means blue, and the higher *b* denotes* yellow colour of sample).



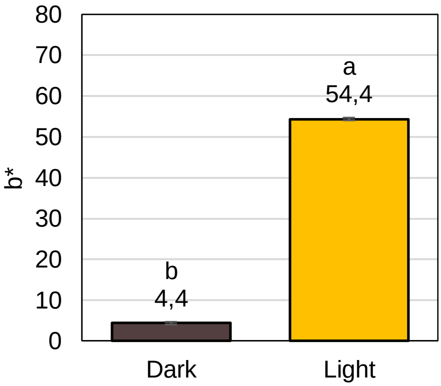
Values are means of four replications ± SD. Values with different letters (a-b) are significantly different (p<0.05)

Figure 4. Results of the brightness value for different beer samples



Values are means of four replications ± SD. Values with different letters (a-b) are significantly different (p<0.05)

Figure 5. Results of the green-red chromatic component value for different beer samples



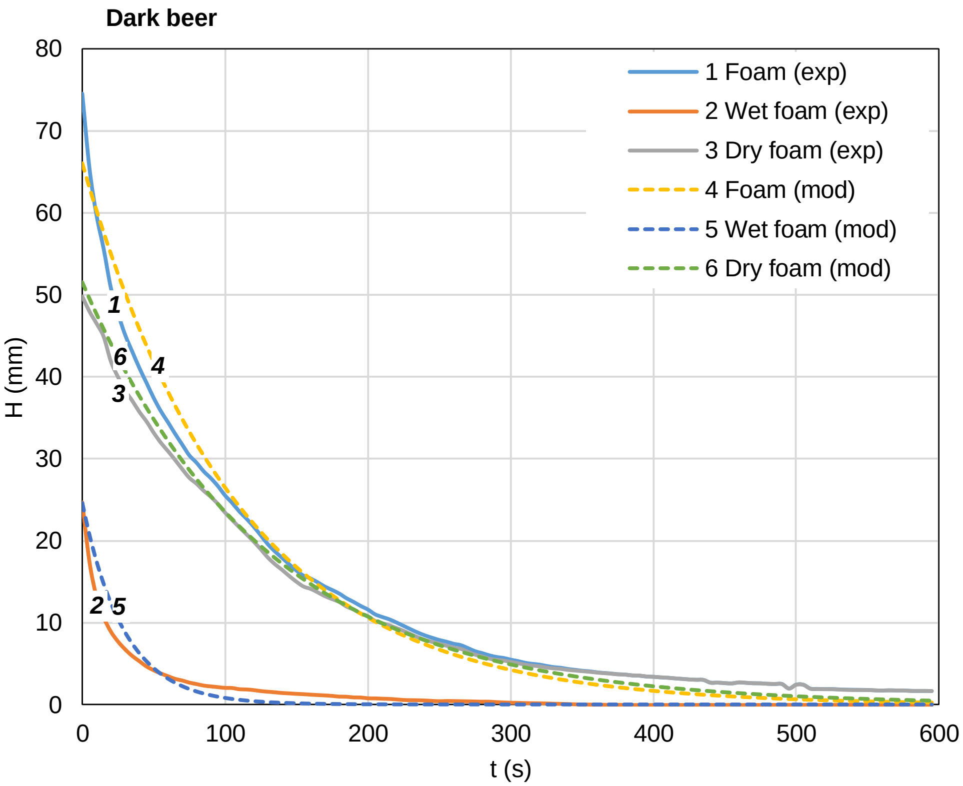
Values are means of four replications ± SD. Values with different letters (a-b) are significantly different (p<0.05)

Figure 6. Results of the blue-yellow chromatic component value of different beer samples

As can be seen in Table 2 and on Figures 4–6, light beer had the lower EBC values, the higher *L** values and lower *a** values than a dark beer. That indicates that these are the palest samples as they do not contain or contain a very low amount of special malts, which can contribute to their colour. Dark beer had higher EBC, lower L^* and higher a^* values than pale beer, due to the use of colouring malts which were kilned and roasted at a higher temperature where Maillard reaction products were formed [25].

