

# Effect of physicochemical properties of maltitol on color characteristics of sugar free sponge cakes

Valentina Dobreva<sup>1\*</sup>, Veselin Nachev<sup>2</sup>, Georgi Dobrev<sup>3</sup>, Raina Hadjikinova<sup>4</sup>, Petya Boyanova<sup>5</sup>, Hristina Panajotova<sup>2</sup> and Borianna Zhekova<sup>2</sup>

<sup>1</sup>Engineering ecology, Faculty of Economics, University of Food Technologies, 4002 Plovdiv, Bulgaria

<sup>2</sup>Automation, information and control technology, Technical Faculty, University of Food Technologies, 4002 Plovdiv, Bulgaria

<sup>3</sup>Biochemistry and molecular biology, Faculty of Technology, University of Food Technologies, 4002 Plovdiv, Bulgaria

<sup>4</sup>Technology of tobacco, sugar, vegetable and essential oils, Faculty of Technology, University of Food Technologies, 4002 Plovdiv, Bulgaria

<sup>5</sup>Technology of milk and milk products, University of Food Technologies, 4002 Plovdiv, Bulgaria

**Abstract.** Maltitol (E 956) is a disaccharide sugar alcohol belonging to the group of sweeteners, food additives that are used in food formulations to obtain reduced calorie and weight control products. Its low energy value (2.4 kcal/g), low glycemic index (35 – for powdered maltitol) and 0.9 sweetness intensity make maltitol an appropriate sugar alternative for production of soft drinks, desserts, sweets and dairy products. Physicochemical characteristics of maltitol have important impact on overall quality of produced product – its taste, structure and color properties. Under conditions of acid and enzyme hydrolysis with invertase maltitol is practically not hydrolyzed unlike sucrose which reached degrees of hydrolysis 100% (acid hydrolysis) and 35 % (invertase hydrolysis). Maltitol and sucrose didn't participate in reactions of alkaline degradation and nonenzymatic browning at pH 9, pH 10 and in temperature of 80 °C. The replacement of sucrose with maltitol in sponge cake affects its color characteristics. It was measured that surface and inner layers of products with maltitol were with lower brightness then those with sucrose.

## 1 Introduction

Maltitol (E 956) is a disaccharide sugar alcohol belonging to the group of sweeteners, food additives that are used in food formulations to obtain reduced calorie, weight control and no added sugar products [1]. It is often used in a wide range of food applications due to its relatively low energy value (2.4 kcal/g), low glycaemic and insulinaemic responses - GI of 35 [2] and lack of cariogenic capacity [3, 4]. Maltitol has similar sensory profile to sucrose. Its sweetness intensity reaches 0.9 (1.0 for sucrose) and usually replace sucrose at approximately one-for-one concentration giving similar bulking effect.

Due to its technological advantages, maltitol application as sugar alternative in bakery products oftentimes attracts author's attention [5-10]. In [11], the authors researched the application of maltitol and other polyols in sucrose free sponge cakes. They noticed that products containing maltitol and xylitol had similar technological characteristics to the product obtained with an equivalent amount of sugar. Other studies focused on maltitol application in pastries revealed that its use in muffin formulation did not lead to significant differences in sensory acceptance of product [6]. In the work [5] is proposed a recipe composition for sponge cakes with a complete replacement of sugar syrup with maltitol. The resulting product is characterized by lower sweetness

and a lighter skin color. The structure and organoleptic indicators of cake dough and cake were analyzed, depending on used polyols for complete replacement of sugar in the composition. Best results were obtained for the dough and cakes with maltitol, lactitol and oligofructose, which came close to the sugar control sample [12]. More recently, Hao et al. [13], who studied the effect of sucrose substitution with polyols on foaming and thermal properties of egg protein in sponge cake found that sucrose and maltitol exhibited similar foaming properties. In addition, among other polyols, samples with sucrose and maltitol resulted in bigger and softer sponge cake and maltitol acted closer to sucrose in sponge cake system than xylitol and erythritol. Moreover, for sponge cake formulations it was found that sugar and maltitol interact with starch polysaccharides, stabilize the amorphous regions of the starch grain, which has an additional inhibitory effect on starch gelatinization [6, 14-16]. The retardation of starch gelatinization under certain conditions facilitates the formation and uniform distribution of air bubbles throughout the dough volume and the formation of the porous structure characteristic of all sponge products.

