Determination of the Energy Value of Beer

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ABSTRACT

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Beer is an important source of crucial nutritional compounds such as carbohydrates and proteins. Therefore, beer has become an indispensable part of the diet in many cultures. Apart from carbohydrates and proteins, alcohol also contributes to the total energy value of beer. There exist several approaches to the calculation of the energy value of beer, which are defined in brewery analytical methods (EBC, MEBAK, and ASBC) and in legislative rules. Two approaches were compared. The first is the direct calculation method defined in EBC 9.45. The second can be found in Regulation (EU) Number 1169/2011 of the European Parliament and of the Council. Whereas the direct method is fast, simple, and feasible, the calculation method is laborious and time consuming. However, the direct method does not provide accurate results for some types of beer (e.g., nonalcoholic beer or low-alcoholic beer mix manufactured by mixing beer and sweetened soft drinks). Therefore, the modification of the direct method was suggested and verified. In this form, the direct method of determining the energy value of beer complies with the conditions of high-throughput and a green method.

Keywords: Alcohol, Beer, Caloric content, Carbohydrates, Determination of energy value, Energy value

Nutrition labeling is a topic that attracts attention from both researchers and the general public. The great interest follows primarily from the increasing rates of obesity and obesity-related diseases in this era. Therefore, the development of high-performance and high-throughput methods for the determination of macronutrients (carbohydrates, fats, and proteins) and energy value (EV) (in other words, caloric content) of food and beverages is a subject of interest for many scientists; for example, analytical chemists, experts in human medicine and biology, and, last but most importantly, business-oriented experts, including marketing and communication professionals, general strategists, and food producers. It has been recorded at a higher frequency lately that food companies are on trial for contributing to the growing problem of obesity in the United States and abroad. They have been threatened with taxes, fines, restrictions, and legislation (21). This fact, together with consumer empowerment and the right to be informed approximately the nutritional value of what people are eating, has led to new regulations on the provision of food information on labels (13). "The goal has changed from the original position of 'not mislead' to the current position of 'inform and guide', in the context of an environment where there are increasing rates of obesity and obesity-related diseases." As such, the debate on nutrition labeling, format, and wording of such labels as well as the design, placement, and extent to which this needs to be unified, regulated, and communicated has been put in the spotlight. With the newly introduced Regulation (EU) 1169/2011 (20) on the provision of food information to consumers, any previous supranational European legislation on food and nutrition labeling has been revised and updated. The new rules are intended to consolidate and update Food Labeling Directive 2000/1 3/EC and Directive 90/495/EEC on nutrition labeling. In the United States, the rules of food labeling are determined in a Code of Federal Regulations, § 101.9 from 1 April 2012 (5).

The issue of nutrition labeling, of course, relates not only to food but also to beverage commodities, including beer and beverages based on beer (for example, beer mix). Due to beer's long-term worldwide tradition and the fact that it is an important source of main nutritional compounds such as carbohydrates and proteins, beer has become a basic part of the diet in many cultures (3). Beer is often a great source of energy and contributes significantly to daily energy intake. The major source of beer energy is carbohydrates and alcohol. There exist several basic ways to determine the EV of food and beverages. The first one is using a bomb calorimeter, which directly measures the total or gross EV of various food macronutrients; the former information has been known since the beginning of the last century (4). The bomb calorimeter operates on the principle of direct calorimetry, measuring the heat liberated as food burns completely (15). The heat of combustion refers to the heat liberated by oxidizing a specific food; it represents the food's total EV. This method is applicable for food, but only for solid matrices (16).

A different approach to this problem was described by authors who measured the carbohydrate concentration and EV of fruit- and milk-based beverages through partial-least-squares attenuated total reflectance-Fourier transform infrared spectrometry (19). Using these statistical methods, the authors managed to find a relationship between the absorbance of these drinks in various areas of the infrared spectra and the resulting value of the carbohydrate content and EV.

