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The analysis of approaches to assessing the sugar content of fruit and vegetable products

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Abstract. The relevance of this study is due to the growing interest of modern consumers in healthy eating, where fruit and vegetables play an important role, which should not only be aesthetically pleasing but also have high taste potential. The purpose of the article is to analyse and compare different approaches to assessing the sugar content of fruit and vegetable products, their effectiveness, and to substantiate areas for improvement. For this purpose, the author analysed the literature and regulatory and technical documents. Traditional methods for determining the sugar content are considered: total content, soluble solids content, and total soluble solids content. It has been established that the soluble solids content and the total soluble solids content of fruits cannot be equated and should be adjusted using an appropriate coefficient based on the percentage of sugars. It has been shown that the content of total soluble substances does not always correctly reflect the sugar content and does not correlate with the taste of sweetness of fruit and vegetables. The necessity of taking into account acidity, which significantly affects the perception of sweet taste, has been established. High acidity can inhibit the sweet taste of fruit and vegetables, even with a very high sugar content. It is proposed to use the ratio of sugar content to titratable acidity for a comprehensive assessment of the sugar content and taste of products. The necessity of using the BrimA and sweetness indices, which combine the indicators of sugars and acidity, as well as reflect the contribution of a single carbohydrate to the total sugar content of the product, is substantiated. These indices allow for a comprehensive assessment of sugar content and predict the sensory perception of fruit and vegetable raw materials. The absence of a single standardised approach and the need for comparative analysis to select optimal methods for measuring the sugar content of fruit and vegetable products are noted, so there is an urgent need to standardise such approaches to improve data comparison. The results of the article can be used to select the most informative methods of sugar content analysis. This will optimise quality control procedures and standardisation of measurements in the food industry

Keywords: carbohydrates of fruit and vegetable raw materials; sugar content; acidity; sugar content indices; sensory perception of sugar content

Introduction

Modern consumers are increasingly focused on healthy eating and consuming more fruit and vegetables. They are looking for products that not only look attractive, but also have high flavour potential. Assessing the quality of fruit and vegetables by their appearance can help identify batches of products with signs of damage or defects before they reach store shelves. This will help to avoid loss of marketable weight and reduce waste. The ability of fruit and vegetable producers to manufacture products with an attractive appearance and high-quality taste can have a positive impact on their competitiveness in the market.

N. Sameshima & R. Akamatsu (2023) noted that various aspects of the appearance of fruit and vegetables influence their primary consumer choice, particularly in the context of their quality and aesthetic characteristics.

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Typically, consumers evaluate the quality of fruit and vegetable products by their appearance, colour, shape, and size. However, the decision to make further purchases will be determined by the taste and quality of the fruit, which cannot be assessed by appearance. K. Jürkenbeck *et al*. (2020) found that the flavour characteristics of fruit are directly related to the sugar and acid content of the fruit, its acidity, and texture. The sugar content of fruit and vegetables is determined by the content of sugars, mainly fructose and glucose. This characteristic is key to determining the quality and flavour of plant products.

The sugar content is an important indicator of the nutritional value of fruits and vegetables. In their study, M. Prada *et al*. (2021) notes that sugars are a source of energy and healthy carbohydrates for the human body. This is especially important in diets that emphasise natural and unaltered foods. Fruit and vegetables high in sugars add flavour and satisfaction and provide important nutrients to the human body. A.O. Bawajeeh *et al*. (2020) argues that consumers most often choose foods that satisfy their taste buds. High sugar content plays a key role in shaping a positive perception of taste at any age. The natural sugars (fructose and lactose) found in fruits and vegetables exist in combination with other nutrients such as vitamins, minerals, antioxidants, and fiber. This contributes to their slow absorption, avoiding a rapid rise in blood sugar levels and improving their metabolic effects (Zaitoun *et al.*, 2018). Therefore, natural sugars included in a diet with a varied and balanced diet can be part of a healthy lifestyle.

The sugar content of fruit and vegetable raw materials is a highly desirable characteristic for food producers, so it is regulated by adding sucrose or other sugars to the finished food product. With this in mind, quantifying the sugar content of foods of plant origin is extremely important. Usually, the content of natural sugars fructose, glucose, and sucrose is determined by physicochemical methods, as well as organoleptically (Dudarev & Kuzmin, 2023).