Most undertaken studies emphasize the influence of maltitol on structural characteristics and taste profile of sponge cake formulations. Considering this, aim of current study, was to evaluate the reaction of enzyme and acid hydrolysis of sucrose and maltitol, their

\* Corresponding author: [valentina.dobreva@yahoo.fr](mailto:valentina.dobreva@yahoo.fr)

capacity to participate in Mayard browning reaction and alkaline degradation and to determine their effect on color characteristics of sponge cakes formulations.

## 2 Materials and methods

### 2.1 Acid hydrolysis

To study the acid hydrolysis are used 1% water solutions of sucrose and maltitol and 1% HCl. Each sample was tempered for 5 min. at temperatures from 25 °C to 75 °C, in 5 °C increments [17]. After cooling to 20 °C, the concentration of reducing substances in samples has been determined by Luff Schoorl method [18]. Degree of hydrolysis was calculated in percentages as a ratio of reducing sugars expressed as invert sugar to the mass of sucrose or maltitol in the studied samples.

### 2.2 Enzymatic hydrolysis

Enzymatic hydrolysis was performed by preparing 10% solutions of sucrose and maltitol in acetate buffer with pH 4.6. The samples were tempered for 5 min at the investigated temperatures, after which 1 cm<sup>3</sup> of invertase enzyme extract with an activity of 4000 U/ml was added. The duration of the enzyme reaction is 10 min at temperatures from 25 °C to 70 °C in 5 °C intervals [17]. After completion of the enzyme reaction, 10 cm<sup>3</sup> of Fehling I and Fehling II solutions and 24 cm<sup>3</sup> of H<sub>2</sub>O are added to 1 cm<sup>3</sup> of the reaction mixture. Schoorl's method was used to determine the concentration of reducing sugars and the degree of hydrolysis was calculated in percent as a ratio of reducing sugars expressed as invert sugar to the mass of sucrose or maltitol in tested samples.

### 2.3 Preparation of invertase enzyme extract

10 g biomass of commercial product bread yeast (*Saccharomyces cerevisiae*), 0.5 cm<sup>3</sup> toluene, 10 cm<sup>3</sup> H<sub>2</sub>O and quartz sand are placed in a mortar. The biomass is crushed for 10 min and another 10 cm<sup>3</sup> of H<sub>2</sub>O is added. The sample is placed in thermostat for 18 – 20 h at 37 °C, after which the volume of sample is brought up to 100 cm<sup>3</sup> with distilled water and centrifuged at 5000 min<sup>-1</sup> for 10 min. The resulting clear supernatant contains active invertase [19].

### 2.4 Determination of invertase activity

To determine the invertase activity was applied a polarimetric method based on a change in the angle of rotation of the polarized light of a sucrose solution under the action of the enzyme [20].

One unit of invertase activity is defined as the amount of enzyme that hydrolyzes 1 μmol of sucrose in 1 min, at t = 30 °C and pH 4.6.

### 2.5 Alkaline degradation

The formation of colored products as a result of alkaline degradation of carbohydrates was monitored. 20% aqueous solutions of invert sugar, sucrose and maltitol at pH 9 and pH 10 and t = 80 °C were used. The color change of solutions was determined spectrophotometrically by measuring the light absorption of the samples at A = 420 nm during 10 min to 200 min [21].

### 2.6 Mayard browning reaction

The formation of colored products as a result of the non-enzymatic browning reaction was monitored. 20% aqueous solutions of invert sugar, sucrose and maltitol with 0.1 M glycine and with 0.1 M lysine were used. The color change of the solutions at pH 9 and pH 10 and t=80 °C was determined spectrophotometrically by measuring the light absorption of the samples at A = 420 nm during 10 min to 200 min [21].

