Cómo afecta al procesamiento y a la producción cosechar los trozos de caña verde con distintos niveles de residuos. Parte II: Procesamiento en planta piloto hasta azúcar

Las nuevas refinerías en Louisiana, EE.UU., están solicitando a las industrias azucareras que entreguen azúcar cruda con muy alto polí y muy bajo color (VH/P/VC) y con baja concentración de cenizas. Esta azúcar cruda de alta calidad les permitirá a los culturistas y a las industrias de procesamiento compartir incentivos económicos de las nuevas refinerías. Se llevó a cabo en Louisiana un extenso estudio para determinar cómo las diferentes velocidades de los ventiladores de extracción de dos cosechadoras (los modelos 3500 y 3510 de John Deere) afectaban los niveles de residuos en trozos verdes de la variedad L 99-226 de caña (tratada con madurador) así como el procesamiento anterior y posterior. Se estudiaron velocidades de 1050, 850 y 650 rpm en los días 1, 2 y 3 (20 al 22 de noviembre de 2010) respectivamente con una velocidad constante de molienda de 3,5 mph (5,6 kph). Los niveles totales de residuo (punta de crecimiento + hojas verdes + hojas secas) fueron de 12,1, 18,9 y 22,7% respectivamente, lo que no impidió a la refinería la manufactura de VHP para una total de -30 min. Una muestra masiva de jugo mezclado (MJ) fue transportada al USDA-ARS-SRRC pilot plant en New Orleans para producir clarificado juice, syrup, A-massesuites, A-molasses, A-raw, and affinity sugars. Most quality and processing parameters, including soluble solids, sucrose, color, ash, starch, and mud volume durante clarification became progressively peores con increase in trash levels and decrease in fan speed. For every 1% increase in trash there was an approximate 0.13-0.21% decrease in MJ purity. Furthermore, purity of subsequent raw sugar became progressively worse with increased trash levels. Total trash levels between 18,9 and 22,7% from 850 to 650 rpm fan speeds, respectively, impeded the manufacture of VHP/VLC for a refinery, but the types of trash tissues influenced the raw sugar color, particularly the growing point region. Overall, at 850 rpm fan speed, VHP sugar (<2200 CU) cannot be commercially attained for L 99-226 in late November. Net proceeds to the grower were optimal for both growers and processors at the 850 rpm setting. More data are still needed for L 99-226 and other varieties, especially early in the Louisiana processing season when trash levels are considerably higher.

Keywords: combine harvester, leaves and tops, pilot plant processing, sugarcane trash

abstract

New refineries in Louisiana, USA are requesting Louisiana sugarcane factories to deliver very hot/very low color (VHP/VLC) raw sugar with low ash concentrations. This high quality raw sugar will allow both growers and factory processors to share economic premiums from the new refineries. A comprehensive factory trash trial was conducted in Louisiana to determine how different speeds of the extractor fans on two combine harvesters (John Deere 3500 and 3510 models) affect trash levels of green billets from L 99-226 commercial sugarcane variety (ripened treated) as well as upstream and downstream processing. Fan speeds of 1050, 850 and 650 rpm were studied on Days 1, 2, and 3 (20-22 Nov, 2010), respectively, at a constant ground speed of 3.5 mph. Total trash levels (growing point region + green leaves + brown leaves) were 12.1, 18.9 and 22.7% for the 1050, 850, and 650 rpm fan speeds, respectively, and significantly (P < 0.05) different. Sufficient cane of each treatment (24-27 truck loads) was harvested and processed each day to purge the tandem mill of other cane and to process the selected cane for a total of -30 min. A bulk sample of mixed juice (MJ) was transported to the USDA-ARS-SRRC pilot plant in New Orleans to produce clarified juice, syrup, A-massesuites, A-molasses, A-raw, and affinity sugars. Most quality and processing parameters, including soluble solids, sucrose, color, ash, starch, and mud volume during clarification became progressively worse with increased trash levels and decreased fan speed. For every 1% increase in trash there was an approximate 0.13-0.21% decrease in MJ purity. Furthermore, purity of subsequent raw sugar became progressively worse with increased trash levels. Total trash levels between 18.9 and 22.7% from 850 to 650 rpm fan speeds, respectively, impeded the manufacture of VHP/VLC for a refinery, but the types of trash tissues influenced the raw sugar color, particularly the growing point region. Overall, at 850 rpm fan speed, VHP sugar (<2200 CU) cannot be commercially attained for L 99-226 in late November. Net proceeds to the grower were optimal for both growers and processors at the 850 rpm setting. More data are still needed for L 99-226 and other varieties, especially early in the Louisiana processing season when trash levels are considerably higher.