The standard method of EV (i.e., caloric content) by calculation (calculation method) uses a mathematical equation, where the total EV of a food or beverage is calculated as a sum of the EV of the significant components determined by relevant methods. The concentration (c, g/100 g) of individual nutrients is multiplied by conversion factors. The relationship can be generally expressed as:

$$\begin{aligned} \text{EV (kJ/100 g)} = {} & 17 \times c_{\text{carbohydrate}} + 10 \times c_{\text{polyols}} \\ & + 17 \times c_{\text{proteins}} + 37 \times c_{\text{fats}} + 29 \times c_{\text{alcohol}} \\ & + 13 \times c_{\text{organic acids}} + 8 \times c_{\text{fiber}} \end{aligned} \quad (1)$$

EV is expressed in kilocalories (kcal) or kilojoules (kJ); 1 kcal = 4.1868 kJ.

This formula is used in accordance with the requirements of the EC Directive 90/496/EEC, Nutritional Labeling Rules, together with Decree Number 330/2009 Coll. "Nutrition labeling of food" from the Collection of Laws of the Czech Republic (7) and, finally, newly introduced Regulation (EU) 1169/2011. Because the calculation method requires the development of specific analytical methods for the determination of each given macronutrient in a specific matrix and the subsequent determination of all nutrients in every sample, this method is expensive and also time-consuming.

Brewing analysis conventions such as EBC, MEBAK, and ASBC use simplified methods for EV determination. EBC method 9.45, which is designed for the EV determination in beer (11), uses a simplified alternative, where an estimated EV can be

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calculated from the alcohol and real extract of the beer. Mostly, beer analyzers are equipped by software, which directly calculates EV from real extract, alcohol, and density measured (direct method):

$$EV_{dir}\ (kJ/100\ mL) = \varrho \times (15 \times E_r + 29 \times c_{alcohol}) \quad (2)$$

where ϱ is density of beer (g/mL), E_r is real extract in %w/w, and 15 is the approximated conversion factor, which takes into account the major components of the extract, carbohydrates and proteins, as well as glycerol; β-glucans; organic acids; amino acids; phenolic, sulfuric, heterocyclic, and inorganic substances; and so on. The MEBAK method 2.10.3.7 (18) provides two alternatives; the first one is the calculation of EV based on residual carbohydrates, proteins, and alcohol:

$$EV_{calc}\ (kJ/100\ mL) = 17 \times c_{carbohydrate} + 17 \times c_{proteins} + 29 \times c_{alcohol} \quad (3)$$

The second one uses an approximated equation as equation 2. The ASBC method (1) presents another equation:

$$EV_{ASBC}\ (kcal/100\ g) = 6.9\ (A) + 4\ (B - C) \quad (4)$$

where A (%w/w) is alcohol content, B (%w/w) is real extract, and C (%w/w) is ash content.

This calculation corrects the real extract value as a measure of the sum of carbohydrates and proteins.

The big advantage of the method using equation 2 is its simplicity and high throughput. Laboratories dealing with beer analysis are mostly equipped with analyzers, which can easily determine alcohol and real extract concentration. The measurement of alcohol is based on near-infrared technology and the measurement of real extract, which is calculated from density. The principle behind the densitometer is based on the fact that the characteristic frequency of an oscillating U-tube depends on the density of the filled-in sample density. Equation 2 is included in the software of this instrument, and the process of EV calculation is fully automatized, for example, with Anton Paar (2).

As was mentioned above, Regulation (EU) 1169/2011 defines a determination of EV as the sum of energetic contributions of present nutrients and alcohol. Undoubtedly, this assay is absolutely correct; however, this approach is very time-consuming and more expensive compared with brewery reference methods (EBC, MEBAK, and ASBC). Therefore, the aim of this study was a comparison of methods using the sum of all nutrients and alcohol in beer (equation 3) with the direct method, which utilized only values of alcohol and extract processed with an approximated equation according to EBC 9.45 method (11). Beer samples with various ratios of alcohol and extract (34 samples of lagers, 22 samples of beer mix, and 32 samples of nonalcoholic beers) were used for this purpose.

EXPERIMENTAL

Beer samples (lagers, nonalcoholic beer, and beer mix) were obtained from the Czech market and analyzed according to the routine methods described below.

