Color Formation in White Beet Sugars

Marianne McKee, Ronnie Triche, Mary An Godshall and Charley Richard
Sugar Processing Research Institute, Inc.,
1100 Robert E. Lee Boulevard, New Orleans, LA 70124

Previous studies by SPRI have shown that beet sugar colorants tend to be very reactive and autocatalytic in nature. These studies have shown the development of colorants over the course of sugarbeet processing. Colorants that tend to transfer into the crystal usually have high molecular weight and are formed during processing, most likely the result of alkaline degradation of invert sugars during carbonation. From this point, the colorants increase throughout the process especially during evaporation where the increase may be as much as 15% to 25%. White beet sugar color increases during storage are usually due to two factors – the syrup layer around the crystal and the high molecular weight colorants found inside the crystal. The differences in these two factors will be discussed for white sugars produced during a beet campaign and a thick juice campaign.

Introduction:

The perception by customers and consumers that high color sugar is lower in quality makes color an important quality indicator in sugar processing. Color is a generic term used to describe a wide range of components or colorants that contribute to the visual apperance of sugar. Colorants are materials made up of various molecular weight, pH sensitivity, ionic charge, chemical composition, and affinity for the sugar crystal. Colorants can transfer into the sugar crystals creating sugar that is not white and therefore presumed lower quality. Higher color can lead to increases in viscosity of sugar processing solutions causing lower sucrose yields. By causing a lower yield of sugar, higher color may be linked to a loss of money for the sugar factory. Higher color may also be linked to filterability issues leading to another problem for sugar factories.

The major component of beet raw juice is sucrose. Several minor components of beet raw juice include organic acids, anions, cations, oligosaccharides, fatty acids, nitrogenous compounds, reducing sugars, enzymes, polyphenolics, and polysaccharides. Many of the minor components are removed during processing, but a few remain and can contribute to color formation. Organic non-sugars such as organic acids, amino acids, or reducing sugars may act as catalysts for color formation in sugarbeet solutions. The presence of this mixture of compounds in contact with moisture, air and light seem to present the opportunity for color formation in sugarbeet processing.

Colorants form by various reactions in sugarbeet processing. These reactions include ones that occur in high pH environment, low and high temperatures all found in beet processing. The interaction of organic non-sugars also leads to colorant formation. One example of this is the beet sugar color created during the carbonation step of the process at high temperature and pH.[1] Examples of low temperature reactions include oxidation, the reaction of non-sugars with oxygen. Two examples of oxidation reactions are the reaction of oxygen and the amino acid tyrosine to form colored compounds in solution as well as the browning of the cossettes after slicing. Another low temperature reaction is melanization. This reaction results in a class of compounds referred to as melanins. They are formed by the interaction of phenolic compounds with amino acids or proteins and they are usually created between slicing of the beets and heating of the juice in the diffuser.

High temperature colorant reactions include Maillard reactions and caramelization. An example of a Maillard reaction is the interaction between an amino acid and reducing sugars to form melanoidins. These reactions produce high color and viscous solutions that can reduce crystallization rates. Most of the colorants formed by this reaction type are removed during juice purification, but they can reform due to the high temperatures in evaporation and crystallization. A second type of high temperature reaction is caramelization. This is the decomposition of sucrose to glucose and fructose and finally caramel at temperatures close to the melting point of sucrose (around 185°C).

The color that is formed during the processing of sugar beets tends to be reactive in nature and subject to increasing over time. Beet sugar color is considered to be autocatalytic due to the increase of color over time without the addition of any other components to the sugarbeet system. Minor constituents found in beet processing have the ability to influence color formation. Two examples of these autocatalytic reactions include self-polymerization reactions for example that of hydroxymethylfurfural (HMF) and oxidation of polyphenolics. Other minor constituents such as organic acids, amino acids, and reducing sugars can act as catalysts for color formation reactions.

Changes in quality, specifically color, have long been an interest of SPRI. In a study of soft sugars, it was found that high moisture content was the best predictor of color increase over time. Organic acids and phenolic acids were also found to contribute to the formation of color over time.[2] Another study by SPRI examined components of thick juice and extract over time to determine the effect of storage on color under laboratory conditions.[3] Pyroglutamic acid and lactic acid were two components identified in the study that changed over time as color increased. Lactic acid is a primary product of alkaline decomposition of sucrose and a major microbiological product that may have several sources. Pyroglutamic acid is a major nitrogenous compound found in sugar beet processing from the glutamine in the sugarbeet plant. Under the alkaline or heated conditions used in sugarbeet processing, glutamine will lose ammonia to form pyroglutamic acid.