Assessing sugar content is an important aspect for producers and consumers, as it affects the quality and flavour of products. The relationship between the chemical composition of fruits, in particular their sugar content, and their flavour profile is an important aspect for understanding consumer perception of products. Among the publications related to the study of the relationship between sugar content and sensory perception of sweetness for fruits, it is worth noting the study by H.H. Wang *et al*. (2022). The paper presents an analysis of the relationship between the chemical composition of fruit, in particular sugars, and the perception of sweetness using sensors or flavour profile analysis.

The publication by K.B. Mejía-Correal *et al.* (2023) investigated the sugar content of fruit and vegetable products based on traditional indicators: soluble solids content and total soluble solids content. The work of M. Trius-Soler *et al.* (2020) describes the effect of acidity of fruit and vegetables on the perception of sweet taste, as well as the feasibility of using indices that allow to assess the effect of organic acids on the sugar content of fruit and vegetable products.

The purpose of this article is to review the carbohydrates of fruit and vegetable raw materials that determine their sweet taste, analyse and compare the main approaches to assessing the sugar content of fruit and vegetables; to establish indicators that allow the most informative and comprehensive assessment of the sugar content of fruit and vegetable products. In preparing the article, modern and fundamental works on the subject of research, data from experimental studies of fruit and vegetable sugar content assessment were processed. The following methods were used: search and analysis of scientific and technical information, systematisation and comparative analysis of literature data, analysis of regulatory documents (DSTU ISO 2173:2007).

Carbohydrates and their role in photosynthesis and nutrition

The sweet taste of plant material is mainly due to natural carbohydrates. Plants produce carbohydrates during photosynthesis. Plants can use carbohydrates either to obtain the energy necessary for vegetation and growth or as precursors in the processes of biosynthesis, synthesis of lipids, proteins, polysaccharides and other substances (Shanmugavelan *et al.*, 2013). Simple sugars (monosaccharides) are quite common and are found in almost all fruits and vegetables. The main monosaccharides in fruit and vegetables are glucose and fructose. Glucose is the most common natural monosaccharide. It is the main sugar in honey and is also found in large quantities in fruit, vegetables and legumes. It is most abundant in grapes, black currants, quince, and pears (BeMiller, 2018).

Fructose is considered to be the sweetest sugar among natural sugars and is found mainly in fruits, especially in persimmons, figs, mangoes, and cherries (BeMiller, 2018). Fructose is about 1.5-2 times more sweet than glucose (Merino *et al.*, 2019). This is due to the peculiarities of its chemical structure and interaction with taste buds, in particular, fructose has higher solubility, lower crystallisation capacity, and binds better to taste buds than glucose, which leads to its higher sweetness. Monosaccharides are the basic building blocks of most natural di-, oligo- and polysaccharides. Due to their ability to form glycosidic bonds, monosaccharides can be linked together in chains to form complex carbohydrates of various lengths and structures.

In contrast to monosaccharides, oligosaccharides, especially the disaccharides sucrose and lactose, are much more common in nature (Lim & Pullicin, 2019). Sucrose, which consists of glucose and fructose residues, is synthesised by plants during photosynthesis and is a source of energy for them, so it is present in edible parts of plants in various concentrations. In addition to imparting a sweet taste to fruit and vegetables, sucrose performs a number of technological functions in food products, in particular during caramelisation and canning processes. Raffinose and stachyose are oligosaccharides found in some fruit and vegetables. Raffinose is found mainly in legumes such as peas, beans, and soybeans. It can also be found in small amounts in onions, cabbage, and carrots. Stachyose is present in cereals such as wheat, barley, rye, and in small amounts in some vegetables. Jerusalem artichoke rhizomes contain the most stachyose. Raffinose and stachyose are inferior to sucrose in terms of sweetness, with a sweetness of 40-50% of sucrose (Ibrahim, 2018).