Real extract measurement was performed on a DMA 4500 densitometer (Anton Paar, Austria) according to EBC 9.4 method (10). Alcohol content was measured on the Alcolyzer (Anton Paar) according to EBC 9.2.6 method (9).

Carbohydrate concentration was determined on a high-pressure pump with a degasser, column thermostat (SISw, Czech Republic), and autosampler Midas (Spark, Holland) connected with a high-sensitivity refractive index (RI) detector (Shodex RI 101, Japan). Chromatographic data were collected and processed by the DataApex Clarity data system, version 3.0.5.505. The measurement procedure and conditions are described by Jurková et al. (14).

Total nitrogen content was determined on a mineralization unit SK-06-RXT (MK Servis s.r.o., Czech Republic) and Büchi 323 (Büchi Labortechnik AG, Switzerland) according to EBC 9.9.1 method (12). Protein content was calculated by multiplying the total nitrogen content by factor 6.25.

RESULTS AND DISCUSSION

The development of the method for determining total carbohydrates, including polyols determination in beer, was the necessary previous step of this study. Carbohydrates are the main part of beverage extracts; therefore, the accuracy of this method affects the ensuing final formulae for EV calculation. Regulation (EU) 117/2010 recommends the determination of oligomers in food using an enzymatic reaction with amylase or amyloglucosidase, with subsequent analysis of produced glucose by HPLC (6). The method described in Analytica EBC 9.26 and MEBAK 2.7.3, the determination of total carbohydrate content in beer using the hydrolysis of carbohydrates with sulfuric acid (85% v/v) into glucose units with the following color reaction and UV/VIS spectroscopy detection at 625 nm (9,17), does not meet the requirements of Regulation (EU) 117/2010, which requires the enzymatic conversion of polymers and oligomers of carbohydrates into glucose using amylase or amyloglucosidase with a following HPLC determination. Therefore, in the first step, we developed and verified a new method (14), where the carbohydrates in beer are cleaved using an enzymatic reaction with amyloglucosidase into glucose and short glucose oligomers of less than 10 units, and separated on an HPLC ionex column in Ag+ mode Rezex RSO-Oligosaccharide. An HPLC method with RI detection is consequently used

TABLE I
Comparison of Energetic Values Determined Using Direct Method (EV_{dir}, Method 1) and Calculating Method (EV_{calc}, Method 2)[a]

Beer	Ex_r (% w/w)	Total sacch. (% w/w)	Proteins (% w/w)	Alcohol (% w/w)	EV_{dir} (kJ/100 g)	EV_{calc} (kJ/100 g)	Rel. diff. (%)
Lager							
Average	4.5	3.7	0.5	3.8	179	181	1.0
Standard deviation	1.8	1.7	0.2	0.7	41	41	2.1
Nonalcoholic beer							
Average	4.7	4.5	0.2	0.2	78	82	4.8
Standard deviation	1.4	1.3	0.1	0.1	21	21	3.1
Beer mix							
Average	6.1	5.8	0.2	1.7	144	151	4.7
Standard deviation	1.7	1.7	0.1	0.5	37	40	3.7

[a] Ex_r = real extract, Total sacch. = total saccharides, EV_{dir} = direct method according to method EBC 9.45 (after conversion of w/v to w/w), EV_{calc} = calculation method according to Regulation (EU) 1169/2011, and Rel. diff. = relative difference between EV_{dir} and EV_{calc}.

for the determination of resulting glucose and traces of oligomers with chains shorter than 10 glucose units. The enzymatic reaction was optimized with respect to the inhibition effect of ethanol in beer. The resulting recovery of the method in nonalcoholic and alcoholic beer was 98.5 and 92.3%, respectively.

The EV value of analyzed beer was determined using two methods. Method 1 was the direct method on the automatic analyzer of extract and alcohol using approximated equation 2 according to EBC method 9.45. Method 2 was the calculation method (equation 3) according to legislative recommendation. Consequently, EVs obtained from both methods were compared, and the difference was expressed (Table I).