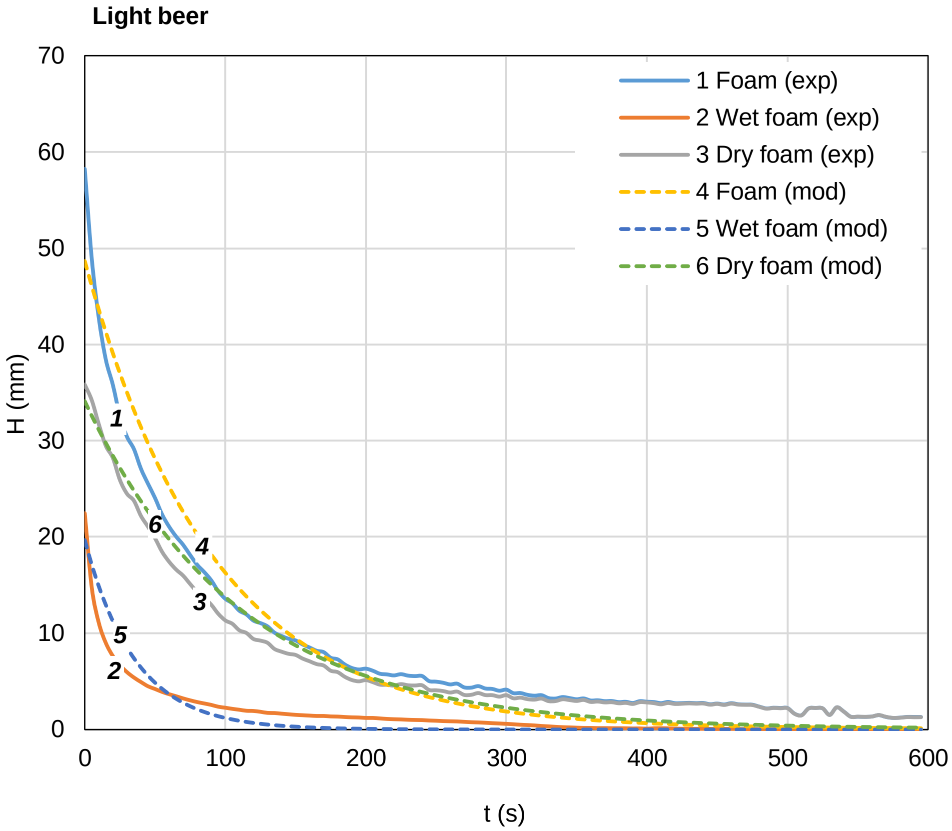
Results of foam stability measurements of different beer samples using the computer vision system and image analysis

The foam stability of different types of beer was analysed by CVS and image analysis and expressed as the change in the height of the foam column (H_0) over time (t). Figures 7 – 8 shows the collapse of the head of a beer poured into a glass.



Values are means of four replications ± SD.

Figure 7. The height of the beer foam as a function of time (dark beer)



Values are means of four replications ± SD.

Figure 8. The height of the beer foam as a function of time (light beer)

The decay of beer foam takes place in three phases, i) the initial phase – it takes about 300 seconds, where the liquid beer drainage is driven by gravity, ii) the consolidation phase – characterised by an increase of the concentration of polypeptide material in the foam leading to bubble coalescence and foam collapse, iii) the residual phase.