Keywords: combine harvester, leaves and tops, pilot plant processing, sugarcane trash
Combinar colheita de tarugos de cana verde com diferentes níveis de resíduos afeta produção e processamento. Parte II: Planta piloto de processamento de açúcar

Novas refinarias em Louisiana, Estados Unidos estão solicitando que as usinas de cana de Louisiana ofereçam cana com alto pol e baixa coloração (VHP/VLC) com baixas concentrações de cinzas. Este açúcar bruto de qualidade superior permitirá que os produtores e processadores compartilhem vantagens económicas nas novas refinarias. Uma abrangente avaliação dos resíduos de usina foi conduzida em Louisiana para determinar como diferentes níveis de resíduos afetam a produção e processamento de açúcar. Velocidades de 1050, 850 e 650 rpm foram estudados nos dias 1, 2 e 3 (20-22 Nov de 2010), respectivamente, a uma velocidade constante de base de 3,5 mph. Níveis totais de resíduos (região de crescimento, folhas verdes e folhas marrons) foram 12,1, 18,9 e 22,7% para as velocidades de 1050, 850 e 650 rpm, respectivamente e significativamente (p<0,05) diferentes. Cane suficiente de cada tratamento (24-27 cargas de caminhão) foram coletadas e processadas por dia para limpar o moído de outa cana e processar a cana selecionada para um total de ~ 30 min. Uma amostra global de caldo misto (MJ) foi transportada para a planta piloto do USDA-ARS-SRRRC no Nova Orleans para produzir caldo clarificado, xarope, A-masa, A-melaza, A e açúcares. A maioria dos parâmetros de qualidade e processo, incluindo sólidos solúveis, sacarose, cor, cinzas, amido, e volume de lama durante a clarificação tomou-se progressivamente pior com aumento nos níveis de resíduo e diminuição da velocidade do ventilador. Para cada aumento de 1% no resíduo, houve uma redução aproximada de 0,13-0,21% na pureza MJ. Além disso, a pureza do açúcar bruto subseqüente tomou-se progressivamente pior com níveis resíduos aumentados. Níveis de resíduos total entre 18,9 e 22,7% de velocidade de ventilador entre 650 e 650 rpm, respectivamente, impediam a fabricação de VHP/LC para uma refinaria, mas os tipos de tecidos de resíduos influenciaram a cor do açúcar bruto, particularmente a região de ponto crescente. Em geral, a velocidade do ventilador de 650 rpm, açúcar VHP (<2200 cl) não pode ser obtido no nível comercial para L.99-226 no final de novembro. As receitas líquidas ao agricultor foram ideais para os produtores e processadores com a definição de 850 rpm. Mais dados ainda são necessários para L.99-226 e outras variedades, especialmente antecipada na temporada de processamento de Louisiana quando resíduos são consideravelmente mais elevados.

Introduction

New and proposed sugar refineries in Louisiana (LA) have requested the delivery of very high pol Very low color (VHP/VLC) raw sugars from LA sugarcane factories since 2010. One refinery wants lower ash concentrations in the VHP/VLC sugar because (i) some of the refined sugar at the new refinery will be manufactured into liquid sugar, which requires low ash, and (ii) lower ash is needed for short, medium, and long term refinery strategies (Chapman, LSR, personal communication). This higher quality raw sugar will allow both growers and factory processors to gain economically by sharing premiums from the new refineries. One of the main keys to manufacturing VHP/VLC sugar is the removal of color. Current color removing strategies at the factory include: (a) improved unit process operations and designs, (b) chemical processes, and (c) physical processes, which are typically expensive. However, most of the color across the factory, and in sugars manufactured, is from the trash in the cane supply (Muir and Eggleston, 2009). Muir and Eggleston (2009) recently suggested that even a small reduction, e.g., <10% in total trash levels processed at the factory, could be more efficient and cost-effective than other factory color removal processes and has additional advantages of increased purities and lower ash contents. Smith (1999) also concluded that elimination of color for VHP and VLC raw sugars “would require attention to cane quality factors” rather than process manipulations. Conversely, in other parts of the world, e.g., South Africa and Australia, some factories have encouraged the delivery of increased non-stalk material to increase their feedstock to the boilers (bagasse) and cogeneration plants without realizing the full detrimental effect this would have on processing operations (Reid and Lionnet, 1989).

Observations on the effect of trashy/green sugarcane on the performance of factory unit processes have been reported sporadically for the past 60 years but, because of logistical limitations, only up to clarification. In general, an increase in tops (growing point region) and trash entering a factory with sugarcane results in: (i) reduced payloads per consignment due to the lower density of trash and tops resulting in increased transport costs and sometimes reduced payment, (ii) reduced crush and throughput rates because of the larger volume of fiber associated with any given amount of sucrose (also resulting in a longer processing season), (iii) slippage on the mill rolls because of leaves, (iv) choking in the knives and shredders because of high fiber load, (v) adjustment of mill settings, and (vi) lower extraction because of sucrose losses to an increased volume of bagasse, (vii) higher bagasse moisture content that is detrimental to the boilers for steam production, (viii) lower mixed juice purity because of increased impurity levels, such as reducing sugars, ash, and colorants, with associated effects on clarification, (ix) reduced mixed juice pH (higher lime demand) because of the presence of organic acids (the reduction in pH is not as great as with deteriorated cane), (x) evaporator fouling because of extra impurities, (xi) lower recovery of sucrose from molasses because of increased impurity content of molasses, and (xii) reduced filterability of raw sugar (Archuneaux and Davidson, 1944; Reid and Lionnet, 1989; Bernhardt et al., 2000; Kent, 2007; Larrohando et al., 2009; Muir and Eggleston, 2009; Kent et al., 2010). Muir and Eggleston (2009) in South Africa reported the first study on effects of trash on downstream factory processing by using a pilot plant. For every 1% increase in trash, there was an approximate 0.41% decrease in mixed juice (MJ) purity and a 0.2% drop in expected recoverable crystals (Muir and Eggleston, 2009). The effect of trash on processing of the MJ in the pilot plant was a reduction in purity all the way through to A-massesuete.