As follows from our results, the EBC method (namely, equation 2 used for EV determination) is useful only for lager beers. When we analyzed nonalcoholic beer or beer mix using this method, we found various differences (ranging from 5 to 20%) between the results from equations 3 and 2 (calculation and direct methods, respectively). This discrepancy is probably caused by different ratios between the concentration of alcohol and carbohydrates, and the conversion factor 15 for extract is not accurate in these cases. Different energy contributions of alcohol and carbohydrates in the studied beer samples are shown in Figure 1. These results were obtained during EV measurement using the direct method (method 1). It is evident that alcohol is a major contribution to total energy in lager samples (approximately two-thirds). Carbohydrates contribute to total energy with approximately one-quarter. A completely different situation occurs for the samples of beer mix and nonalcoholic beer, where the major proportion of energy belongs to carbohydrates: approximately two-fourths and four-fifths for beer mix and nonalcoholic beer, respectively. Finally, in beer mix samples, one-third of energy is composed of alcohol whereas a negligible contribution of alcohol was found in nonalcoholic beer. The amount of proteins and glycerol is insignificant in this context in all samples studied. The overall comparison of EV regarding the three types of studied samples is shown in Figure 1; the average EV of lagers is the highest, 182 kJ/100 mL, whereas the average EV of nonalcoholic beers (produced by interrupted fermentation) is half compared with lagers, 83 kJ/100 mL. The energy of beer mix (with a low content of alcohol, less than 2%) depends on the level of sugar added; the average EV of our samples was 150 kJ/100 mL.

A statistical summary of results obtained is shown in Table I and demonstrates trends for the three types of beer studied. The comparison was performed on 34 samples of lagers (original gravity 9 to 18°P), 32 nonalcoholic beers, and 22 beer mixes. It should

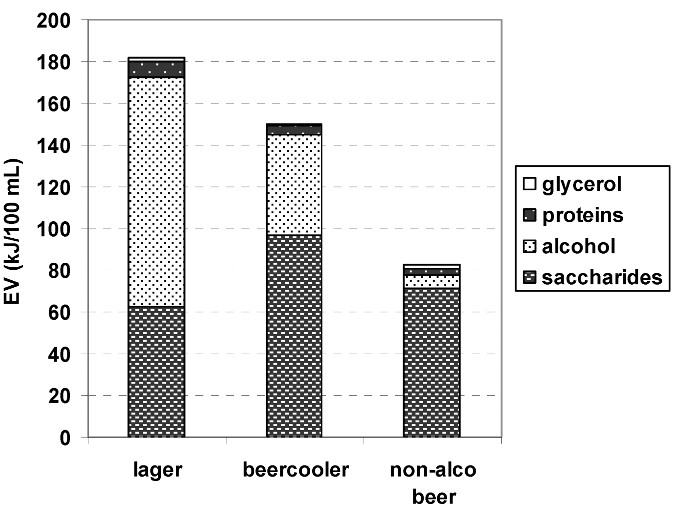

Fig. 1. Contribution of components to the total energy value of beer.

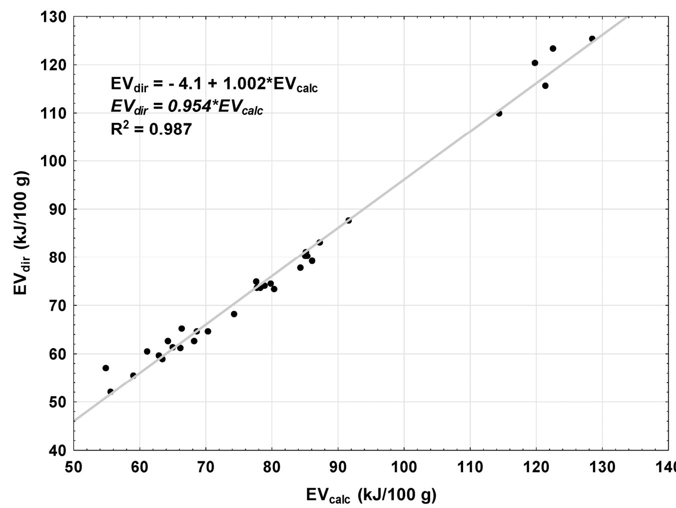

Fig. 3. Correlation between direct and calculating methods: nonalcoholic beer.