### 2.7 Determination of color characteristics

It was used a standard spectrophotometric method by which the color characteristics are presented in the CIELab system, where the color coordinates are respectively: L\* - brightness, (L\* = 0 – black color; L\* = 100 – white color), a\* - green color (-) / red color (+); b\* - blue color (-) / yellow color (+), Cab\*, saturation, a value that characterizes the perception in a different way of the same color tone and expresses the following dependence:  $Cab^* = \sqrt{a^{*2} + b^{*2}}$  and hab\*, color tone or hue, describing the difference between primary colors and expressing the following relationship:  $hab^* = \tan^{-1} \left( \frac{b^*}{a^*} \right)$ .

Both characteristics describing the color of the crust of sponge boards and those defining the color of their middles are defined.

The results presented are average values from measurements of two separate batches of sucrose and maltitol sponge cakes prepared under equal conditions. In order to eliminate differences from inhomogeneity in the distribution of characteristics, they were determined at four different randomly selected points.

### 2.8 Analyze of color measurements results

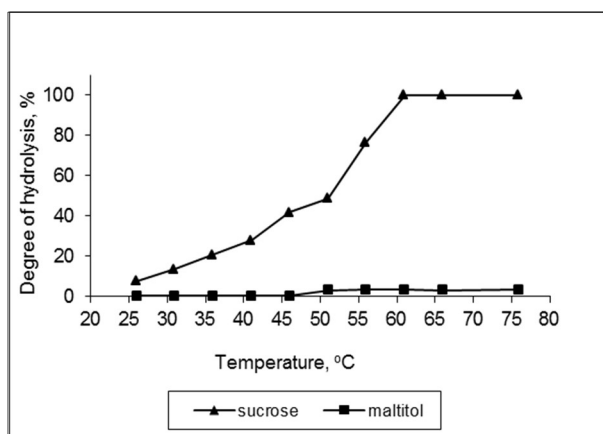
The principal component method (PCA) was used to analyze the results. This method allows determining the linear combinations of the output variables that best describe the differences between two samples. These combinations are called principal components. They are calculated interactively, with the first principal component carrying the most information (explaining the largest part of the variance in the source data) and the second carrying the minimum proportion of residual information (that which was not explained by the first). Through PCA, a visualization of the information contained in a data set is achieved. The method makes it possible to discover in what aspect one sample differs

from another, which variables have the greatest contribution to the appearance of this difference, and whether the variables influence unidirectional or are independent of each other. PCA provides a quantitative expression of the useful information contained in the measurement data [22].

### 3 RESULTS

#### 3.1 Acid hydrolysis

The obtained data from analysis on maltitol and sucrose stability in conditions of acid hydrolysis are shown on Fig.1. With temperature increase from 25 °C to 60 °C, degree of sucrose hydrolysis increases from 20% to 100%. Under the same conditions, maltitol is practically not hydrolyzed.

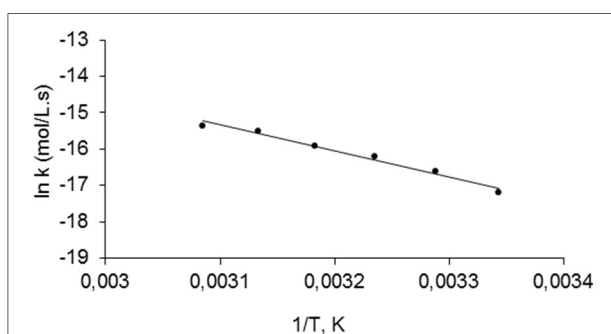


**Fig. 1.** Acid hydrolysis of sucrose and maltitol.

To determine the activation energy ( $E_a$ ) of sucrose hydrolysis, Svante Arrhenius equation was used:

$$k = Ae^{-E_a/(RT)} \quad (1)$$

The relationship between the rate constant of the reaction and the temperature is presented on Fig.2.



