Journal of Food Biosciences and Technology,
Islamic Azad University, Science and Research Branch, Vol. 5, No. 2, 11-18, 2015

Measurement of Morphological Characteristics of Raw Cane Sugar Crystals Using Digital Image Analysis

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Received: 8 February 2015 Accepted: 21 April 2015

ABSTRACT: Raw cane sugar is one of the most important product in the sugar industry and is the main raw material for the white sugar production. Morphological and physical properties of this product might influence the final white sugar. For instance, the behavior during centrifugation, transport and storage is related to the characteristics of these crystals. The object of this study was to determine the morphological factors in raw cane sugar using digital image processing. For this purpose, two sets of imported and domestic raw cane sugars were collected and different factors related to the area size, perimeter, squareness and crystal count were determined. The results showed that the mean area for the imported sets of raw sugars was 154.1994 pixel while for the domestic sets was 220.6249 pixel. This parameter reflects the size of crystals. Perimeter and squareness characteristics and count of crystal in 0.5 g sample were also demonstrated. The results of this study demonstrated that digital image processing technique might be regarded as a useful way to determine the physical and morphological characteristics of different raw sugar crystals.

Keywords: *Digital Image Analysis, Morphological and Physical Properties, Raw Cane Sugar.*

Introduction

Raw sugar is one of the main products in the sugar industry. It can be obtained from sugar cane and sugar beet sources (Asadi, 2007). Raw cane sugar consists of sucrose crystals covered with a thin layer of low-purity syrup. This syrup has a much lower purity (55 to 70% depending on the raw-sugar quality) than crystals (above 99%) (Chou, 2000; Asadi, 2007). The importance of raw cane sugar is that its application as the major raw material for the production of white sugar (Engida *et al*., 2013). Research has shown that the morphology or behavior of a crystal is the significant parameter in industrial manufacture of chemicals that might influence the processing condition such as filtration, efficacy and product formation (Asadi, 2007) and obtaining an unexpected morphology might lead to time delays or products rejection (Motta & Pons, 2005). In the sugar manufacturing factories, the sieve method for determining the size and shape properties of raw and refined sugar crystals is well established internationally for quality assessment (Miller & Beath, 2000). This method has several advantages and disadvantages. It is relatively straightforward technique that can be implemented in the production environment and requires only low technology equipment to give acceptable reproducibility. It does, however, require a large sample and relatively long preparation and measurement time as well as limited quantitative information (Argaw *et al*., 2006; Chou, 2000).

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Digital image processing is a methodology that emerged in 1970s to process simple images without specific applications (Du & Sun, 2004). Over the time, this technique was refined and multiple applications of digital image processing emerged. Image processing and computer vision, an important research area due to rapid technological development, have applications including machine vision, medical imaging, satellite imagery, video, digital cinema and art. The main objective of image processing is to improve the appearance of images and to augment certain details that will be used for further interpretation (Abraham *et al*., 2011; Brosnan & Due, 2004).

Digital image processing systems, to determine the qualitative and quantitative properties of sugar crystals, have attracted the attention of scientists in recent years. Argaw (2007) studied, determined and evaluated sugar crystallization using image processing techniques and concluded that size distribution of the sugar particles during crystallization process is essential for high quality sugar with a good appearance.

Determination of morphological features of sugar crystals by image processing was the subject of a study by Faria *et al*. (2003). They reported that valuable information concerned with the size and morphology of sugar crystals can be obtained by image processing techniques using an applied algorithm to show the crystals' growth and by controlling the growth using image processing systems, they took some steps forward in using novel and faster methods for quality control in industrial processes.

Daliziel *et al*. (1999) also indicated that image analysis techniques might be used to determine the size of crystals at the pan stage and showed that results were more accurate than manual microscope estimation and more rapidly available than using a sieve analysis. Martins et al (2005) used image analysis technique to measure the crystal mean size during a boiling run. Nevertheless, the applicability of this method was limited to small crystal contents (up to 10%) due to the image complexity.

Image analysis techniques were widely used to explain the precipitation of calcium oxalate (Bernard-Michel, 1999), calcium carbonate precipitation (Vucak *et al*., 1999), agglomeration of gibbsite (Pons *et al*., 2005) and NaCl crystallization in the presence of an impurity (Ferreira *et al*., 2005).