The objective of this work is to determine the effect of storage on the color of white beet sugar produced from beet and thick juice campaigns. Sugar samples were analyzed for initial quality parameters including pH, ICUMSA color and turbidity, indicator value (IV) and ash. Ethanol washing was performed to determine the amount of color in the surface layer. Sugars were submitted to accelerated storage conditions in order to demonstrate the effect of storage on color of these samples.

Experimental:

White beet sugars produced either during beet campaigns or thick juice campaigns were provided by SPRI sponsors. Three beet campaign sugars and three thick juice campaign sugars were collected. Upon receipt at SPRI, the sugars were analyzed for pH, ICUMSA color and turbidity, indicator value (IV) and ash. A portion of each sugar was washed with ethanol to remove the surface layer of material surrounding the crystal to determine the amount of color on the surface as well as the amount of color in the crystal. The sugars were submitted to an accelerated storage test at 55°C for 4 weeks. Color was measured by ICUMSA Method GS1/3-7, and turbidity determined by difference using the same method.

Results and Discussion;

The three beet juice campaign and three thick juice campaign sugars were analyzed for initial quality immediately after receipt at SPRI. The results are shown in Table 1. pH varied for the different campaign sugars. The beet campaign sugars pH ranged from 6.75 to 6.83 while the thick juice campaign sugars pH was higher ranging from 7.35 to 7.39. The color of the beet campaign sugars ranged from 28 IU to 32 IU while all three thick juice campaign sugars had a color of 34 IU. Turbidity was lower in the beet campaign sugars (8-9 IU) compared to 13-17 IU for the thick juice campaign sugars. Indicator value (IV) ranged from 1.20 to 1.25 for all sugars. This is within the range that is typical for beet sugars indicating that the colorants in these sugars are primarily formed in process by thermal degradation, caramel, or melanin type reactions and not phenolic in nature which would suggest that the colorants were derived from the sugarbeet plant. Ash for all samples ranged from 0.014 to 0.016% showing no difference between the different campaign sugars. Moisture of the beet campaign sugars ranged from 0.045% to 0.075% with an average of 0.06% while the thick juice campaign sugars ranged from 0.055% to 0.065% with an average of 0.06%; therefore, no difference in the average moisture for beet campaign or thick juice campaign sugars was noted.

Table 1. Initial quality of sugars as received. B indicates beet campaign sugars and TJ indicates thick juice campaign sugars.

Sample	pH	Color (IU)	Turbidity (IU)	IV	% Ash
B1	6.83	28	9	1.21	0.014
B2	6.80	32	9	1.25	0.015
B3	6.75	32	8	1.21	0.014
TJ1	7.35	34	15	1.23	0.015
TJ2	7.39	34	13	1.20	0.016
TJ3	7.36	34	17	1.20	0.015

Next the sugars were washed with ethanol to remove the surface layer and determine the amount of color contained in the surface layer and in the crystal. Figure 1 illustrates the original color and the color after washing in each of the samples. The color decreased after washing for all the samples studied indicating the removal of the surface layer colorants.

Table 2 shows the percentage of color in the surface layer for each sugar sample.

Table 2. Color in surface layer for each sugar sample

Sample	Original Color (IU)	Color after washing (IU)	Color on Surface (IU)	% Color on Surface
B1	28	22	6	21.4
B2	32	26	6	18.8
B3	32	27	5	15.6
TJ1	34	31	3	8.8
TJ2	34	28	6	17.6