**Fig. 2.** Dependence between rate constant and temperature of acid hydrolysis of sucrose.

From Svante-Arrhenius equation and the expressed graphical dependence (Fig.2), the mathematical

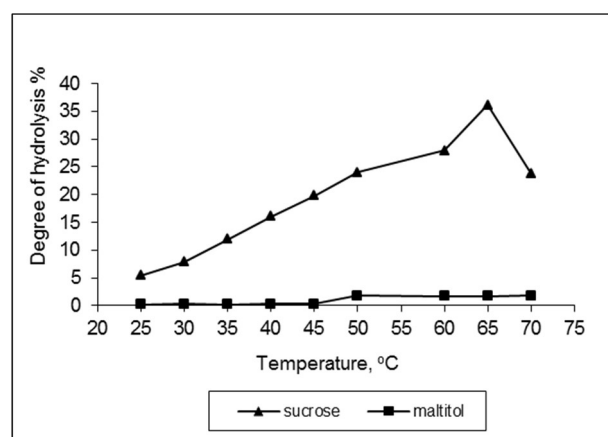
dependence between the slope of the curve ( $Slope$ ) and the relationship between the activation energy and the gas constant ( $E_a/R$ ) can be deduced, represented by the following formula:

$$Slope = -\frac{E_a}{R}, \quad (2)$$

from which the value of the activation energy of the chemical reaction of acid hydrolysis of sucrose is calculated:  $E_a = -7158,2 * (-8,314) = 59513,27 \text{ J/mol}$  (59,51 kJ/mol).

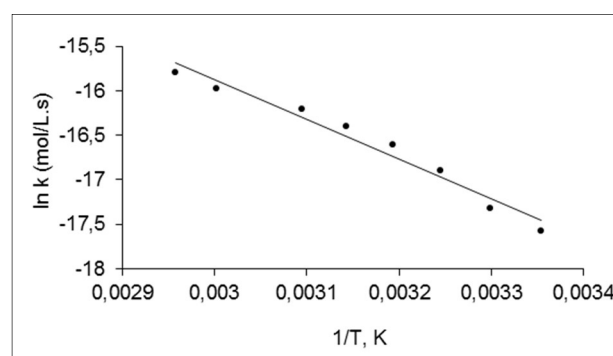
#### 3.2 Enzymatic hydrolysis

Obtained results for maltitol and sucrose stability in conditions of invertase enzyme hydrolysis are illustrated on Fig. 3.



**Fig. 3.** Enzymatic hydrolysis of sucrose and maltitol by invertase.

As the temperature increases, the degree of sucrose hydrolysis increases, reaching 36% at 65 °C. Under the same conditions, maltitol is practically not hydrolyzed. At  $t > 65 \text{ °C}$ , the degree of hydrolysis of sucrose decreases, which is due to inactivation of invertase.



**Fig. 4.** Dependence between the rate constant and temperature of enzymatic hydrolysis of sucrose with invertase.

From Svante-Arrhenius equation it was calculated  $E_a = -4462 * (-8,314) = 37097 \text{ J/mol}$  (37,1 kJ/mol).

Under studied conditions, the enzymatic hydrolysis reaction of sucrose is characterized by a significantly lower activation energy (37.1 kJ/mol) compared to the

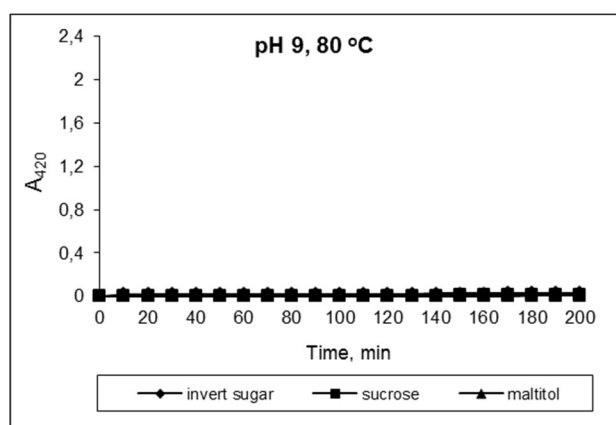
activation energy of the acid hydrolysis reaction (59.51 kJ/mol). This is due to the catalytic action of the enzyme invertase.

Invertase did not catalyze the enzymatic hydrolysis reaction of maltitol.

