The effect of grinding on the apparent color of the yellow sugar powder

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Understanding the grinding technique as a very useful tool for super fine powder manufacturing is critically important. The colors of powders are related to the fineness of the powder. This paper contains the results of experimental studies of the effect of grinding on the color of the yellow sugar powder. The fineness of the yellow sugar samples has been monitored by a granulometric analysis. The powder sample is sifting through a stack of mesh sieves, separating it into discrete size ranges. After sieving, yellow sugar powder distinguished by various degrees of grinding is transferred directly to the computer screen by a USB microscope. Color changes have been studied by using RGB (Red, Green, Blue) and HSL (Hue, Saturation, Lightness) color models. For the yellow sugar, color changes from dark yellow to white due to diffuse reflection on the powder particles. By fitting the experimental data the dependence of the L and S values on diameter has been established. Based on recorded Raman spectra, the diffusive reflectance and the absorption coefficients have been determined.

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1. Introduction

Food powders can be considered as systems of a solid disperse and a gaseous phase widespread in people's daily life and food industry production [1,2]. From food ingredients such as sugar or flour to instant foods, compounding nutritional supplements, and functional foods, numerous food products are found in powder forms leading to the rapid growth of the powder industry, and relevant industries that manufacture the machines for making powders. Knowledge of the particle size distribution of a powder is a critical step in most production and processing operations [3-5]. Furthermore, the size and distribution of particles in food and drink products can affect the taste, texture, appearance, and stability of the product.

It was shown that grinding of colored material may cause a different color as compared to the original material [6]. The color of the powder depends on dehydration, storage, and powder coarseness [7]. The personal perception of color varies in dependence on the sensitivity of the eye, the size of the object being viewed, background color, illumination, etc. Particle size distribution has a significant effect on the mechanical strength, density, electrical and thermal properties of the finished object. The relationship between the apparent color of the powder and the particle size has a wide range of practical applications including food production, paints, ceramics, the conservation and restoration of historical artifacts, in pharmacology and dentistry [8-13]. The improper size analyses may result in poor product quality, high rejection rates, and consequently economic losses.

Depending on the particle size, one may distinguish 'fine grain' with dimensions smaller than 1 μm, 'medium grain' between 1 and 10 μm, while greater dimensions correspond to 'coarse grain'. The dimension of the particles determines the smoothness, gloss, and uniformity of the powder. Powders consisting of coarse grain particles induce very saturated color but have poor hiding power unlike those with fine grain, which instead have greater hiding power [14]. In powders consisting of larger and irregular particles, the light easily penetrates through the different paint layers, and then, the contribution of the support to the light reflected is greater. On the other hand, homogeneous and thin grains ensure good hiding power, but little tinting strength. When light shines onto a powder sample, some of the light undergoes specular reflection at the powder surface. Some of the light passes through particles and is partially absorbed. At the boundary surfaces of the powder grains, there is reflection and transmission of the beam. Since these boundary surfaces are stochastically oriented, the trajectory of the beam through the powder is also stochastic. Therefore the reflection of the light on the particles of the powder has a diffuse character [15]. To obtain a more accurate diffuse reflectance spectrum the specular reflection and thereby the particle size must be reduced. Diffusion affects the color since it determines the average path of light in the material and therefore the absorption of different wavelengths. The relation between the absorption coefficient and diffuse reflectance is given by Kubelka-Munk (K-M) expression [16]. The dependence of the reflection coefficient on wavelength determines the powder color.

Food powders are obtained from solid materials by grinding, milling, crushing, granulation or mixing. The most widely available refined sugars in stores are granulated, powdered, and yellow sugars. In this paper, we have studied the color changes due to the grinding of yellow sugar. Grinding powder is passed through a sieve and the particles fall through the mesh. The color of powders was analyzed by using RGB (Red, Green, Blue) and HSL (Hue, Saturation, Lightness) color models [17]. Graphs showing the dependence of the RGB and HSL values on the diameter of particles are plotted. Based on the Kubelka-Munk formalism correlation between Raman intensity and diffuse reflectance has been provided.