The main harvesting method in LA is the combine (aka chopper) harvesting of green, billeted cane. This study investigated the effect of the combine harvesting of green cane billets with different levels of trash on sugarcane production and processing. The main objectives of the study were to provide crucial knowledge on what levels and types of trash are impeding the manufacture of VHP/VLC sugar for the new LA refineries, find the critical “threshold” level of trash that causes VHP/VLC sugar to be produced over raw sugar, and provide optimum fan speeds under the conditions tested to control the levels of processed trash for
VHP/VLC sugar manufacture that is of economical benefit and satisfactory to both growers and processors. How the different levels of trash affected field yields, and delivered cane quality and some factory processing parameters is discussed in Part I of this study (Eggleston et al., 2012). This Part II reports effects on downstream processing.

Experimental

**Harvesting.** A 3-day trial was conducted at Cora Texas (CT) factory from 20-22 Nov, 2010. One grower (Mr. John Gay, St. Louis Planting Co.) supplied the cane for the trial from a single 59.1 acre precision graded field in the Plaquemine area of Louisiana, 8 miles from CT factory. All the cane was L 99-226 variety; first ratoon; lodged; treated with glyphosate artificial ripener (Roundup PowerMAX™, Monsanto, St. Louis, MO; 4.75 oz/acre applied on Oct 21, 2010). The field cane was harvested with John Deere™ 3500 and 3510 series combine harvesters at a constant ground speed of 3.5 mph. Harvesting occurred each day from 6:00 am to -12:00 pm and delivery to the factory by 12:30 pm. No topping occurred and cane billet sizes were set for 6-7 in (15-18 cm). Approximately 600 tons of cane were supplied for each trial date equivalent to 24-27 truck loads. The environmental conditions during harvesting were not as wet on Day 3 as Days 1 and 2 of the study (Eggleston et al., 2012). Four random grab samples of billeted cane (-16 kg) were obtained from the factory conveyor belt and separated into brown leaves (BL), green leaves (GL), growing point region (GPR), Stalk, and Soil. If roots were present these were associated with the Soil. Leaves with any green color were designated GL and could also have included brown-colored weeds. Leaves with brown color were designated BL and could also have included other brown-colored weeds. Each tissue type was weighed and the percent trash on a wet weight basis calculated and results are listed in Table 1. Core press analyses of each truck for grower payments were undertaken by the factory, as well as prepared cane and bagasse analyses, cane preparation index and mill extraction; these were reported in Part I of this study (Eggleston et al., 2012).

**Factory Trial.**

**Factory operation during the trial.** Cane preparation equipment at the CT factory consisted of a leveller 0.6 m above the main cane carrier followed by two heavy duty knife sets. The factory operated a seven 4-roll mill tandem (eight tandem mills with one mill by-passed) with a fibre residence time of -5 min (Eggleston et al., 2012). For each day of the trial, the factory biocide dosage was continued during the trial.

**Crushing, extraction, and Mixed Juice (MJ) collection.** Every effort was made to minimize cut-to-crush delays and, therefore, catareriation to evaluate the effects of trash alone. Each trial at CT factory lasted 30 min to ensure that the previous juice in the tandem mill was purged to ensure that the MJ samples collected were representative of the trashy cane supplied. After 9 min of trial time had elapsed to purge the tandem mills, twelve 5 gal (19 L) containers were filled with MJ and transported immediately to USDA in New Orleans. The containers contained 16 drops (-0.5 ml) of biocide (Russlan 881, Buckman Labs., US). Preliminary experiments had been undertaken to ascertain the level of biocide required to preserve the juice until it reached New Orleans after 1.5 h of transportation time. A composite sample of MJ was collected for purity analysis in the factory laboratory. In New Orleans, most of the contents of the containers were drained into the MJ tank (70 gal or 265 L full capacity), sub-sampled (for analysis) then processed into clarified juice. All sub-samples were stored in a -40°C freezer.

**Pilot plant processing.**

The USDA-ARS-SRRC pilot plant facility was used to produce clarified juice (CJ), mud, final evaporator syrup (FES), A-massacuite, A-molasses, A-sugar and affined sugar from the MJ collected at the factory. The full design and operation of the pilot plant can be found in Eggleston et al. (2011). Clarification took place in a 70 gal full capacity clarification tank using a hot lime clarification method (Eggleston et al., 2003) used by the factory. The MJ was heated with constant mixing to 98°C and was then limed (MOL; 11 baumé) to pH 7.3 and heated to boiling. After 1 min of boiling the heat source was removed and polyarionic flocculant (same as factory: Stockhausen; 0.1%; 3 ppm) was added, mixed by hand with a paddle then dropped into the clarification tank below. The mud was allowed to settle for 1.5 h before CJ was removed from side ports. Final mud was removed from the bottom of the tank (Eggleston et al., 2011). The CJ was immediately placed in 5 gal containers and stored in a walk-in cooler (4°C) overnight until

**Scientific laboratory instruments since 1796**

**KRÜSS**

A.KRÜSS OPTRONIC

GERMANY

---

**analytik Munich**
April 17-20th, 2012
hall B1
booth 121/220

---

www.kruess.com
evaporation the following morning. Preliminary experiments were undertaken to ensure no unwanted deterioration occurred during overnight storage at these temperatures. 