This paper has aimed to test a system that measures the raw cane sugar morphological properties, such as area size, perimeter, squareness and crystal number counts, using a simple digital image processing techniques to automatically analyse a crystal captured by the flat-bed scanner that is interfaced with computer.

Materials and Methods

- *Raw cane sugars*

Different raw cane sugars, as mentioned in Table 1, were prepared. The samples were taken from the crops of the 2012-2013 fiscal years. They were stored in sealed packages protected from light and air. The samples were classified into two groups to simplify the statistical tests and the comparisons; imported and domestic group, therefore numbered 1-6 are imported samples while the samples numbered 7-11 were the domestic samples.

- *Image analysing tests*

Image processing was performed using a flat-bed scanner (Epson Ea-GI1-16, Japan), a personal computer and MATLAB software (ver.7). In order to obtain the desirable result, 0.5 g raw sugar crystal was weighed and dispersed on the flat-bed scanner. The images were scanned at 800 dpi and stored as uncompressed TIF file. The sampling method used in the flour mills – i.e. bamboo was employed to ensure that the collected sample would be a representative from all parts of the specimens. Tubes with diameters and lengths of 1cm and 30cm were used respectively. The dimensions of the tube ensured that the whole specimen would cross the tube. A Sartorius scale made in Germany with the accuracy of 0.00001 was used for this purpose. Samples were collected from 11 raw cane sugar with 3, 4, and sometimes 5 replications to ensure the accuracy. Images of the sample were analysed on a PC with the image processing toolbox in Matlab Software. Several image descriptors were obtained from each crystal such as mean area, median area, maximum area, mean perimeter, median perimeter, maximum perimeter, mean squareness, median squareness and maximum squareness. Green, red, and purple numbers represent squareness, perimeter, and area factors of sugar crystals respectively (Figure 1).

Table 1. The list of raw cane sugars used in this research study

No.	Origin	Type
1	India (A)	Imported raw cane sugar
2	India (B)	Imported raw cane sugar
3	Brazil (A)	Imported raw cane sugar
4	Brazil (B)	Imported raw cane sugar
5	Brazil (C)	Imported raw cane sugar
6	Brazil (D)	Imported raw cane sugar
7	Iran (Amir Kabir Agro Industry)	Internal raw cane sugar
8	Iran (Karoon Agro Industry)	Internal raw cane sugar
9	Iran (Dehkhoda Agro Industry)	Internal raw cane sugar
10	Iran (Mirza Kochak Khan Agro Industry)	Internal raw cane sugar
11	Iran (Farabi Agro Industry)	Internal raw cane sugar