2. Method

Powdered sugar is granulated sugar that has been mixed with a small amount of cornstarch available in varying degrees of fineness [18]. For this study, we have performed a granulometric analysis of yellow sugar by using sieving as one of the oldest techniques of powder classification. Sieving is among the most widely used and least expensive techniques for the determination of particle size distribution over a broad size range [19]. The advantages of using this technique are relative simplicity of the technique, low capital investment, high reliability, and low level of technical expertise required in its application, characteristics not often associated with other techniques of size analysis. In sieving, samples are exposed to the vertical movement (vibratory sieving) or horizontal motion (horizontal sieving) comparing particles with the apertures of every single sieve. The appropriate sieving method depends on the degree of fineness of the sample material, while the probability of a particle passing through the sieve mesh depends on the ratio of the particle size to the sieve openings, the orientation of the particle, and the mesh openings. In our measurements, the open of the sieve mesh was varied from 3 mm to 61 μm. After sieving, powder of yellow sugar characterized by various degrees of grinding is transferred directly to the computer screen by a USB microscope. Then, Little RGB Color Picker [20] was used to determine colors that correspond to the RGB (Red, Green Blue) model. In our studies, RGB analysis consists of the following steps: 1) taking a single layer of granular material, 2) taking pictures, 3) determination of RGB values on a different part of pictures, 4) averaging RGB values for 5 different parts of pictures and then 5) using RGB to HSL converter to determine HSL (Hue, Saturation, Lightness) values. Besides, the Raman spectrum has been used to determine diffusion and absorption coefficients of yellow sugar powder since the Kubelka-Munk formalism correlates the diffuse reflection of a sample with an apparent absorption.

3. Results

The effect of the grinding on the color of yellow sugar is shown in Fig. 1. When the particle size is around 3 mm, the color of sugar is dark yellow. With decreasing the particle's diameter, R, G, and B values increase and the color gradually changes from yellow to white. With a further decrease of the particle size, R, G, and B values become closer and the powder becomes lighter.

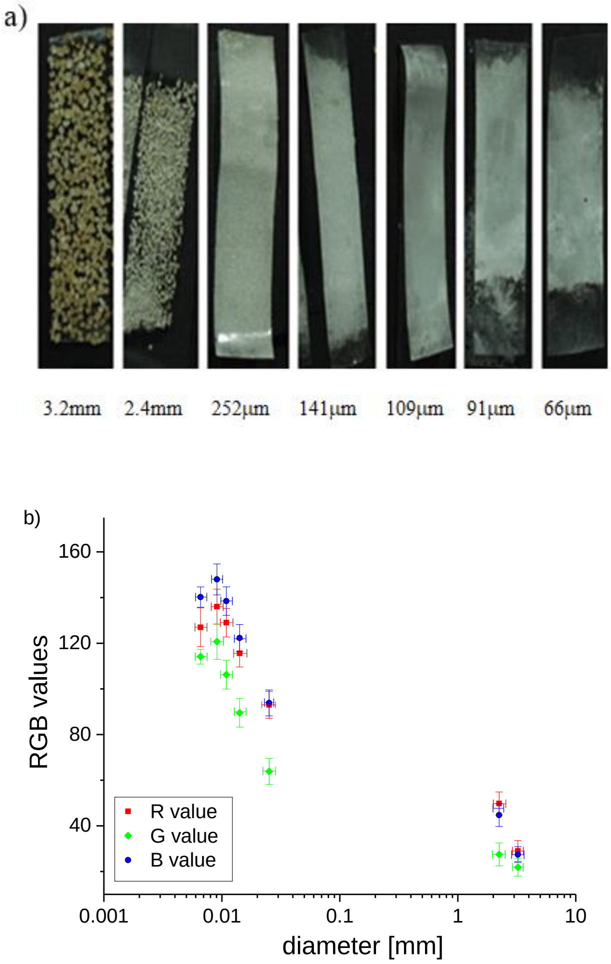

Fig. 1. a) Grinding of yellow sugar and b) corresponding dependence of the RGB values on the particle diameter (color online)

The effect of grinding on the HSL values is depicted in Fig. 2. When the particle size is around 3 mm, the hue is around 50 that corresponds to the color between orange and yellow. With decreasing the diameter, the H value increase, and approaches to 130. With decreasing the diameter, the lightness increases while the saturation decreases. By fitting the experimental data we suggest the dependence of the L and S values on diameter.