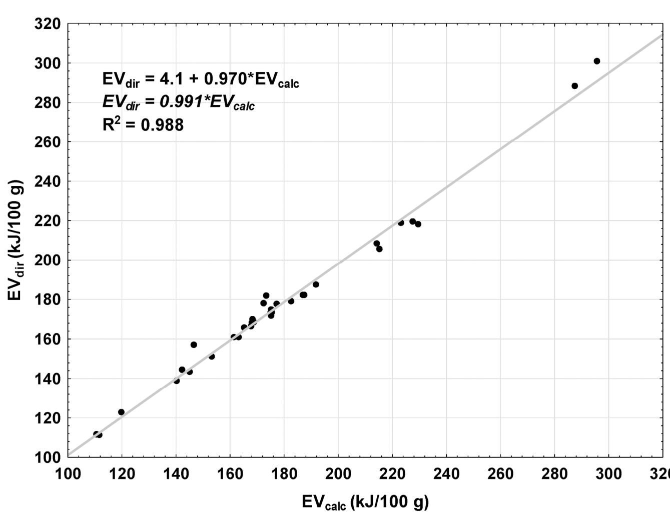

Fig. 2. Correlation between direct and calculating methods: lager beer.

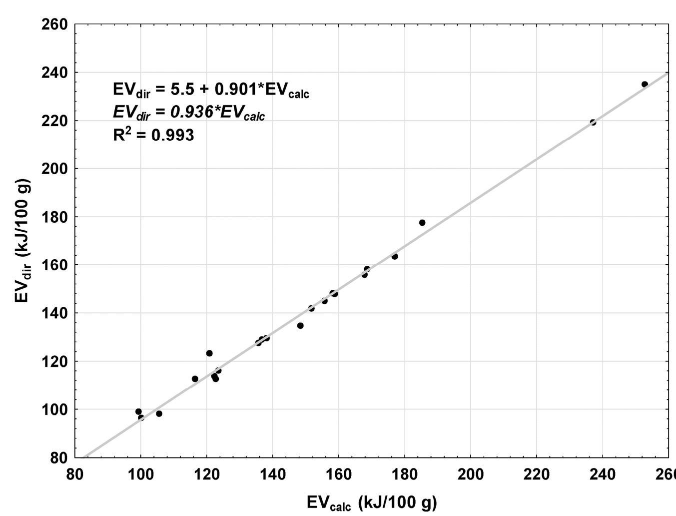

Fig. 4. Correlation between direct and calculating methods: beer mix.

be noted that this study was concerned with the discrepancies with the nonalcoholic beer, which is produced by the interruption of fermentation, and beer mix manufactured by mixing beer and sweetened soft drinks with a ratio of approximately of 1:1.

For further calculations, all results were converted to percentages by weight (Table I).

Unfortunately, the direct method underestimates results for nonalcoholic beer and beer mix; however, it is a higher-throughput method, which is a desirable feature for laboratories. Whereas the analysis time of EV_{dir} (using the direct method) is several minutes, the analysis time of EV_{calc} (using the calculation method) is several hours. Therefore, we propose a new equation for each type of beer using the obtained data, which were subsequently processed in the form of correlation EVs regarding the compared methods.

As is evident from Figures 2, 3, and 4, we have a good correlation for each tested beer type; coefficients of determination were 0.988, 0.987, and 0.993 for lagers, nonalcoholic beers, and beer mix, respectively. These were determined using least squares regression with and without intercepts (Figs. 2–4, shown by italics), which allows a comparison of EV_{dir} and EV_{calc} values.

However, only the equation for lagers is closest to the ideal form $EV_{dir} = 1 \times EV_{calc}$. Different results were found for nonalcoholic beers and beer mix (Fig. 3 and 4, respectively). The results for these two beverages (Table I) show that the value of EV_{dir} obtained by method 1 is underestimated.