When a beer is poured into a glass the initial burst of CO_2 creates foam with a high liquid fraction. There are actually two types of foam: "wet foam" consisting’s of spherical bubbles with liquid beer between them and "dry foam" consisting of polyhedral bubbles with no liquid between them. Liquid foam slips and slides while dry foam is stiff and sticky. The drainage of beer from the foam begins as soon as the pour is complete. The rate of foam collapse depends on the progress of three physical processes involved in the breakdown of the foam: drainage, coalescence and disproportionation. When beer is poured into a glass, initially, drainage is the main process, and at a later stage, coalescence and disproportionation become more important. Creaming, also called beading, is the continuous formation of new bubbles. Creaming is how foam forms from bubbles rising out of a glass of beer. Drainage is the liquid flow from a foam to the liquid underneath. It is not well-defined where creaming stops and drainage begins. The main driving force for both processes is gravity. Drainage occurs if the bubbles become more densely packed. The foam becomes dryer, and the bubbles become deformed. Coalescence in foam is the merge of two bubbles caused by the rupture of the film between the bubbles. Two smaller bubbles become one larger bubble [26].

Figures 7–8 show the experimentally obtained and model-predicted values of the height of the foam column change as a function of time for the dark and light beer style. The values of the height of the beer foam H_0 of the dry and wet part of the foam was well predicted with the exponential decay law model, in contrast to the predicted values of the height of the beer foam for the initial foam. The diagram shows the exponential decay of the beer head associated with the measurement. The regression curves match the measured data well, which means that the beer foam collapsed quickly, as does the beer drainage. Correspondingly, the model of beer height estimate well the real height. This was expected because at the beginning of the foam decay, the packing density of the bubbles in the foam was much less than later in the experiment (which leads to a rapid loss of beer in the foam in the first 30 seconds following the pour) [27].

Using regression and curve fitting techniques, the generalized parameters for each foam sample was obtained, which is shown in Tables 3–5. The success of approximation of experimental data by the selected mathematical model was analysed on the basis of several statistical criteria. In this paper, the coefficient of determination (R^2) is presented, which would ideally have a value of 1, and the mean square deviation (RMSE) at which smaller values indicate a more successful approximation of the data by the applied model. In Tables 3–5, a comparison of R^2 for the least squares regression of the change in the height of the foam column over time indicates that R^2 was higher in the dry foam set, (dark beer $R^2 = 0.9972$, light beer $R^2 = 0.9765$) than in the wet part of the foam (dark beer $R^2 = 0.9595$, light beer $R^2 = 0.9201$) or in the total foam (dark beer $R^2 = 0.9893$, light beer $R^2 = 0.9695$). This is a consequence of in-creasing the variance in the pour value for dry foam since it contains the variance from three measurements [28].

Table 2

Statistical analysis and parameters of an exponential decay mathematical model for foam stability

Beer type	H_0 (mm)	k (s^{-1})	$t_{1/2}$ (s)	R^2	***RMSE***
Dark	66.1±2.0	0.0091±0.0004	76.1±3.4	0.9893	1.7242
Light	48.7±1.4	0.0110±0.0000	63.2±0.1	0.9695	2.2525
p-value	0.0194*	0.0465*	0.0640		

Values are means of four replications ± SD. Values marked with *are statistically significant ($p < 0.05$).

The effect of drainage time on the amount of beer in the foam was similar to curves found by Blom [5], who suggested a first-order reaction model, i.e., the rate of collapse decreases logarithmically with time. After the mathematical modelling of the beer foam stability, the parameters of the exponential decay model were obtained: the rate constant k and the foam half-life time $t_{1/2}$. If the values of the rate constant are lower and the foam half-life time is higher, then the foam of the analysed samples is more stable.

Considering the obtained results of the height of the beer foam, there was a statistically significant difference ($p<0.05$) between the light and dark beer, where the samples of dark beer showed a higher initial height of foam (Table 3). There was a statistically significant difference between the values of rate constant and no statistically significant difference between the values of foam half-life time in the observed beer samples. Dark beer samples had lower rate constant (0.0091 s^{-1}) values and higher foam half-life time values (76.1 s), which means that dark beer had more stable foam than light beer. The foam height of the light beer was less stable than that of dark beer (Table 3). This means that the growth of the bubble size in the case of the light beer type mentioned leads relatively quickly to bursting. The foam-forming proteins of the dark beer type on the other hand, appear to stabilize the large foam lamellae well so that its fluffy, large-pored foam remains intact for a long time [29].