CJ was evaporated in a Robert's-type calandria (rising film) evaporator (55 gal or 210 L full capacity) manufactured by Honiron Corporation™ (Jeanerette, LA). Feed CJ was fed into the evaporator at the bottom by suction until it covered just above the calandria tubes (~8 gal or 30.3 L). The CJ was then evaporated under ~15 in. Hg at ~180 °F (82.2°C). Evaporation under these conditions continued until the syrup was ~45 Brix. The vacuum was then increased to 20 in. Hg and the temperature lowered to ~165°F (74°C) to simulate raw sugar manufacturing conditions. Eventually the vacuum was allowed to increase to 25 in. Hg at 140-150°F (60 – 66°C) with the CJ still continuously fed into the evaporator. FES was removed when it was approximately 70 Brix and stored in the walk-in cooler. 

The FES was boiled in a calandria vacuum pan (34 gal or 130 L full capacity) manufactured by Honiron™ (Eggleston et al., 2011a). The pan was operated at 150°F (65.6°C) under 25 in. Hg vacuum to simulate raw sugar manufacturing conditions. Feed syrup (first adjusted to 65 Brix) was fed into the pan at the bottom by suction. Because of limited syrup feedstock the pan was operated just above the calandria tubes which caused the temperature of the syrup to be slightly higher than normal (150°F). Therefore, to ensure the seed crystals did not melt, seeding occurred at ~82 Brix, i.e., the metastable zone, and this Brix was maintained during the crystal growth phase. Boiling was stopped, and the syrup allowed to cool and stabilize at ~150°F and the seed crystals (68 g/88 ml isopropanol; 0.229 mean aperture MA) were immediately added into the pilot vacuum pan. Three min after seeding, the pan boiling began again, and the volume of syrup inside the pan was maintained by adding feedstock syrup (65 Brix) to allow the crystals to grow. Once the grain crystals had grown to ~0.4 mm MA (and little syrup was available for further growth) the grain produced was dropped out of the pan at the bottom, leaving enough grain to just cover the calandria tubes. Feedstock syrup was then (65 Brix) fed into the pan until the volume had increased 2-fold again, and the mixture allowed to boil. The second and final "strike" was dropped after further crystal growth to ~0.5 to 0.6 mm MA (and little syrup was available for further growth). Under these pilot plant conditions, syrups from each day of the trial were studied. 

The raw sugar crystals and molasses in the massecuites produced were immediately separated in an Ametek (Paoli, PA) Mark III basket centrifuge (0.30 m diam.; 26.8 kg full capacity). Inside the centrifuge basket was placed a screen (41 cm length x 5 cm wide; 0.87 x 4.4 mm slots) obtained by cutting a piece of used, undamaged screen from an AvB Centrifugal at a LA factory. Approximately 0.75 gal (2.8 L) of uncooked massecuites were placed in the basket and then centrifuged beginning with speed 1200 rpm for 1 min and then accelerated to 2290 rpm for 10 min and decelerated again. Distilled water (2% on volume of massecuites) was uniformly applied by hand using a container with a fine spray nozzle to wash the raw sugar. The A-raw sugar produced was spread out thinly on paper and left to air dry. 

Affinities of raw sugar was undertaken following the Contract No. 10 Method (Anon. 1984a,b) used in the U.S. sugar refineries (Jack Thompson, LSR refinery, personal communication). 

Clarification performance

A sub-sample (500 ml) of heated and limed juice that entered the pilot plant clarification tank was poured into a 500 ml glass cylinder and allowed to settle. Mud level readings were taken after 30 min settling. The mud volume after 30 min (MV₃₀) was expressed as a volume percentage. Mud removed from the bottom of the clarification tank was stored in a ~40°F freezer before density measurements, in triplicate, were performed with an Anton Paar (Graz, Austria) DMA 35N portable density meter. The turbidity in NTU of clarified juices was measured using a Hach (Loveland, CO) 2100N Turbidimeter. 

Sample analyses

Color was measured at pH 8.5 as the absorbance at 420 nm and calculated according to the modified ICUMSA method GS2/3-9 (1994). Samples were diluted in triethanolamine/hydrochloric acid buffer (pH 8.5) and filtered through a 0.45 μm filter. 

Starch was measured using the rapid SPPI iodometric method (Godshall et al., 2004) with modifications (Eggleston et al., 2007). Because of the large variability in the Brix’s of the different samples collected, their dilutions in de-ionized water differed to give final Brix values of ~15.0. Starch was assayed in duplicate samples, and concentrations are quoted as average ppm/Brix. 

Conductivity ash in the samples was determined according to ICUMSA Method GS1/3/4/7/8/-13 (1994) and calculated on a % Brix basis. 

Sucrose, fructose and glucose. See Eggleston and Monge (2005) for the gas chromatography (GC) method used. Triplicate analyses were undertaken. Samples were first diluted to the approximate Brix of the clarified juice sample. 

