Introduction

The types and amounts of pigments in sugarcane juice are dependent on a number of factors such as the variety and maturity of the raw material, climatic conditions, agricultural practices, time between cutting and processing, quantity of impurities, soil conditions and grinding types [1].

Sugarcane contains many colorant compounds that could be extracted from its juice [2]. In 1971, a study on sugarcane juice identified chlorogenic acid, cinnamic and flavones as colored compounds [3].

Those colored substances (pigments) are derived from plants and can be found in raw sugar after processing [4]. The presence of a several colorant compounds, such as chlorophylls a, b, c1, c2, d and f [5-7], have been described for agricultural and food chemistry aspects, however, the literature has widely described chlorophylls a and b [8]. Other colored substances described are anthocyanins [9], flavonoids [9-12] and phenolic acids [13-17].

Pigments are widely distributed in the sugarcane plant cell [17]. Authors have associated these pigments with color in sugarcane juice for white sugar production [1,18-21]. During the clarification process, plant pigments decompose to form polyphenolic compounds with subsequent enzymatic browning [1].

Sugar mills in Brazil remove these pigments, as well as other impurities, for the bleaching action of sulfur dioxide during the sulphitation process [22,23]. The clarified sugarcane juice as matter for sugar production is concentrated up to white crystals [23,24].

Chromatography is a versatile technique widely used for the separation of chemical compounds in a suspension or solution [25] and this technique can also be used for separation of pigments from plant extracts [26].

Adsorption is a low-cost technique depending on the used adsorbent and operation [27]. Chemical compounds can be separated through identification and quantification [28,29]. Adsorption resins have a specific area and pore diameter for rapid diffusion of ions and improved extraction kinetics with an increase in the complexing capacity [30]. Dowex\textsuperscript{TM} Optipore\textsuperscript{TM} SD-2 has been used in the food industry to remove color, flavor and odor in sweeteners as it has pore structures to maximize the load, as well as the high mechanical, chemical and thermal capacity [31].

Previously, we studied the effect of color to evaluate the sugar quality without or with different treatments, such as gamma radiation and electron beam [32,33], Fenton-like reaction [34], ozone [35,36] and hydrogen peroxide [20,36,37]. These studies evaluated the isolation of pigments in sugarcane juice as potential purification process and isolation system of pigments, which have been associated by antioxidant activities [35,38], by absorption chromatography column, as described by Lima and Aguiar [39].
Table 1: Product specifications of adsorbent resin used for syrup treatment.

| Parameters            | Descriptions* |
|-----------------------|----------------|
| Matrix                | Macroporous styrene-divinylbenzene copolymer |
| Functional group      | Tertiaryamine |
| Typical surface area  | 800 m²/gL |

Chlorophyll analysis:

\[
\text{Chlorophyll } \alpha = \frac{(12.7 \times A_{663}) - (2.69 \times A_{645})}{V}
\]

\[
\text{Chlorophyll } \beta = \frac{(22.9 \times A_{645}) - (4.68 \times A_{663})}{V}
\]

\[
\text{Total chlorophyll} = \frac{A_{652} \times 1000 \times (V/1000 \times W)}{34.5}
\]

Where: \(A_{663}\): absorbance at 663 nm; \(A_{645}\): absorbance at 645 nm; \(A_{652}\): absorbance at 652 nm; \(V\): final volume of ethanolic extract of chlorophyll (mL); \(W\): mass of plant matter (g).

Total phenolic contents: The spectrophotometric Folin-Ciocalteu phenol reagent was used to measure total phenolic in the samples. For calibration, curves 0, 0.04, 0.08, 0.12, 0.16 and 0.2 mL of solution (0.1 mg/mL tannic acid) were separately mixed with 1.0, 0.96, 0.92, 0.88, 0.84 and 0.8 mL of distilled water, respectively. Next, 0.5 mL of 10 fold dilute Folin-Ciocalteu reagent (note: recently prepared) was mixed and allowed 30 min at room temperature. Before 2.5 mL of 20% (w/v), sodium carbonate was mixed and the absorbance at 725 nm was read in UV Mini-1240 spectrophotometer (Shimadzu Inc.; Kyoto, Japan). Similarly, 0.5 mL of samples was used to determine total phenolic contents, without the distilled water [41] (JULKUNEN-TIITTO with modifications).

Aluminum chloride colorimetric method for flavonoid analysis:

For calibration, curves 0, 10, 15, 20, 30, 40 and 50 mL of the solution (0.05 grams of rutin dissolved in 70% (w/v) ethanol) were separately mixed with 4.8, 4.79, 4.785, 4.78, 4.77, 4.76, 4.755 and 4.75 mL of 70% (v/v) ethanol, respectively. Next, 0.1 mL of 2% (w/v) aluminum chloride (≥99.0%) and 0.1 mL of 1 M sodium acetate (≥99.0%) was added. After 40 min at room temperature (26±1 °C), absorbance was measured at 415 nm with in UV Mini-1240 spectrophotometer (Shimadzu Inc.; Kyoto, Japan). Similarly, 0.5 mL of samples was used to determine flavonoid contents and the quantity of 70% ethanol was 4.3 mL [42] (MABRY, et al. with modifications).

Results and Discussion

The spectrophotometric analysis of extract sugarcane tops showed that eluates along the chromatographic run were characterized as polar to nonpolar due to the characteristics of the added eluents, ethanol followed by methanol, hexane and chloroform, respectively.