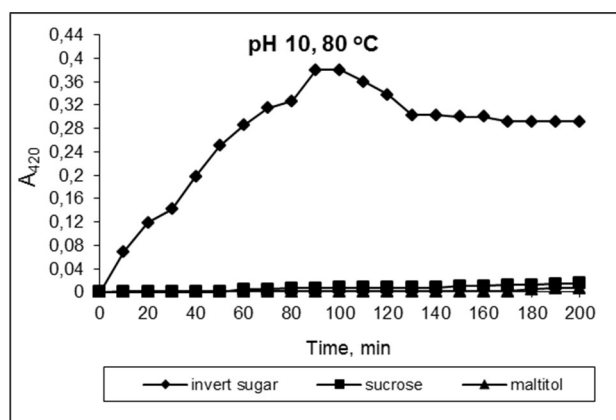
### 3.3 Alkaline degradation and non-enzymatic (Mayard) browning reaction

In alkaline conditions, depending on temperature and duration of its action, carbohydrates gradually change color from colorless to dark brown. The change in color is also accompanied by changes in the aroma, which to a large extent determine the aromatic-tasting qualities of a number of food products [23].

Took in consideration, the capacity of maltitol and sucrose to participate in alkaline degradation have been evaluated and compared to that of invert sugar (Fig.5 and Fig.6).



**Fig. 5.** Alkaline degradation of invert sugar, maltitol and sucrose at pH 9.

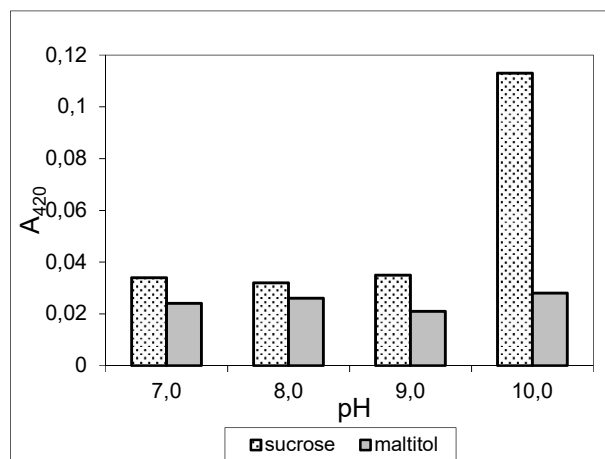


**Fig. 6.** Alkaline degradation of invert sugar, maltitol and sucrose at pH 10.

It was found that at pH 9 and  $t = 80$  °C, no color change was observed in all samples. At pH 10 and  $t = 80$  °C, maltitol and sucrose solutions remained stable, but the invert sugar underwent alkaline degradation, resulting in formation of colored products. In studied conditions maltitol and sucrose solutions exhibited

significantly higher resistance to alkaline degradation than the invert sugar solution.

The obtained results were supplemented by establishing the influence of pH (7–10) on color characteristics of aqueous solutions of sucrose and maltitol in  $t = 120$  °C for 30 min. (Fig.7).



**Fig. 7.** Absorbance of maltitol and sucrose water solutions at pH 7-10.

At pH values of 7 - 9, no significant change in the color of the tested samples was observed. At pH 10, a slight browning of the sugar solution is reported, which may be due to alkaline degradation.