In their work, N.C. Kim & A.D. Kinghorn (2002) noted that the sweet taste of vegetables and fruit is mainly due to carbohydrates such as glucose, fructose and sucrose, which are formed either directly as a result of photosynthesis in plants or as products of hydrolysis of polysaccharides. In the work of H. Zheng *et al.* (2016) stated that sucrose, fructose, and glucose are the main sugars in grapefruit and account for 80% of the total soluble solids. In the work of Z. Li-Jing *et al.* (2015), while studying the content and composition of soluble sugars in apple fruits of different varieties, it was found that the main sugars in apples are fructose, glucose and sucrose. The sucrose content in oranges and grapefruits is predominant and the ratio of sucrose to glucose and fructose in all citrus fruit is almost constant and amounts to approximately 2:1:1 (Yu *et al.*, 2012).

The sweet flavour of plant material is therefore the result of natural carbohydrates that plants produce through photosynthesis, and these carbohydrates can be used for energy or as building blocks for the synthesis of other nutrients. Monosaccharides, such as glucose and fructose, are known for their widespread occurrence in fruit and vegetables, with fructose in particular being considered one of the sweetest sugars in nature, slightly surpassing glucose in its sweetness. Naturally occurring disaccharides, such as sucrose and lactose, not only impart a sweet taste to fruit and vegetables, but also perform important technological functions by assisting in preservation and caramelisation processes.

Traditional indicators for assessing the sugar content of fruit and vegetables

The traditional indicator used to assess the sugar content of fruits and vegetables is the total sugar content. It indicates the total weight of sugars (glucose, fructose, sucrose, etc.) in 100 g of the product. This indicator is generally accepted for comparing the sugar content of food products in accordance with the national standard of Ukraine (DSTU ISO 2173:2007, 2007), which is based on the International Organization for Standardization's ISO 2173:2003. This document establishes a refractometric method for determining the mass fraction of soluble solids in processed fruit and vegetables and allows estimating the content of natural and added sugars in grams per 100 grams of finished food product. The total sugar content indicator makes it easy to compare the sugar content of fruit and vegetable raw materials and food products, as well as to control the amount of added sugar in them.

The term "soluble solids content" or SSC is quite common in the modern (Guo *et al.*, 2019; Huang *et al.*, 2022). This indicator is a complete correspondence to the total content of sugars (glucose, fructose, sucrose) in fruit and vegetable raw materials and indicates their mass fraction (%). Along with the SSC indicator, another one is used – TSS (total soluble solids) – the total content of all soluble substances, including sugars, organic acids, vitamins, proteins, pigments, phenolic substances and minerals (de Brito *et al.*, 2021; Valverde-Miranda *et al.*, 2021; Mejía-Correal *et al.*, 2023). The total dissolved solids content is usually measured refractometrically or with an areometer and expressed in degrees Brix (Jaywant *et al.*, 2022). One Brix degree is equal to 1 g of sucrose in 100 g of solution (1°Brix = 1% sugar).

Table 1 shows the ranges of change in soluble solids and total soluble solids for some fruit and vegetables. The terms are very similar and closely correlated for most fruit and vegetables, as the majority of soluble solids are sugars. However, TSS is a more general indicator and it should be noted that for some fruits, natural sugars will not be the main component of all soluble substances. Citrus fruits are characterised by a high content of organic acids and, accordingly, sugar values will be lower, ranging from 25% of total soluble solids for lime to 85% for other citrus fruits (Wu *et al.*, 2021). Therefore, the SSC and TSS values for these fruits cannot be equated; the TSS value needs to be adjusted with an appropriate factor based on the percentage of sugars. The TSS value does not always correspond to the sensory perception of sweetness of fruit and vegetables (Kader, 2008). The results of this study show that the TSS value does not reflect the actual sugar content, so it should not be used as the sole indicator of sugar content for fruit and vegetable products.