Figure 1 shows that the chlorophylls are presented in the final fractions of eluates as phenolics and flavonoids in peaks in the early and final fractions.

Chlorophylls \(a\) and \(b\) total

Chlorophylls \(a\) and \(b\) in a raw ethanolic extract of sugarcane tops were separated from the phenolic compounds and flavonoids with eluted nonpolar organic solvents such as hexane and chloroform.

The behavior of both chlorophylls along the chromatographic run was the same, however at different concentrations (Figure 2). Chlorophyll \(a\) showed higher concentrations compared to chlorophyll \(b\).
b in the same fraction. [43] TOMO, et al. reported that chlorophyll a is the majority found in nature and that it performs fundamental role in the donation of electrons in photochemical reactions of photosynthesis.

The maximum concentration of chlorophyll a was 0.0752 mg/g, while chlorophyll b was 0.0457 mg/g fresh material (Figure 2). The addition of eluents with decreasing gradient polarity to the column showed an increase in the concentration of chlorophylls, characterizing them as nonpolar. This feature is justified by the presence of the isoprene tail in the molecules (Figure 3).

Plant pigments, such as chlorophyll, xantophyll and carotene are responsible for two thirds of color in raw sugar [44] and a small amount can be found in polymeric colorant in raw sugar if they are not removed or destroyed in the clarification process [45].

Total phenolic acids and flavonoids

The highest concentration of phenols in the early fractions compared to the final fractions of the chromatography eluate shows a characteristic of polar phenolics in the first fractions, as the eluents used were ethanol and methanol, that is, the polar pigments are loaded in and out on the first fractions by the characteristics of the eluents. Furthermore, there are nonpolar phenolic compounds and this can be observed in the final fractions of the chromatographic run in which hexane and chloroform were used as eluents.

Different phenolic compounds are widely identified in a sugarcane juice allowing studying their molecules (Figure 4; [17]).

The phenolic compounds are responsible for the increase in color in different types of sugars, when present in the sugarcane juice, due to their molecular characteristics. Phenolic compounds in the presence of amino acids initiate the reaction known as Maillard, thus, leading to the production of dark compounds that crystallize with crystal sugar, increasing the product color [46]. Melanoidins are a small part removed from the clarification process and may constitute up to 60% of the color of the clarified juice [47]. Dark colored polyphenols originate when they are exposed to Fe+3 ions in acidic solutions due the continuous contact of sugarcane juice with metal surfaces [1].

With the onset of mechanized harvesting, the adding of sugarcane tops to processing increased. The increase of 1% of tops causes a 1.3% increase of color in a sugarcane juice [48].

The profile of flavonoids attached to phenolics, since the types of flavonoids are phenolics, is at lower concentration in sugarcane juice.

Flavonoids such as apigenin, tricine, glycosylated luteolin, orientin, vitezxin, schaftoside and swertisin are found in sugarcane juice, however, some steroids and polycosanols can also be found in other parts of sugarcane, such as stalk wax [17]. This pigment group is rather critical because it can cause up to 30% of color when raw sugar production occurs at pH 7.0 [4] and not a large quantity is removed when the clarification process occurs [1].

Therefore, glycosylated flavonoids have been identified in a sugarcane juice and leaves such as diosmetin-8-C-glucoside, tricin-7-O-neohesperoside, 4', 5'-dimethoxy-8-luteoline C glucoside, tricin-7-O-rhamnosylgalacturonide, tricin-7-O-glucoside, schaftoside, isoschaftoside, vitezxin, orientin [44,49-51], swertisin, tricin-7-O-neohesperoside-4’-O-rhamnoside, tricin-7-O-methylglycosuronic acid-4-O-rhamnoside, tricin-7-O-methylglucuronide-4-O-rhamnoside, tricin-7-O-beta-(6'-methoxycinnamic) -glucoside, luteolin-8-C-glucoside rhamnosyl,
tricin-4’-O- (erthroguaicylglyceryl) -ether [11]. Some of these molecules can be observed in Figure 5.

Phenolic and nonpolar flavonoid potentially have aglycone characteristics such as the chlorogenic acid, cinnamic acid, hydroxycinnamic acid, sinapic acid, chlorogenic acid, apigenin, luteolin and tricin [13].

Methodological interferences

The analysis of total phenolics, using the Folin-Ciocalteu reaction spectrophotometry, occurs with deprotonation hydroxyls and consequent formation of carbonyl through reduction of Mo$^{6+}$ to Mo$^{5+}$ (Figure 6) [53].

For the analysis of flavonoids, the complexation of aluminum occur originating aluminum chloride at 2% methanol, between carbonyl-hydroxyl and hydroxyl-hydroxyl (Figure 7) [54].

At the end of the chromatographic run, there are three peaks corresponding to phenolics, flavonoids and total chlorophyll. However, observing chlorophyll $a$ and $b$ molecules, we can state that deprotonation of hydroxyls and aluminum complexing are not possible since these molecules have no hydroxyls and carbonyls in places and amounts that promote these reactions. Therefore, the analytical method of phenolics and flavonoids did not affect determination of chlorophylls.

Conclusion

The extraction of pigments was effective in 96% ethanol, once the analysis resulted in phenolic, flavonoid and chlorophyll concentrations along the eluted fractions and SD-2 Dow™ Optipore™ adsorption resin, together with eluents. These allowed separating all compounds by polarity, where a decrease in the polarity of the pigments molecules occurred during the chromatographic run.

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