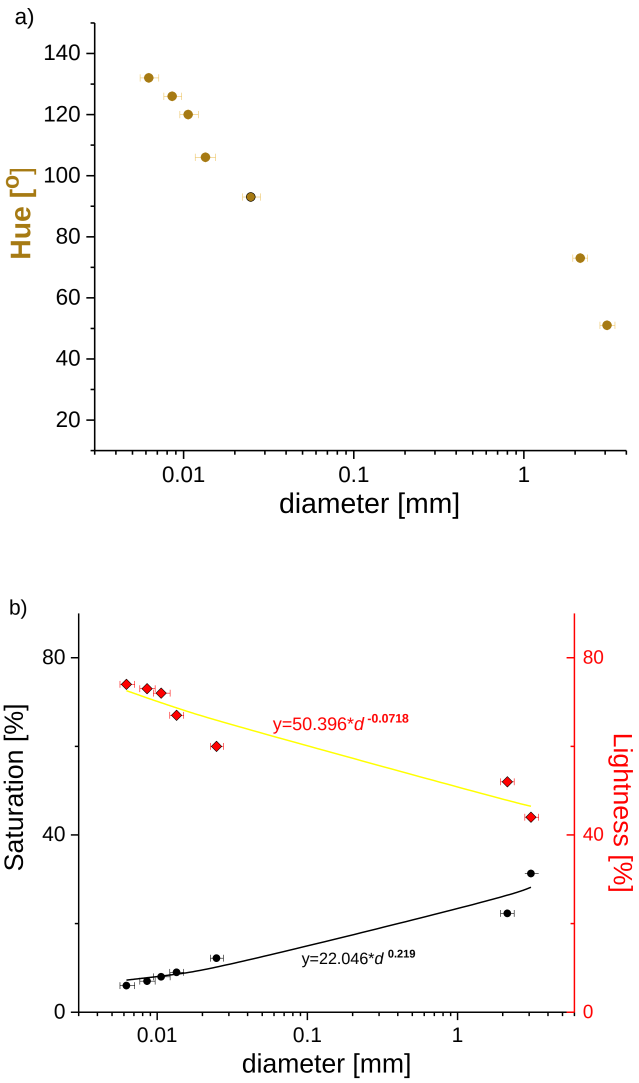

Fig. 2. a) Hue and b) Saturation and Lightness values as a function of the particle diameter (color online).

Fig. 3 shows the particle shape and degree of agglomeration of the yellow sugar determined by SEM imaging at different magnifications to illustrate powder and particle morphology. A range of particle sizes is often used in seasoning to achieve an initial flavor impact by the finer particles, followed by a lingering aftertaste from the coarser particles.

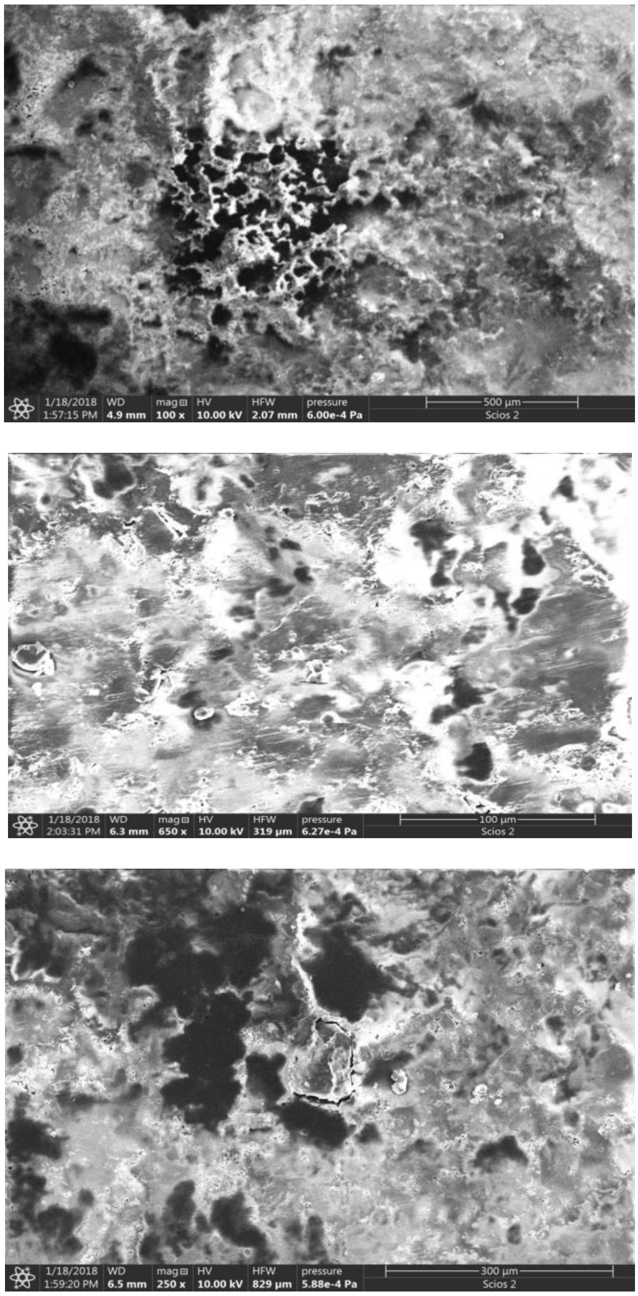

Fig. 3. Scanning electron microscopy (SEM) Micrographs of yellow sugar at different magnifications

The Raman spectrum of yellow sugar depicted in Fig. 4a is expressed in a form of the intensity of scattered light versus Raman shift. When light is incident on a powder sample, reflection, scattering, absorption, and transmission through the sample may occur [21]. Based on the Kubelka-Munk formalism Raman intensity can be correlated to the diffuse reflectance [22] and thereby absorption coefficient as plotted in Fig. 4b. It is well known that the color of a material is determined by the wavelengths that were absorbed and reflected. Therefore, if the material reflects all wavelengths of visible light it appears white.