Table 1. *Soluble solids content (SSC) and total soluble solids content (TSS) for some fruit and vegetables*

Products	Soluble solids content (SSC, %)	Soluble solids content (TSS, °Brix)	Source SSC/ TSS
Oranges	8-12	9-13	G. Suszek *et al.* (2017)
Lemons	5-8	6-10	S. Wu *et al.* (2021)/M.G. Aguilar-Hernández *et al.* (2020)
Grapefruits	8-10	10-13	J. Zhang *et al.* (2020)/B.S. Buslig (2018)

Table 1. Continued

Products	Soluble solids content (SSC, %)	Soluble solids content (TSS, ∘Brix)	Source SSC/ TSS
Cherries	13-22	14-25	I. Ivanova *et al.* (2021)/R.R. Pullanagari & M. Li (2021)
Strawberries	7-10	8-11	P. Abeytilakarathna *et al.* (2013)
Apples	10-16	11-17	L.M. Yuan *et al.* (2016)
Tomatoes	4-6	5-7	A.A. de Brito *et al.* (2021)/X. Hong *et al.* (2014)
Onions	8-12	9-13	G.A. Chope *et al.* (2012)/S.A. Shehata *et al.* (2017)

Source: *compiled by the author*

In the practice of determining the sugar content of fruit and vegetables, the indicator of total sugars is usually used. The terms "soluble solids content" (SSC) and "total soluble solids" (TSS) are used to assess the sugar content of fruit and vegetables, but the difference between them is that TSS takes into account not only sugars but also other substances that may affect the flavour of the product. Although TSS can be a useful indicator for some products, such as citrus fruits, where the presence of organic acids changes the ratio of sugars, it should be noted that this indicator does not always accurately reflect the sweet taste of a product and cannot be the only criterion for assessing its sugar content.

Sugar indices based on the acidity of the raw material

The organic acid content has a significant impact on the flavour of fresh fruit and vegetables. Sweet fruit do not necessarily have a high sugar content, but their acidity level is usually low (Zhang *et al.*, 2020). The contribution of different organic acids to the perception of sour taste is ranked relative to citric acid (weighting factor 1.0). The weighting factors for malic and tartaric acid are 0.9 and 0.8, respectively (Kader, 2008). Some amino acids, such as aspartic and glutamic acids, can also increase the acidity of fruit and vegetables. A.A. Kader (2008) states that the acidity of fruit and vegetables, in addition to organic acids, can be caused by some amino acids (aspartic and arginine), as well as by the products of the interaction of calcium, phosphorus and potassium with organic acids, which change the buffering capacity of the product and, accordingly, the perception of acidity. Higher acidity reduces the perception of sweetness, even with the same sugar content (Trius-Soler *et al.*, 2020). This is due to the masking of sweet flavour by sour flavour. The article by T.M.M. Malundo *et al.* (2001) states that at a threshold value of acidity (about 0.9%), the sweetness of taste is significantly suppressed. E.A. Baldwin *et al.* (2008) found that when 0.2% of organic acids were added to tomato puree, the sweetness sensation was significantly reduced.

The acidity of fruit and vegetable products is assessed by the titratable acidity in percentage terms, recalculated to malic, citric or other dominant acid in the product under study. Titratable acidity is a key factor in determining the perceived sweetness of fruit in combination with the sugar content. That is why the ratio of soluble solids to titratable acidity is often used to assess the perception of sweetness. J. Zhang *et al.* (2020) stated that the ratio of sugar content to titratable acidity is more informative than the total sugar content of fruit and vegetables to assess the sugar content and taste perception.

However, it should be noted that the soluble solids and titratable acidity values depend on many factors and can change as fruit and vegetables ripen (Song *et al.*, 2019). As the fruit ripens, the soluble solids content increases, the acid content decreases, and the ratio of soluble solids to titratable acidity will increase. That is why this ratio is used as a measure of fruit and vegetable maturity in many countries around the world (Gecer *et al.*, 2020).

Although the aforementioned indicator is quite common for assessing the sensory perception of sugar content of fruit and vegetables, there are some caveats to its use. The same ratio of soluble solids to titratable acidity can be obtained by varying the sugar and acid content. Therefore, with the same ratio of sugars to titratable acidity, there will be a different perception of the taste of fruit and vegetables.