Particle Laser Scattering Analysis (PSA) was conducted on a Partica Laser Scattering Particle Size Distributor Analyzer LA-950V2 by Horiba™ (Kyoto, Japan). A juice (1 to 5 ml) was added in the liquid mode of the instrument. Using Horiba LA-950 software (ver. 5), it was ensured that the % transmittance was in the valid range. 

Statistical analyses. Following one-way ANOVA, means comparisons were undertaken using PC-SAS 9.1.2 (SAS Institute, Cary, North Carolina) using Duncan’s New Multiple Range Test. 

Results and discussion 

Mixed juice (MJ) collected from the factory 

Since the MJ samples were obtained from the factory, it allowed for a direct comparison of the physico-chemical properties of the MJ from the various fan treatments (Table 2). The Brix levels in MJ are
How combine harvesting of green cane billets with different levels of trash affects production and processing. Part II: Pilot plant processing to sugar.

Table 1. Trash levels of L 99-226 commercial sugarcane from the 3-day trash trial on a tissue wet weight basis (%). (From Eggleston et al., 2012)

<table>
<thead>
<tr>
<th>Type</th>
<th>Hand-cut cane*</th>
<th>Day 1 1050 rpm</th>
<th>Day 2 850 rpm</th>
<th>Day 3 650 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stalk</td>
<td>82.3 ± 0.7b</td>
<td>77.7 ± 2.4c</td>
<td>76.8 ± 2.1c</td>
<td></td>
</tr>
<tr>
<td>GPR</td>
<td>3.3 ± 0.5a</td>
<td>3.7 ± 1.1a</td>
<td>4.3 ± 0.9a</td>
<td>4.8 ± 1.0a</td>
</tr>
<tr>
<td>GL</td>
<td>3.6 ± 0.6a</td>
<td>5.4 ± 0.7b</td>
<td>5.0 ± 0.4b</td>
<td></td>
</tr>
<tr>
<td>BL</td>
<td>4.8 ± 0.1c</td>
<td>5.3 ± 0.5c</td>
<td>10.5 ± 0.8b</td>
<td>11.9 ± 0.8a</td>
</tr>
<tr>
<td>Soil and roots</td>
<td>0.0 ± 0.0b</td>
<td>1.1 ± 0.8a</td>
<td>1.1 ± 0.1a</td>
<td>0.6 ± 0.4ab</td>
</tr>
<tr>
<td>Total trash</td>
<td>17.7 ± 0.7b</td>
<td>12.1 ± 1.8c</td>
<td>18.8 ± 2.7b</td>
<td>22.7 ± 1.7a</td>
</tr>
<tr>
<td>Total trash + soil and roots</td>
<td>17.7 ± 0.7b</td>
<td>13.2 ± 1.8c</td>
<td>19.9 ± 2.7b</td>
<td>23.2 ± 2.1a</td>
</tr>
</tbody>
</table>

GL/B/L ratio: 2.01  0.59 0.51 0.50

* Average of 3-day trial.
* Extractor fan speed on combine harvester, average of four replications.
* The same lower case letters represent no statistical differences (P < 0.05) among all cane types for an individual tissue only.

Table 2. Mixed juice analysis (average values shown)

<table>
<thead>
<tr>
<th>Extractor fan speed:</th>
<th>1050 rpm</th>
<th>850 rpm</th>
<th>650 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total trash %</td>
<td>12.1</td>
<td>18.8</td>
<td>22.7</td>
</tr>
<tr>
<td>MJ pol %</td>
<td>14.90</td>
<td>14.58</td>
<td>13.83</td>
</tr>
<tr>
<td>Brix %</td>
<td>16.6</td>
<td>16.4</td>
<td>15.7</td>
</tr>
<tr>
<td>Purity %</td>
<td>89.76</td>
<td>88.90</td>
<td>88.08</td>
</tr>
<tr>
<td>Fructose % on Brix basis</td>
<td>1.18</td>
<td>1.35</td>
<td>1.37</td>
</tr>
<tr>
<td>Glucose % on Brix basis</td>
<td>1.07</td>
<td>1.27</td>
<td>1.29</td>
</tr>
<tr>
<td>Color (CU)</td>
<td>21459</td>
<td>22667</td>
<td>26338</td>
</tr>
<tr>
<td>Cond. Ash % on Brix basis</td>
<td>2.86</td>
<td>3.07</td>
<td>3.18</td>
</tr>
<tr>
<td>Starch ppm/Brix</td>
<td>1546</td>
<td>1745</td>
<td>2105</td>
</tr>
</tbody>
</table>

* Factory laboratory data.
* ppm/Brix is equivalent to mg/kg

generally determined by operational factory settings (such as the imbibition water to cane ratio) and not by the cane quality or type. Comparisons can, therefore, only be made on results expressed on a Brix basis. Most MJ parameters became worse with decreased fan speed and concomitant increase in total trash levels (Table 2). However, it was easier to gauge the full impact of the fan speeds/trash levels by calculating the changes in the MJ parameters for every 1% increase in total trash (Table 3). As the relationship between fan speed and trash levels was not linear but more of a progressive, hyperbolic relationship (see Figure 3), the changes were not expressed as averages but as rate changes from 1050 to 850 rpm, and from 850 to 650 rpm (Table 3).