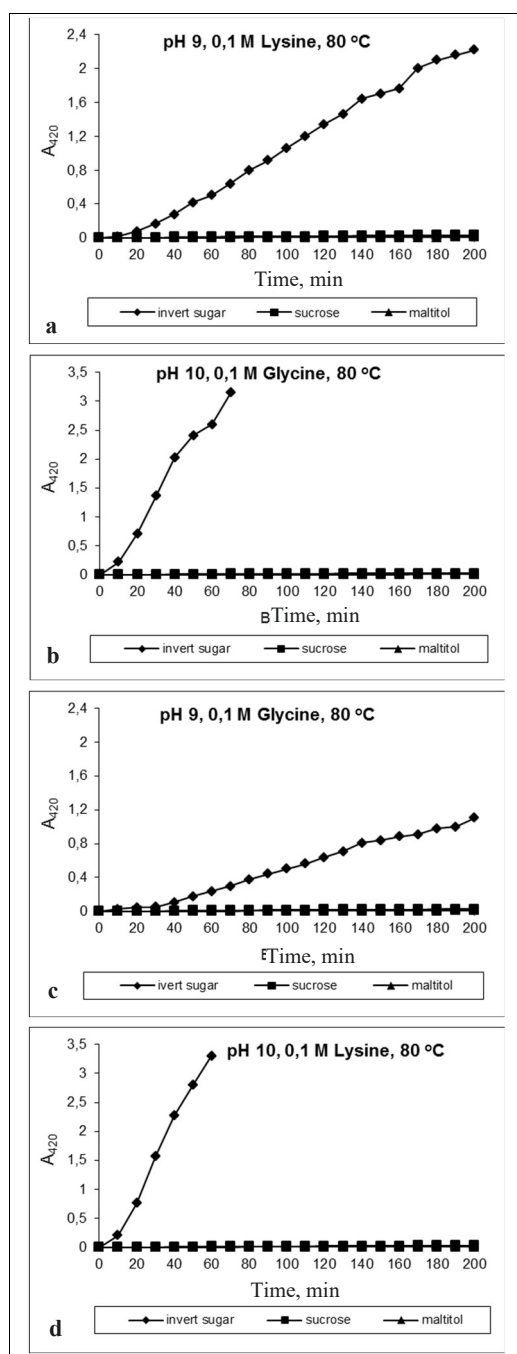
Of the known processes of non-enzymatic browning of food products, the sugar-amine reaction (Mayard reaction) has a significant impact on the formation of the appearance, aroma and nutritional value of the products. The Mayard reaction is based on a chemical interaction between the carbonyl group in reducing sugars with the amino group of free amino acids, peptides and proteins. The so-called schiff bases that polymerize into colored products. The factors that have a significant influence on the course of the reaction are the pH of medium, the temperature, the type of carbohydrate component and the amino acid.

Properties of maltitol, sucrose and invert sugar to participate in a non-enzymatic browning reaction at pH 9 and pH 10, temperature of 80 °C and in the presence of 0.1 M glycine and 0.1 M lysine have been studied.

Under studied conditions maltitol and sucrose do not participate in a non-enzymatic browning reaction (Fig. 8). In contrast, the invert sugar exhibits reactivity, which is measured by a change in light absorption. At pH 9, invert sugar reacted more intensively with lysine than with glycine and at 80 °C for 200 min, the light absorption of the sample with invert sugar and glycine is 1.2, while under the same conditions, but in the presence of lysine, the light absorption is 2.4. However at pH 10 the amino component did not affect significantly the rate of colored products formation in invert sugar sample.

It can be expected that the properties studied may affect the color of sponge cakes made with sugar and maltitol. For this purpose, the color characteristics of two sponge cake samples were examined – a control sample

with sucrose and a sample in which the sucrose was completely replaced with maltitol.



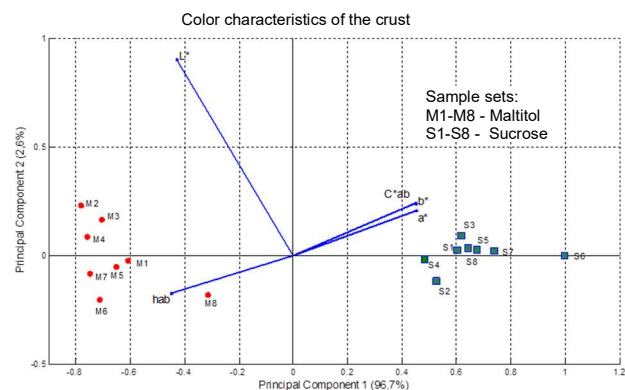
**Fig. 8.** Non-enzymatic browning reaction of invert sugar, sucrose and maltitol.

### 3.4 Color characteristics of sponge cakes prepared with maltitol and sucrose.

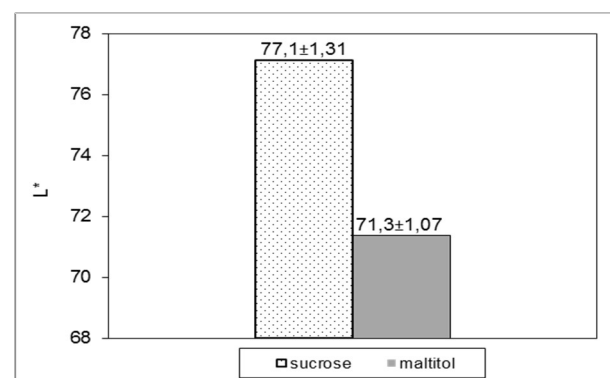
The measurements of L\*, a\*, b\*, Cab\* and hab\* characteristics of the sponge cake crusts are presented on fig.9.