In the work of A. Ikegaya *et al.* (2019) proposed to use the BrimA index to assess the sugar content of fruit and vegetables, which allows to establish a balance between the sugar content of raw materials and their acidity. This index is based on the difference between the total soluble solids content and the acid content, not on their ratio. BrimA can be calculated as follows:

$$\mathrm{BrimA} = SSC - k \cdot TK, \tag{1}$$

where *SSC* – soluble solids content; *TK* – titratable acidity index; *k* – constant that reflects the contribution of acid to sensory sensitivity compared to sugars.

The sensitivity constant *k* can take on values from 2 to 10 depending on the type or variety of fruit or vegetables. The value of the constant depends on the ratio and type of organic acids and sugars in certain types or varieties of fruit and vegetables. L. Chen & U.L. Opara (2013) note that the sensory sensitivity constant can be as high as 2 for pomegranate and 5 for citrus and grapes.

Taking into account that the BrimA index correlates well with the flavour characteristics of fruit and vegetables, it can be used as a better indicator than the traditional sugar-to-acidity ratio (Ikegaya *et al.*, 2019). This index is used as an indicator of the maturity and sweetness of fruit and vegetables and their suitability for long-term storage (Gupta *et al.*, 2021). The authors point to the prospects of using the BrimA index in the food industry and horticulture. However, the index has a number of drawbacks that limit its widespread use. In particular, the calculation of the index requires the adjustment of the constant *k* in equation (1) for different types and varieties of fruit and vegetables and additional validation for new hybrids and varieties. The BrimA index does not take into account the contribution of individual sugars to sweetness and needs to be compared with other methods of sweetness assessment.

M.A. Rosales *et al.* (2011) describes the use of the sweetness index (SI) as a measure of the sugar content of horticultural products. The essence of the sweetness index is the specific contribution of individual sugars (glucose, fructose and sucrose) to the total sugar content of the product (2):

$$SI = 2.3 \cdot C_{fructose} + 1.35 \cdot C_{sucrose} + 1.0 \cdot C_{glucose}, \qquad (2)$$

where *C* – molar concentration of glucose, fructose and sucrose.

The coefficients in equation (2) reflect the contribution of a single carbohydrate to the total sugar content of the product. The choice of these coefficients is due to the fact that, according to the authors' study, fructose and sucrose are 2.30 and 1.35 times sweeter than glucose, respectively.

There is another approach to assessing the contribution of individual sugars to the total sweetness of fruit and vegetable raw materials. The contribution of each carbohydrate to the total sweetness of the product is estimated relative to sucrose as a reference sugar, which is assigned an arbitrary value of 1, and for fructose and glucose the weighting factors are 1.5 and 0.76 (Beckles, 2012). However, different studies have used different sucrose concentrations as a reference. In the work of M. Carocho *et al.* (2017), a sucrose solution containing 30g of this substance in 1 liter at 0°C was used as a reference and assigned a sweetness of 1. Other researchers, such as M. Grembecka (2015) and S. Chattopadhyay *et al.* (2014) used a 10% sucrose solution as a reference and also indicated its sweetness as 1. Similarly, the relative sweetness of natural sugars compared to sucrose was determined differently in the above works: for glucose 0.5 or 0.75; for fructose 1.5-1.8 or 1.1-1.5; for lactose 0.2-0.4 or 0.15, etc.

In the work of A.A. Kader (2008), the coefficients reflecting the contribution of each carbohydrate to the total sugar content of products are different and amount to 1.20, 1.0, 0.64 for fructose, sucrose and glucose, respectively. In the work of Z. Li-Jing *et al.* (2015) found that the weighting coefficients of fructose, glucose and sucrose in the total sugar content of fruits are 1.75 for fructose, 1.0 for sucrose and 0.7 for glucose.

The issue of the optimal choice of coefficients that reflect the contribution of individual carbohydrates to the total sugar content is controversial. The analysis of scientific publications leads to the conclusion that there is no unified approach to the numerical values of the weighting coefficients of individual carbohydrates in the calculation of the sweetness index. Further research is needed to more accurately determine SI and assess sugar content, clarifying the contribution of each sugar for different types of fruit and vegetable products. However, in combination with other sugar content indicators, the sweetness index (SI) provides a comprehensive assessment of the sweetness of a product and is convenient for practical use.