For most MJ parameters, changes for every 1% increase in total trash became progressively worse with increased total trash/decreased fan speed (Table 3). Results were not as clear for glucose and fructose. Nevertheless, increased trash levels typically caused an increase in these reducing sugar levels in the MJ. Compared to the other parameters, conductivity ash showed a more linear relationship with fan speed/total trash levels. That is, although increases in ash for every 1% increase in trash become worse with the decreased fan speed/increased total trash levels, they did not become progressively worse (Figure 1). In contrast, Muir and Eggleston (2009) found no relationship between % trash levels and conductivity ash levels, but diffuser tandem mill factories were studied and treatments included whole-stalk cane, burnt billets and green billets. Reducing sugar to ash ratios increased from 0.79 at 650 rpm (12.1% total trash) to 0.85 at 850 rpm (18.8% total trash). However, the ratio did not increase further at the 1050 rpm/22.6% trash remaining at 0.84. Since this ratio is an indicator of expected molasses exhaustion downstream in the process, it is an important factory performance parameter. Starch levels and especially color levels (Figure 1), became progressively worse to a much greater degree than the other MJ parameters (Table 3). These results confirm previous reports that, generally, increased trash levels increase the juice color (Scott et al., 1978; Kent, 2007; Muir and Eggleston, 2009).

Pilot plant clarification performance

Pilot plant clarification results are listed in Table 4. As the trash levels increased with decreased fan speed, the mud volumes and mud volumes per unit MJ brix became progressively worse. Kent et al. (2010) in Australia reported that mud solid levels increased with increasing
levels of trash. On average, a 1% increase in trash caused an approximate 0.07% increase in mud volume per unit MJ Brix after 30 min settling, which is considerably higher than the equivalent 0.0125% increase reported by Muir and Eggleston (2009) for South African sugarcane. The relationship was not linear and became progressively worse as illustrated in Figure 2. However, like Muir and Eggleston (2009) observed, the initial Brix of the MJ was not responsible for actual mud volumes (Table 4) which is also in agreement with results reported on the clarification of juices obtained from trash and stalk cane tissues (Eggleston et al., 2010a). Although the mud density tended to increase with increased trash content, (Table 4), there were no significant differences for mud density among the three fan treatments.

Although it was not possible to measure the settling rate inside the clarification tank accurately, the settling could be followed through the series of ports on the clarification tank (see Eggleston et al., 2011). Generally, the settling was slowest and the pH drop the lowest on Day 3 of the trial when the fan speed was 650 rpm and the trash level was highest at 22.7%. Moreover, the difference in settling between Day 1 and 2 was less than between Days 2 and 3. The turbidity of the CJs produced in the pilot plant are listed in Table 4 and, generally, increased from Day 1 to 2 but did not significantly increase again on Day 3. Eggleston et al. (2010a) reported that the GPR was critical to sugarcane juice clarification, and the higher GPR with increased total trash (see Table 1) may have mitigated the effects of the trash on settling. Eggleston and Muir (2009) observed that an increase in trash, generally, caused a corresponding increase of the settling rate and higher mud volumes per unit mixed juice Brix.

Particle size analyses of the mixed and clarified juices are illustrated in Figure 3. At both 1050 and 850 rpm fan speeds, the MJ particle size distributions were similar. However, at 650 rpm the particle size distribution was different with a shift to much smaller particles (0.1 to 3 μm).
How combine harvesting of green cane billets with different levels of trash affects production and processing. Part II: Pilot plant processing to sugar

Table 3. Changes in mixed juice parameters for every 1% increase in total trash

<table>
<thead>
<tr>
<th>Fan speed rpm</th>
<th>Loss in pol %</th>
<th>Loss in Brix %</th>
<th>Loss in purity %</th>
<th>Increase in fructose %</th>
<th>Increase in glucose %</th>
<th>Increase in color</th>
<th>Increase in ash %</th>
<th>Increase in starch ppm/Brix</th>
</tr>
</thead>
<tbody>
<tr>
<td>1050 to 850</td>
<td>-0.05</td>
<td>-0.03</td>
<td>-0.13</td>
<td>+0.026</td>
<td>+0.03</td>
<td>+182</td>
<td>+0.032</td>
<td>+30.3</td>
</tr>
<tr>
<td>850 to 650</td>
<td>-0.019</td>
<td>-0.18</td>
<td>-0.21</td>
<td>+0.003</td>
<td>+0.02</td>
<td>+344</td>
<td>+0.031</td>
<td>+92.5</td>
</tr>
</tbody>
</table>

*See original data in Table 2.

Table 4. Pilot plant clarification results

<table>
<thead>
<tr>
<th>Fan speed rpm</th>
<th>Pilot plant clarification results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
</tr>
<tr>
<td></td>
<td>Total trash (%)</td>
</tr>
<tr>
<td>1050</td>
<td>12.1</td>
</tr>
<tr>
<td>850</td>
<td>18.8</td>
</tr>
<tr>
<td>650</td>
<td>22.7</td>
</tr>
</tbody>
</table>

*When the mixed juice was laboratory clarified (see Eggleston et al. 2009 for method) with the target inlet pH the same as for the pilot plant, i.e., 7.3, the NTU followed the trend in descending order: 12.1% trash<18.8% trash<22.7% trash.