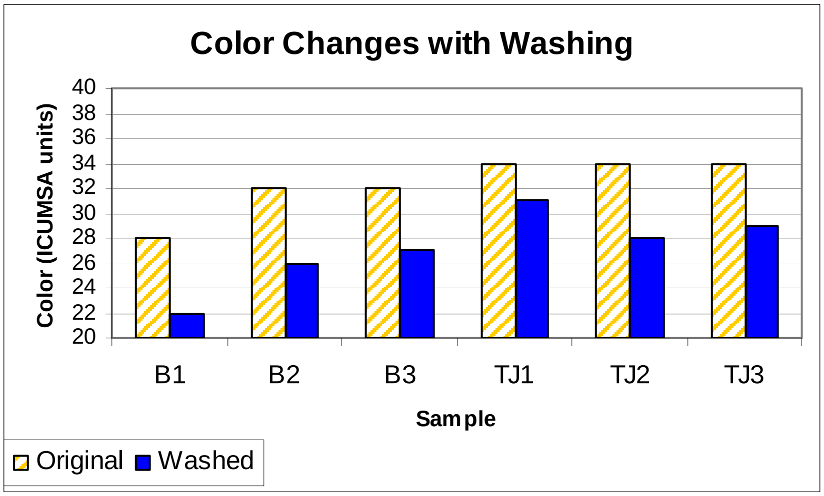

Figure 1. Changes in color after washing with ethanol

All sugars showed a decrease in color after washing with ethanol as shown in Figure 1. The surface syrup layer is thought to be removed by washing the sugars with ethanol causing a decrease in the color of the sugar. The amount of the decrease in color is representative of the amount of the color that is found in the syrup layer surrounding the crystal. For the beet campaign sugars, the percent of color on the surface ranged from 15.6 to 21.4 with an average of 18.6% as shown in Table 2. The thick juice campaign sugars had an average of 13.7% color on the surface with individual samples ranging from 8.8% to 17.6%. The beet campaign sugars had approximately a 5% greater amount of surface layer color when compared to the thick juice campaign sugars.

Another parameter that showed differences after washing the sugars was the pH. The beet campaign sugars decreased an average of 11.8% with pH values ranging from 5.93 to 6.04 after washing compared to 6.75 to 6.83 before washing. The thick juice campaign sugars decreased in pH an average of 9.1% with pH values ranging from 6.65 to 6.74 after washing when compared to pH values of 7.35 to 7.39 originally. These results are shown below in Figure 2.

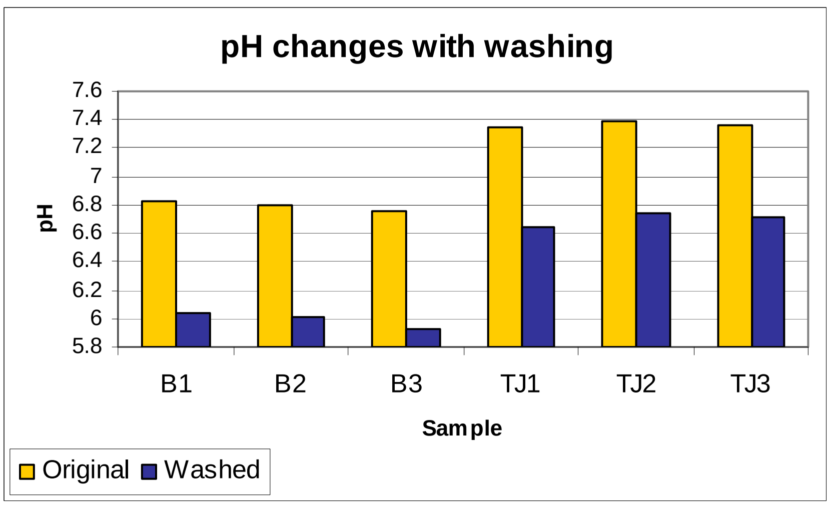

Figure 2. Graph illustrating pH changes during ethanol washing of white beet sugars

Sugars produced during both campaigns were submitted to an accelerated storage test with conditions consisting of 4 weeks at 55°C. After the storage test, the color of the sugars was measured and the results shown in Table 3 below.

Table 3. Color results after accelerated storage

Sample	Original color (IU)	Color after accelerated storage (IU)	% color increase
B1	28	38	35.7
B2	32	38	18.8
B3	32	39	21.9
TJ1	34	37	8.8
TJ2	34	37	8.8
TJ3	34	37	8.8

B1 with the highest percent of color in the surface layer showed the largest increase in color during the accelerated storage test (35.7%). The thick juice campaign samples with lower colorants on the surface showed less of a color increase (8.8%) during the accelerated storage test.

Results are illustrated in Figure 3 below.

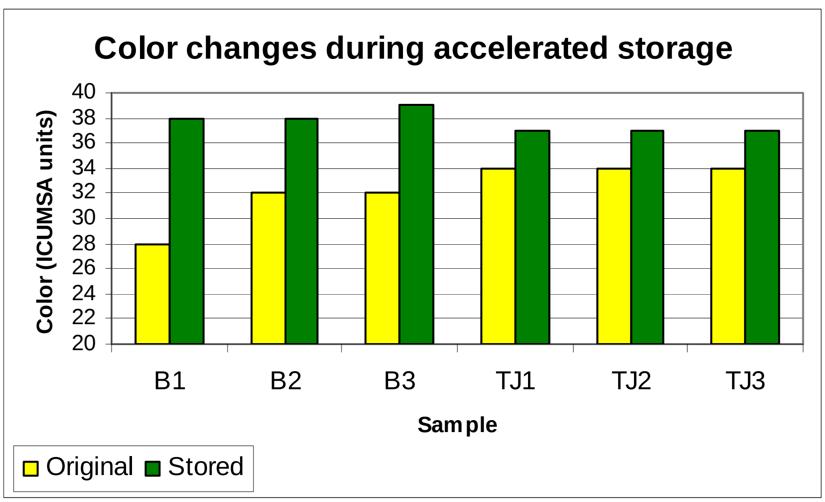

Figure 3. Graphs showing color increase during accelerated storage of white beet sugars.