The first principal component (Principal Component 1) is characterized by 96.7% of the variance of the data and allows the determination of the two types of sponge cakes. The resulting clusters are compact and linearly separable. The luminance (L\*), which represents the

degree of darkness in terms of a range of grays lying between white and black is the main component determining color characteristics of products. In sample measurements, sucrose sponge cake were found to have higher L\* values than the L\* values of maltitol sponge cakes (fig.10).



**Fig. 9.** Color characteristics of sponge cake crusts with sucrose and maltitol.

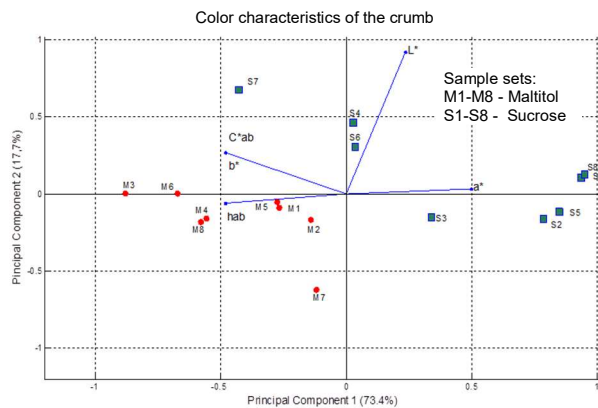


**Fig.10.** Luminance of sponge cake prepared with maltitol and sucrose.

The higher L\* values (77.1 ± 1.31) obtained for the sucrose sponge cake compared to the maltitol product (71.3 ± 1.07) indicate that the sugar sponge base has a darker color. Similar results for the brightness of sponge cakes with sugar and maltitol were also confirmed in the studies of Ronda et al., 2005.

The resulting difference in L\* values is also noticeable by direct visual inspection of the samples. Probably, the differences in color are due to the higher thermal resistance of maltitol compared to that of sugar, which under certain conditions hydrolyzes to invert sugar and participates in a non-enzymatic browning reaction with the amino acids and proteins of the product composition. As a result, the so-called schiff bases that polymerize into colored compounds and have a direct effect on the formation of a darker color of the products. This effect on color is also confirmed by our data from studies of the chemical reactivity of sucrose, maltitol and invert sugar to participate in a non-enzymatic browning reaction (Fig. 8).

The effect of sucrose and maltitol on color characteristics of sponge cake crumbs is shown on fig. 11.



**Fig. 11.** Color characteristics of sponge cake crumbs with sucrose and maltitol.

Both products have similar background color and lightness. Smaller differences in the color characteristics of the crumbs of samples compared to those obtained for the crusts can be explained by their lower temperature during firing. According to [24], during baking, the temperature in the surface layers of sponge cake reaches 170 - 180 °C, while in the middle it is 97 - 100 °C. A significantly lower temperature slows down reactions leading to the formation of colored compounds that give a darker color to the product.

## 4 Conclusion

Maltitol, sucrose, and invert sugar differ in their physicochemical properties, which affects the color characteristics of the cakes. Maltitol is significantly more resistant to hydrolysis compared to sucrose and exhibits higher thermal stability in alkaline medium. At 120°C and pH 10, significant darkening is observed in the sucrose sample compared to the maltitol sample. Alkaline degradation of invert sugar occurs at pH 10, but at a lower temperature of 80°C. Like the non-reducing disaccharide sucrose, maltitol does not participate in non-enzymatic browning reactions. Invert sugar, in the presence of free amino acids, forms colored products. At pH 9.0, non-enzymatic browning depends on the type of amino acid, and lysine enhanced the process. At pH 10, the type of amino acid does not affect the intensity of browning.

The differences in the physicochemical properties of maltitol and sucrose affected the color characteristics of sponge cakes made with these sweeteners. The sucrose sample is characterized by a significantly darker crust and crumb compared to the maltitol sample. This is likely due to either hydrolysis of sucrose leading to non-enzymatic browning or alkaline degradation of sucrose. These results are important for developing technological solutions for producing cakes with desired color characteristics.

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