Therefore, we recalculated the conversion factors of real extract *X* in formula $EV_{dir} = EV_{calc} = X \times E_r + 29 \times c_{alcohol}$. We found variables such as EV_{calc}, density, real extract, and alcohol content using the beer analyzer (densitometer connected with an alcolyser).

The results were calculated by linear regression from the individual beers, and selected statistical parameters were calculated for the coefficient *X* (Table II).

For lagers, the conversion factor of extract corresponds well to equation 2, which is 15; the experimentally determined factor is 15.2. Because the confidence interval for the mean was approximately 0.3 (double the value of the standard average deviation, a 95% probability), it could be considered a good agreement.

Finally, we obtained new conversion factors of extract for nonalcoholic beer and beer mix of 15.9 and 16.5, respectively. The confidence interval for the calculated value for nonalcoholic beer and beer mix is 0.2 and 0.3, respectively.

The new suggested formulae, which correlate with results of indirect method, are:

$$EV_{dir}\ (\text{kJ/100 mL}) = \varrho \times (15.9 \times E_r + 29 \times c_{alcohol}) \qquad (5)$$

for nonalcoholic beer and

$$EV_{dir}\ (\text{kJ/100 mL}) = \varrho \times (16.5 \times E_r + 29 \times c_{alcohol}) \qquad (6)$$

for beer mix.

The new formulae were confirmed using a regression line between EV_{calc} and EV obtained by a modified direct method with new conversion factors ($EV_{dir\ modif}$). The conversion line was constructed from the results of real used samples. The slopes of lines for all types of tested beers are close to unity (Table III). Consequently, the suggested model was verified using paired *t* tests between EV_{calc} and original EV_{dir}, and between EV_{calc} and $EV_{dir\ modif}$ (Table III). It is obvious that an average difference approached zero and standard error of the mean decreased when the modified direct method was used.

In a similar way, formulae for various types of fermented beverages could be derived for this purpose. It is worthwhile to invest time into optimizing the direct method in terms of the derivation of a specific equation, because this gave a fast, simple, feasible method, providing accurate results (comparable with the results from the calculating method). This method could also be considered a green method, because the method will avoid the chemical analysis of all macronutrients. The direct method is based on a simple measurement of the key parameters (density, extract, and alcohol content); the EV is subsequently automatically calculated. This measurement requires neither organic solvent nor derivatization reagent and, finally, the demands on energy and resulting time of the method will be low.

CONCLUSION

The direct method for the determination of the EV of beer based on the measurement of density, extract, and alcohol content was compared with the method based on the calculation from the content of each macronutrient and alcohol. Both methods are in good agreement for lager samples but, for nonalcoholic beers and beer mix, we found significant differences. Therefore, new formulae were developed for each type of drink, and we demonstrated better agreement with the calculation method. With this approach, a new, simplified method for the determination of the EV of nonalcoholic beers and beer mix was obtained, and we recommend this procedure for other beverages for which precise formulae are not yet estimated.

TABLE II
Conversion Factors for Energy Value Determination Using Direct Method

Conversion factor (*X*)	Lager	Nonalcoholic beer	Beer mix
Average	15.2	15.9	16.5
Standard deviation	0.97	0.51	0.66
Standard average deviation	0.17	0.09	0.14

TABLE III
Comparison of Energy Value (EV) Results from Calculation, Direct, and Modified Direct Methods

Comparison	Lager	Nonalcoholic beer	Beer mix
Regression slope with zero intercept (EV_{calc} vs. $EV_{dir\ modif}$)			
Slope	0.997	1.007	0.997
Standard error of slope	0.004	0.006	0.005
P value	<0.0001	<0.0001	<0.0001
Paired *t* test (EV_{calc} vs. EV_{dir})			
Mean difference (kJ/100 mL)	–1.3	–3.9	–9.2
Standard error of mean difference(kJ/100 mL)	4.6	4.9	4.8
Paired *t* test (EV_{calc} vs. $EV_{dir\ modif}$)			
Mean difference (kJ/100 mL)	–0.4	0.3	0.0
Standard error of mean difference (kJ/100 mL)	4.4	2.7	3.7

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