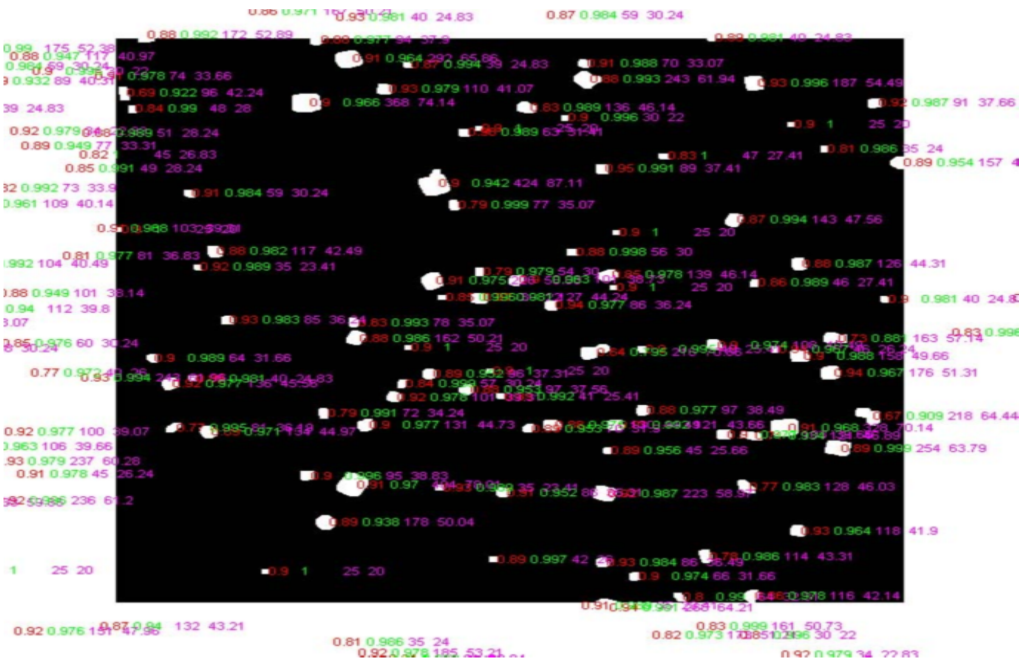

Fig. 1. Images of samples analyzed in MATLAB

Results and Discussion

The results of image processing are shown in Tables 2, 3 and 4. The results show significant differences of area size between the imported and domestic sets. The size of raw cane sugar crystals is one of the most important parameter in sugar industry. Technologically, this parameter influences significant operations like centrifugation, affination and storage. Rheological properties, floatability, solubility, lump formation and hygroscopic behavior are also related to the size of crystals (Mironescu, 2006). It is important to remember that large crystals have spent a longer time in the solution than smaller ones, thus increasing the probability of becoming agglomerates (Faria *et al*., 2003). Agglomeration might lead to profound changes in the final product quality, as well as entrapment of unacceptable levels of occluded solvent causing difficulties in washing and drying (Yu *et al*., 2007). Area mean of the crystals for the domestic and imported samples were 220.62 pixel and 154.2pixel respectively, thus, the imported set had a desirable area characteristics than the other group.

Numerous factors can affect the size and shape of the crystals. The effects of impurities on the crystal size and morphological properties has been investigated over the years (Clarke, 1993; Ravno and Purchase, 2005; Kaour and Kaler, 2008). Some impurities affect the properties of the solutions while others might alter crystals surface changing their morphology or behavior (Faria *et al*., 2003).

Ferreira *et al*. (2011) reported that the presence of invert sugar during crystallization of raw sugars is one of the important parameter that can affect the morphological changes, therefore elongated crystals are produced. Crystals grown in the presence of D-glucose are more elongated that the ones grown in the presence of D-fructose.

Mean of median and maximum areas for the imported samples were 124.45 and 910.75 (pixel), while for the domestic values were 195.23 and 967.67 (pixel) respectively (Table 2).

The mean of perimeter for the imported and domestic samples were 45.99 pixel and 57.29 pixel respectively (Table 3). In mathematics, the perimeter is the distance around a two dimensional shape. The high perimeter index reflects the high porosity, as well as unusual and irregular shape of the crystals in the sample. Motta and Pons (2005) defined the Surface Concavity Index as a factor to show the percentage of porosity on the sugar crystals that is in agreement to the perimeter of crystals (Motta & Pons, 2005). The lowest perimeter belonged to number 4 (Brazilian B) and the highest to number 10 (Iranian, Mirza Kochak Khan Agro Industry).

The impurities either increase or decrease the growth rate of crystals depending on the surface properties of the crystal impurity and also on the solute. Some impurities might exhibit selective influence on a particular crystallographic face and act as a concavity and porosity agents (Martin et al., 2007). The presence of impurities also showed a significant alteration in the morphology of the growing crystals (Murugakoothan *et al*., 1999; Sangwal, 1996; Sangwal, 1993; Martin *et al*., 2007). Macromolecular impurities such as polysaccharides and colorants (melanoidins) can also be included in the crystal in case of rapid growth according to a “finger” growth type where cavities are created at the surface of the crystal that are closed to include the macromolecular impurities (Faria *et al*., 2003; Belharmi and Mathlouthi, 2004).

Table 2. The results of image analysis for area factors

No	Mean Area (pixel)	Standard Deviation of area	Median Area (pixel)	Maximum Area (pixel)
1	285.19	175.33	247.33	1285
2	128.09	94.09	102.00	943.33
3	126.58	90.28	100.37	741.50
4	127.34	96.48	97.33	673.67
5	110.86	87.42	83.33	924.33
6	147.13	107.12	116.33	924.33
7	252.16	152.21	218.33	1071.33
8	193.14	92.46	180.17	720.67
9	189.20	139.69	154.17	1132.33
10	293.94	148.76	275.50	923.67
11	174.67	110.20	148.00	930.33