After accelerated storage, the beet campaign sugars had higher color than the thick juice campaign sugars which were originally higher in color. The beet campaign sugars have more color in the surface layer which may account for the larger increase in color during accelerated storage.

After the storage test, the stored sugars were washed with ethanol to remove the surface layer of color. The results are shown below in Table 4 and Figure 4.

Table 4. Color results after accelerated storage sugars were washed

Sample	Color after accelerated storage (IU)	Color after washing stored sugars (IU)	% color on surface
B1	38	25	34.2
B2	38	29	23.7
B3	39	30	23.1
TJ1	37	29	21.6
TJ2	37	28	24.3
TJ3	37	30	18.9

The color removed from the surface of the stored sugars is higher than that of the original non-stored sugars. This demonstrates the autocatalytic nature of the surface layer by an increase in color when the sample is subjected to the 55°C environment for an extended amount of time. The average difference in the percent of color on the surface between the beet campaign sugars and the thick juice campaign sugars is approximately 5% as was the case when studying non-stored sugars.

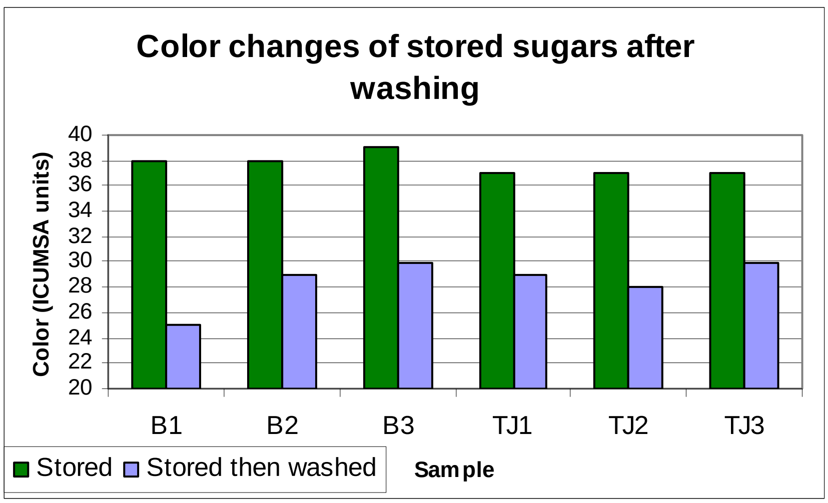

Figure 4. Color decreases of stored sugars after washing with ethanol.

Summary and Conclusions:

For the six sugar samples studied here, the beet campaign sugars had the highest amount of color in the surface layer, average of 18.6%, compared to the thick juice campaign sugars with an average of 13.7%. The beet campaign sugars also showed the greatest decrease in pH with ethanol washing – average of 11.8% compared to an average 9.1% decrease for the thick juice campaign sugars. Upon accelerated storage, the beet campaign sugars showed the greatest color increase with an average of 25.5% compared to an average 8.8% increase for the thick juice campaign sugars. Ethanol washing after the accelerated storage revealed color in the surface layer in the beet campaign sugars of an average 27% while the increase in the surface layer color for the thick juice campaign sugars was 21.6%.

In this study, the beet campaign sugars showed more color increase during storage when compared to sugars produced during the thick juice campaign. The beet campaign sugars had more color contained in the surface layer and this could lead to an increase in color during storage for many reasons. One reason may be that the surface layer is exposed to more air and oxygen and has a higher moisture content which can lead to color formation. The surface layer may also contain more of the smaller, more reactive molecules that carryover from raw juice or that form during processing which can also contribute to color formation.

References:

1. Godshall, M.A.; McKee, M.; Moore, S.: Triche, R. *ASSBT Proc. Operations.* **2005,** p 34.
2. Godshall, M.A.; Miranda, X. *Proc. Sugar Proc. Res. Conf.* **1996,** p 437.
3. McKee, M.; Triche, R.; Godshall, M.A.; Richard, C. *Proc. ASSBT* **2009,** p.