Eggleston et al. (2010b) recently observed that it is the smaller particles (<3 μm) that cause the greatest turbidity in cane juices. In the sugar beet industry, it is small particles or "fines" (<3 μm) that cause filtration problems during carbonation clarification (Burroughs and Wones, 2003). These results suggest that very high trash levels contribute more small particles that are difficult to remove during clarification and that are responsible for CJ turbidity. Particle size distributions of the CJs from each day of the trial were, however, more similar than the MJ (Figure 3) indicating that the hot lime clarification process can mitigate some of the negative effects from high trash levels. Nevertheless, the CJs at the lower fan speeds/high trash levels, exhibited smaller particles that will have contributed to the higher CJ turbidities (Table 4).

Pilot plant processing

The MJ from each trial were processed in the USDA-ARS-SRRC pilot plant; samples of CJ, FES, A-massecuites, A-molasses, A-raw and refined sugar were analysed for a range of physico-chemical properties. Starch values across the pilot plant are illustrated in Figure 4. Starch concentrations in LA have become more important in recent years because of the increased production of green (unburnt) and combine-harvested (billeted) sugarcane, the introduction of new sugarcane varieties with higher starch content, and varying environmental conditions (Eggleston et al., 2010c,d). Starch is an undesirable impurity because it causes processing difficulties in both the sugarcane factory and refinery (especially a carbonation refinery), and in some countries there is a penalty for high starch concentrations in raw sugar. The decrease in starch in the CJ (Figure 4) is most likely because of the action of natural diastase enzymes in the sugarcane juice itself that would have acted in the MJ tank before the juice attained the target high temperature. Once the temperature was attained the heat would have denatured the enzymes. However, in a factory the time in the MJ tank (~3-5 min) is much shorter in LA. The increase in starch from CJ to molasses is most likely a concentration effect. Starch values, generally, showed a clear subsequent ("knock-on") effect across the pilot plant all the way to massecuites. To have demonstrated this effect across an actual factory would have been practically impossible as at least 3-day loads of cane would have been required. As for other processing parameters, starch was progressively worse as the extractor fan speed decreased and the total trash values increased. Starch levels in the A-raw sugar at 650 rpm were particularly higher than the other fan speeds/trash levels.
of lime during clarification. Ash contents across the pilot plant to molasses increased due to a concentration effect. Similar for other processing parameters, the ash contents in the A-raw sugars became progressively worse as the extractor fan speed decreased, and were particularly high when the fan speed was 650 rpm (Figure 5).

Color results are shown in Figure 6, and values showed the same subsequential trend as the juice was processed across the pilot plant. The color of molasses samples (not shown) also followed the trend. Most of the color that entered the factory was with the cane, as evidenced by the MJ color compared to the massecuite color (Figure 6). As trash levels increased with decreased fan speeds, the color became progressively worse. Furthermore, the pattern of differences in color for the MJ governed the differences in the other samples formed across the process (Figure 6), and there was a strong correlation ($R^2 = 0.966; y = 0.2322x - 3.402$) between the MJ ($x$ value) and A-raw sugar colors ($y$ value). The results further emphasize that most of the color in the factory comes from the cane and very little, comparatively, is formed and degraded across the factory and confirms a recent report by Muir and Eggleston (2009). Although all the % trash tissues were significantly correlated to the A-raw sugar color, the highest correlation was with the % GPR tissue ($R^2 = 0.752; y = 945.11x - 980.8$ where $x$ is % GPR and $y$ is A-raw sugar color). There was no significant correlation between the % stalk tissue and raw sugar color. Muir and Eggleston (2009) had found significant correlations between the A-raw sugar color and the GL and GPR tissues, however, whole-stalk and burnt billets were studied as well as green billets. The differences in this study may be due to different varieties and conditions in Louisiana. Although the color of affined sugars was strongly, linearly correlated ($R^2 = 0.916; y = 0.6368x$) with the color of A-raw sugars, there was a weak linear correlation with the total trash levels because the relationship was more progressive. That is, as the trash levels increased the color of A-raw and affined sugars became progressively worse. The color transfer from syrup to affined sugar was on average -9.4% for all of the samples, but was only -7% at 1050 and 850 rpm speeds, compared to -11% at 650 rpm. Likewise, the color transfer from A-raw sugar to affined sugar was 56.9% at both 1050 and 850 rpm speeds, but markedly increased to 69% at 650 rpm. Muir and Eggleston (2009) reported that color transfer from syrup to VHP raw sugar in South Africa is 6%; VHP to affined is 50%.

Figure 7 further illustrates the differences in the color of A-raw and affined sugar colors in this study. In LA, color is measured at pH 8.5 (in color units CU) compared to pH 7.0 for the ICUMSA method (ICU color units) used internationally. Higher juice pH results in higher color measurement (Eggleston et al., 2010c). The soluble (conductivity) ash values across the pilot plant are shown in Figure 5. Soluble ash reflects salts, minerals, and ionized acid contents in the tissues. Ash components can catalyze the acid degradation of sucrose (Eggleston et al., 1996), contribute to scaling downstream, and affect the quality of raw and affined sugars. Ash is also important to liquid sugar production by refiners. For MJs and CJs in this study, as the trash content increased with reduced extractor fan speed, the ash content increased. The ash contents of GL and BL are higher than GPR tissues, and ash in stalk tissues are markedly lower than all trash tissues (Eggleston et al., 2010a). The higher values for ash in the CJs compared to MJs are because of the addition...
trash levels, VHP sugar cannot be commercially attained. However, it must be noted that the types of trash tissues also influence the A-raw sugar color, particularly the GPR and GL (Eggleston and Muir, 2009), and lower total trash levels with higher amounts of these tissues still may not allow VHP sugar to be manufactured. Furthermore, this study was conducted on one sugarcane variety in late November. It is known that trash levels are higher in early season (Eggleston et al., 2010c). For example, L 99-226 the variety in this study had, on average, greater than 23% total trash levels in hand-cut cane in early 2009 and 2010 seasons, and variety HoCP 96-540 (currently the most popular variety in LA) had <25%. Thus, the commercial attainment of VHP sugar in early season could be expected to be even more difficult.