The squareness is defined as a factor that specifies the square properties of the crystals. It takes the value 1 for a square and 0 for a circle crystals, also this parameter is contrary to the circularity characteristic that is illustrated by Ferreria *et al*. (2011) and Motta and Pons (2005). The influence of different impurities on circularity and square property has been studied over the years (Saska and Polack, 1982; Sangwal, 1993; Sangwal, 1996). Polysaccharides decrease the rate of growth of sucrose crystals due to an increase in viscosity of mother solution and also a reduction in the rate of incorporation of molecules into the growing crystal (Belharmi and Mathlouthi, 2004). Dextrans are among the major impurities present in cane sugars (Ravno and Purchase, 2005). Although it can be formed within the factory, it is widely accepted that the bulk of the dextran present in processing streams arises from the post harvest degradation of sugar cane prior to crushing. There is a strong evidence suggesting the effectiveness of dextran on increasing the elongation and deformation and also decreasing the circularity of the final crystal (Sutherland, 1968; Clarck, 1993; Chou, 2000; Faria *et al*., 2003; Argaw, 2006; Kaur and Kaler, 2008; Shaikh *et al*., 2011). Mean squareness of the crystals for the imported set (0.8772) was higher as compared to the domestic set (0.8518). This indicates that square properties of the imported group were closer to the ideal square form than the domestic ones. In addition, squareness median of the imported samples (0.8918) was larger than those of the domestic sets (0.8651).
Maximum and minimum mean values of squareness were obtained for sample No.1 (Indian A) and sample No.7 (Amir Kabir Agro Industry) (Table 4).

Numbers of crystals of raw cane sugar in 0.5g samples were obtained through the image analyzing system. Using the count number of crystals, we can obtain crystal size, therefore for a specific sample, lower mean size of crystals means higher number of crystals. Regarding this, the maximum and minimum numbers of crystals were calculated in the samples number 5 (Brazilian C) and number 1 (Indian A) respectively.

Table 3. The results of image analysis for perimeter factors

No	Perimeter Mean (pixel)	Standard Deviation of Perimeter	Perimeter Median	Perimeter Maximum
1	64.41	20.47	62.08	150.06
2	42.66	15.78	39.70	154.95
3	42.15	14.97	39.25	124.47
4	42.10	15.82	38.76	121.41
5	39.42	15.24	35.76	150.16
6	42.20	16.28	42.34	145.18
7	62.93	22.08	59.46	192.90
8	54.86	14.49	53.83	123.62
9	51.42	19.15	48.59	142.31
10	67.16	19.95	65.94	142.64
11	50.10	16.07	47.71	153.36

Table 4. The results of image analysis for squareness factors

No	Squareness Mean (pixel)	Standard Deviation of Squareness	Squareness Median	Squareness Maximum	Crystal Number
1	0.882	0.055	0.892	0.969	660
2	0.867	0.067	0.886	0.963	1989
3	0.879	0.056	0.893	0.972	1851
4	0.876	0.060	0.891	0.973	1812
5	0.880	0.062	0.897	0.965	2141
6	0.878	0.055	0.891	0.964	1645
7	0.826	0.073	0.838	0.956	842
8	0.834	0.066	0.845	0.961	1018
9	0.874	0.056	0.886	0.961	894
10	0.853	0.067	0.870	0.953	705
11	0.872	0.054	0.884	0.958	1348

Conclusion

In sugar industry the process control is used to ensure that the final exit product meets the required quality standards. The morphological forms and behaviors of crystals are important properties on desirable crystallization, also raw cane sugar crystals having the regular shape and size are more interesting for raw sugar refining process. In this study a computerized method has been developed to measure raw cane sugar crystal morphology. Images were captured by spreading the crystal sample on the flat-bed scanner. Image analysis might be used to assess the morphological properties of raw cane sugar crystals rapidly. In the present work, the possibility of measuring sugar crystal parameters (area, perimeter, squareness and number of crystal) using digital image processing was introduced. The results are more accurate than visual estimates and more rapidly available than using sieve analysis.

The two sets of raw cane sugars were compared by digital image analysis system. The result indicated that the imported raw cane sugars had more desirable characteristics as compared to the other. It has been claimed that raw sugar crystals with regular and uniform size and shapes show better efficiency in refining process. Several factors might influence the raw sugar morphological properties and impurities. The impurities affect the crystal size and morphological properties. It might be suggested that imported set had lower impurity and high sucrose content as compared to the domestic set, therefore it had better remelting and crystallision during processing.

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