Conclusions

The sweet taste of fruit and vegetable products is mainly due to natural sugars such as glucose, fructose and sucrose. Their content and ratio determine the sweetness of different types of fruit and vegetables. Traditionally, sugar content is assessed by total sugars, soluble solids content (SSC) and total soluble solids (TSS). However, these indicators have limitations related to the content of other components. It has been established that standard methods of sugar content assessment, in particular, total sugars, soluble solids, and total soluble solids, do not allow a comprehensive assessment of the sugar content of fruit and vegetables. Their values are not always consistent with the sensory perception of the sweetness of fruit and vegetables. Therefore, they should not be used as the only indicators of sugar content for fruit and vegetable products.

It has been proven that acidity significantly affects the perception of the sweet taste of fruits. Therefore, for a comprehensive assessment of the sweet taste of vegetables and fruits, it is proposed to use the ratio of soluble solids to titratable acidity and the BrimA index, which allow to establish a balance between the sugar content and their acidity. The use of the sweetness coefficient as an optimal indicator for assessing sugar content is described. The sweetness coefficient takes into account the contribution of individual sugars to the total sweetness of fruit and vegetable raw materials, but the values of the weighting coefficients in the works of different scientists vary significantly. The analysis of scientific publications leads to the conclusion that there is no unified approach to the numerical values of the weighting coefficients of individual carbohydrates when calculating the sweetness index.

As of 2024, there is a lack of comparative analysis in available sources of information on the effectiveness of different sweetness indices for evaluating fresh and processed fruit and vegetable products. The use of multiple indices makes it difficult to compare results and points to the need for standardisation of measurement and analysis methods to facilitate data comparison between industry and academia. Further research could focus on clarifying the contributions of the major sugars in raw fruit and vegetables to total sweetness and investigating the optimisation of methods for estimating the sugar content of fruit and vegetables.

Conflict of interest

None.

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Аналіз підходів до оцінки цукристості плодоовочевої продукції

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Анотація. Актуальність даного дослідження зумовлена зростаючим інтересом сучасних споживачів до здорового харчування, де важливу роль відіграють фрукти та овочі, які мають бути не лише естетично привабливими, але й мати високий смаковий потенціал. Метою статті є аналіз та порівняння різних підходів до оцінки цукристості плодоовочевої продукції, їх ефективності та обґрунтування напрямків вдосконалення. Для цього було проведено аналіз літературних джерел та нормативно-технічних документів. Розглянуто традиційні методи визначення вмісту цукрів: загальний вміст, вміст розчинних сухих речовин та вміст загальних розчинних речовин. Встановлено, що показники вмісту розчинних сухих речовин та вмісту загальних розчинних речовин фруктів не можна ототожнювати та потрібно коригувати за допомогою відповідного коефіцієнту, що базується на відсотковому вмісті цукрів. Показано, що вміст загальних розчинних речовин не завжди коректно відображає вміст цукрів і не корелює зі смаковими відчуттями солодкості плодів та овочів. Встановлено необхідність врахування кислотності, яка значно впливає на сприйняття солодкого смаку. Висока кислотність може пригнічувати солодкий смак овочів та фруктів, навіть за дуже високого вмісту цукрів у них. Запропоновано використовувати співвідношення вмісту цукрів до титрованої кислотності для комплексної оцінки цукристості та смаку продуктів. Обґрунтовано потребу використання індексів BrimA та індексу солодкості, що поєднують показники цукрів і кислотності, а також відображають вклад окремого вуглеводу у загальну цукристість продукту. Ці індекси дозволяють комплексно оцінити цукристість та передбачити сенсорне сприйняття плодоовочевої сировини. Констатовано відсутність єдиного стандартизованого підходу та необхідність порівняльного аналізу для вибору оптимальних методів вимірювання цукристості плодоовочевої продукції, тому нагальною постає потреба в стандартизації таких підходів для поліпшення зіставлення даних. Результати статті можуть бути використані для вибору найбільш інформативних методів аналізу цукристості. Це дозволить оптимізувати процедури контролю якості та стандартизації вимірювань в харчовій промисловості

Ключові слова: вуглеводи плодоовочевої сировини; вміст цукрів; кислотність; індекси цукристості; сенсорне сприйняття цукристості