As shown in Table 2, the purity values of the MJ samples decreased progressively with the increase in total trash values caused by the decrease in extractor fan speeds. Purity values by GC (not shown) demonstrated a subsequent (“knock-on”) effect across pilot plant processing all the way to the massecuite products. Muir and Eggleston (2009) showed a similar trend. Figure 8 illustrates the apparent (based on pol) purity values for the A-raw sugars produced in the pilot plant. In particular, the purity of the A-raw sugar of the 650 rpm fan speed cane was significantly (P < 0.01) lower than from the other two speeds. Furthermore, the sucrose decrease (0.10%) with every 1% increase in trash became worse between 850 to 650 rpm fan speeds compared to 1050 to 850 rpm speeds (0.08%). These decreases were even worse when the true sucrose purity values were measured with GC, although it was difficult to measure sucrose purities in sugars because the experimental error of the GC method is in the range of the sucrose differences.

Generally, as for MJ (Table 2), glucose and fructose were higher in the pilot plant products as the total trash values increased and fan speeds decreased. Unlike the purity, starch, ash, and color processing parameters studied, reducing sugars (results not shown) across the pilot plant showed no particular trend which suggests they were the most susceptible to processing conditions.

Conclusions

The most popular method of sugarcane harvesting in the LA sugar industry is combine harvesting of green billets. However, combine harvesting of green cane compared to burnt cane does not necessarily imply an increase in the total trash amount, which is rather dependent on the exact conditions during harvesting, e.g., weather conditions, fan speed, cutter height, and the variety. In this study, total trash levels (GPR+GL+BL) were 12.1, 18.9 and...
22.7% for the 1050, 850, and 650 rpm fan speeds, respectively, and significantly (P<0.05) different.

The progressive increase in trash levels with decreased fan speed resulted in a progressive decrease in percent extraction, imbibitions % cane, factory processing rate, core lab and prepared cane analyses (see Part I of this study; Eggleston et al., 2012), and MJ purities, all of which have serious economic consequences to the LA sugar industry. For every 1% increase in trash there was an approximate 0.13-0.21% decrease in MJ purity.

Most quality and processing parameters, including fiber, Brix (soluble solids), sucrose, color, ash, starch, and mud volumes during clarification became progressively worse with increased trash levels and decreased fan speed. Starch, color, ash and purity values, generally, showed a clear but subtle impact on the results of the trial from the pilot plant from the MJ all the way to massecuites and A-raw sugar.

As the trash levels increased with decreased fan speed, the mud volumes and mud volumes per unit MJ Brix became progressively worse. On average, a 1% increase in trash caused an approximate 0.07% and 0.99% in mud volume % per unit MJ Brix and % mud volume, respectively. Generally, the settling was slowest on Day 3 of the trial when the fan speed was 650 rpm and the trash level was 22.7%. Generally, turbidity increased from Day 1 to 2, but did not significantly increase on Day 3. Worse turbidity levels in MJ and CJs with increased trash are because of the delivery of smaller particles of <3 μm.

VHP sugar (<2000 CU) cannot be commercially attained for sugarcane variety L 99-226 in late November at 650 rpm fan speed. Total trash levels (GPR+GL+SU) between 18.9 and 22.7% from 850 to 650 rpm fan speeds, respectively, impeded the manufacture of VHP/VLS for a refinery. However, it must be noted that the types of trash tissues influence the A-raw sugar color, particularly the GPR, and lower total trash levels with higher amounts of this tissue still may not allow VHP sugar to be manufactured.

Most of the color in the A-raw and affined sugars comes from the cane trash tissues, particularly the GPR. Lowering trash levels by using the extractor fan of the combine harvester or blowing off at the factory offers lower color, lower ash and higher sucrose in VHP/VLS sugars.

Even though TRS values decreased and tons cane/acre increased with lowered fan speeds in this study (Eggleston et al., 2012) and higher trash levels, net proceeds to the grower were not highest at the lowest fan speed. A fan speed of 850 rpm is optimum for L 99-226 sugarcane variety in late November, but more data is needed for early in the LA season and for other varieties.

Acknowledgements

This trial could not have been undertaken without the exceptional cooperation and support of the core lab staff at Cora Texas factory. In particular, the authors would like to thank Mr. Eldwin St. Cyr (USDA-ARS-SRRC), Ms. Jeanie Stein (LSU AgCenter), and Ms. Jessica Gober (USDA-ARS-SRRC) for their excellent technical assistance. The American Sugar Cane League is thanked for funding this research. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture. USDA is an equal opportunity provider and employer.

References