4. Discussions

As can be seen from Fig. 1, the color of granulated sugar with the particle size around 3 mm is dark yellow. After the first sieving (particle size is around 2 mm) the color changes to light yellow. With further decreasing the particle size, R, G, and B values increase, and color gradually become lighter. Fig. 2 demonstrates how the grinding procedure affects the HSL values. Since hue is more specifically described by the dominant wavelength, its value increases as the particle size decreases. On the other hand, saturation is the brilliance and intensity of a color. When a pigment hue is "toned," both white and grey are added to the color to reduce the color's saturation. With decreasing the diameter of the particle *d*, saturation decreases while the lightness increases and both can be fitted by $\sim Ad^B$ (where *A* and *B* are the appropriate coefficients). Changes in the granulation and structure of the yellow sugar with grinding can be seen in Fig. 3. When light interacts with small particles it is either specularly reflected or diffusely reflected. Diffuse reflected light penetrates the surface bearing the structural and chemical information. From the Raman spectrum (Fig. 4a), a diffuse reflection of a sample can be determined and related to an apparent absorption (Fig. 4b).

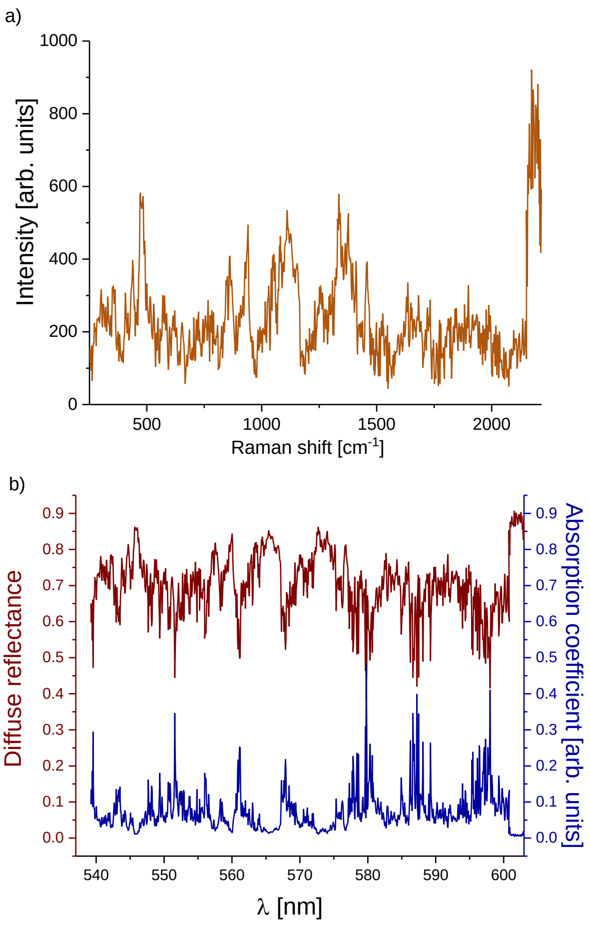

Fig. 4. a) Raman spectra of yellow sugar recorded with a 532 nm excitation wavelength and b) corresponding diffusive reflectance (color online)

5. Conclusions

This paper reports on the experimental study of the effect of the grinding on the apparent color of the yellow sugar. Sugar manufacturers often rely on using sieving analysis due to its low initial cost and its seemingly simple operating procedure. The particle size distribution of a powder is an indicator. Powders with a broad size distribution are characterized by poorer flowing as compared to those with a narrow size distribution. The particle size also affects the color of the powder. By grinding the yellow sugar and sieving it through different meshes the fineness of the powder can be monitored. The colors of powders are related to the fineness of the powder when the powder is illuminated with white light. For yellow sugar, color changes from dark yellow to white due to diffuse reflection on powder particles determining the average path of light in the material and therefore to what extent different wavelengths are absorbed. Kubelka-Munk equation provides the relation between diffuse reflectance and absorption coefficient. Also, Kubelka-Munk formalism correlates the Raman spectrum with diffuse reflectance. Color changes can be also considered by using color models. With decreasing the particle size, Red (R), Green (G), and Blue (B) values increase as well as values of Hue (H) and Lightness (L) while Saturation (S) decreases. Results for S and L have been fitted and an empirical relation has been proposed. Besides fundamentals, the results presented here could be useful in a wide range of practical applications.

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