Table 3

Statistical analysis and parameters of an exponential decay mathematical model for wet foam stability

Beer type	H_0 (mm)	k (s^{-1})	$t_{1/2}$ (s)	R^2	*RMSE*
Dark	24.6±0.7	0.0342±0.0012	20.3±0.7	0.9595	0.7659
Light	19.7±1.2	0.0279±0.0029	25.1±2.6	0.9201	0.9383
p-value	0.0771	0.1786	0.2122		

Values are means of four replications ± SD. Values marked with *are statistically significant ($p < 0.05$).

Table 4 shows the results of the stability of the wet part of the foam of light and dark beer. According to the values of statistical criteria it is evident that the exponential decay model fits well the experimental data (low values of RMSE for all analysed beer type) and can be used to predict the stability of the wet part of foam for the light and dark beer types [21]. Given the higher R^2 values for dark beer samples, the model better predicts the stability of the wet part of the foam in dark beer samples. Considering the obtained results of the height of the beer foam of the wet part of the foam, there was no statistically significant difference between light and dark beer, where the samples of dark beer showed a higher initial height of the wet part of the foam (24.6 mm), higher rate constant (0.0342 s^{-1}) values and lower foam half-life time values (20.3 s) which means that the dark beer type has a less stable wet part of the foam than the light beer type.

Table 4

Statistical analysis and parameters of an exponential decay mathematical model for dry foam stability

Beer type	H_0 (mm)	k (s^{-1})	$t_{1/2}$ (s)	R^2	*RMSE*
Dark	51.5±2.6^{bc}	0.0078±0.0005	88.1±5.6	0.9972	0.6800
Light	34.1±1.5^{ef}	0.0091±0.0001	76.2±0.9	0.9765	1.4704
p-value	0.0289*	0.1325	0.1590		

Values are means of four replications ± SD. Values marked with *are statistically significant ($p < 0.05$).

The values of the rate constant and the foam half-life time indicated a higher stability of the dry part of the foam in samples of dark beer. They had lower values rate constant (0.0078 s^{-1}) and higher values of the foam half-life time (88.1 s) of the loss of the dry part of the beer foam. Given the obtained results, it is evident that there was a statistically significant difference in the stability of the dry part of the foam between light and dark beer.

The dark beer samples showed higher values of the height of the beer foam and longer foam half-life time of the dry part of the foam (Table 5). According to the values of statistical criteria for the success of approximation of experimental data by an exponential decay model, it can be seen that the used model fit well the experimental data (R^2 values are high) and can be used to predict foam stability for both beer types, light and dark.

Conclusion

The computer vision system and image analysis have been shown to be a suitable, objective, reproducible, and reliable method for measuring the colour, foam breakdown rate, and foam stability of beer (namely, total foam, wet foam, and dry part of the foam). Furthermore, the method is sensitive enough that it can be applied to analyse different types of beer (light and dark). The parameters of colour coordinates (defined in CIE$L^*a^*b^{*1976}$ colour space) measured in the entire visible wavelength range can distinguish beers more objectively than methods based on absorbance.

The concept of using a simple technique (naked eye assessment of foam quality), has a high correlation with consumer perception of beer foam quality and can be improved by using computer vision technologies for objective assessment of foam quality parameters.

The change in beer foam over time is a combination of liquid drainage and bubble decay. Measurement of foam decay generally involves measuring beer drainage or decreasing head height. From the foam stability results, dark beers have a more stable foam. The mathematical model used (exponential decay model) was found to be suitable for predicting the change in foam collapse rate and foam stability of light and dark beers. This model can be used as a cost-effective method for rapid screening of beers during processing to evaluate acceptability more efficiently

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