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Processing Sticky Cotton: Effect of Stickiness on Yarn Quality

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ABSTRACT

Seventeen cotton samples with small-to-moderate stickiness contamination were created by mixing sticky cottons with non-sticky cottons, and then processed through ring and rotor spinning. Trehalulose contents ranged from 0.002% to 0.034% of the fiber weight (corresponding to 1.8% and 16.8% of the total sugars), while melezitose contents ranged from 0.023% to 0.071% (corresponding to 10.5% and 22.5% of the total sugars). High-speed stickiness detector (H2SD) readings of the card slivers ranged from 2.0 to 15.7. At these relatively low levels of contamination there was no correlation between ends-down in spinning and H2SD readings. Results showed that in the short term, less than 12 H2SD spots within a mix of cotton does not seem to influence spinning productivity on either ring (Saco-Lowell SF-3H) or rotor (Rieter R20) systems. A slight, but significant, negative effect on the ring-spun yarn quality was found even at low levels of stickiness. In the long term, it appears likely that even very small amounts of trehalulose slowly contaminate the equipment. This accumulation of sugars would be expected to have a cumulative, negative impact on both productivity and yarn quality.

Stickiness is a worldwide contamination problem, as shown by the International Textile Manufacturers Federation (ITMF) Cotton Contamination Surveys [8]. For the period 1989–2001, the average degree of contamination with stickiness of the world production was 22%, with a minimum of 18% in 2001 and a maximum of 27% in 1991.

Sticky cotton contaminates textile equipment, such as opening lines, cards, drawing, roving and spinning frames [1]. The contaminants are mainly sugar deposits produced either by the cotton plant itself (physiological sugars) or by feeding insects (entomological sugars), with the latter being the most common source of stickiness [7]. The main honeydew-producing insects that infest cotton plants are cotton whitefly *Bemisia tabaci* (Gennadius) and the cotton aphid *Aphis gossypii* (Glover). Whiteflies and aphids are both sap-sucking insects that feed by inserting their long and slim stylets into the leaf tissues. The sap is digested and the excreta discharged as honeydew droplets. The honeydew attaches itself to the leaves and the fibers of opened bolls. The ginning process may scatter the honeydew, making it more difficult to detect by visual inspection [4]. The composition of insect honeydew is quite complex. Hendrix *et al.* reported that only a few of the sugars in whitefly or aphid honeydews are found in the insect diet;

most sugars in these secretions are produced by the insect from phloem sap. Among those sugars, melezitose and trehalulose are specific to insects and are not found in the plant [5]. The presence of these sugars on the lint reveals that the contamination is coming, at least partially, from insect honeydew. A high percentage of melezitose along with a low percentage of trehalulose reveals the presence of aphid honeydew. When both melezitose and trehalulose are present and trehalulose is dominant, whitefly honeydew contamination is indicated [6]. The other sugars are generally found on both non-contaminated and honeydew-contaminated cottons. It was reported that glucose and fructose contained in the honeydew are synthesized from sucrose by the insect [9].

The two main causes of sugars becoming sticky are heat and moisture [1].

● During yarn formation the cotton fibers are exposed to friction forces, that elevate the temperature of some mechanical parts, which affects the *temperature-dependent properties* of the sugars present. If one or more of the sugars melt, stickiness results.

● Obviously moisture will cause sugars to change from a crystalline state (non-sticky) to an amorphous state (sticky). In particular, the relative humidity in the manufacturing environment may affect the *moisture-dependent properties* of the sugars present.

A previous report on the effect of changes in temperature and moisture content on contamination of cotton by sugars showed that only trehalulose has a very low

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melting point ($\approx 48^\circ\text{C}$) and is highly hygroscopic (three molecules of water adsorbed per molecule of sugar) [1]. It was concluded that the combination of a low melting point and high moisture uptake was the likely explanation for selective accumulation of trehalulose on the textile equipment.

To further evaluate the thermal/sugar interactions, the high-speed stickiness detector (H2SD) hot plate was manipulated to produce a variety of temperatures [2]. The manufacturer's recommended setting for the hot plate is 53°C . It was observed that with temperatures of 40°C and higher, there is no interaction between sugars present and temperature levels. However, with temperatures of 34°C and lower, there is a strong interaction effect. Trehalulose-rich honeydew (from whiteflies) exhibited stickiness at 27°C , the lowest temperature tested, while melezitose-rich honeydew (from aphids) would stick only at temperatures above 40°C . Based on this principle, a patent application on a multi-temperature, thermo-mechanical testing method was filed and a patent was granted [3].

This paper reports on the investigation of impacts on yarn quality from spinning cottons with moderate contamination by stickiness, as measured by the H2SD instrument. Results are presented for both ring-spun and rotor-spun yarns.

Materials and Methods

Twelve commercial cotton bales contaminated with insect honeydew were selected based on their stickiness level as measured by H2SD. In addition, five non-sticky bales from one module were selected for mixing with the contaminated cottons, in order to obtain mixes with

alternative stickiness levels. The 12 contaminated bales were broken and layered. Ten samples per bale were taken. Each sample was tested with a high volume instrument (HVI) (Table I), H2SD and high-performance liquid chromatography (HPLC) (Table II). On the HVI, four replications were performed for micronaire and color and 10 replications for length and strength, whereas three replications per sample were performed on H2SD and HPLC.

The mechanical processes used in this study for the spinning trials are shown in Figure 1. The opening, carding, drawing, roving, ring spinning and rotor spinning machines used were all industrial equipment. In the ring spinning trial, the yarns were spun to a 19.68 Tex (30 Ne) count. Fourteen spindles were used for each mix, with a running time of 72 hours. For the open-end rotor spinning trials, the yarn produced was 26.84 Tex (22 Ne), 10 positions were used, and each mix was run for 20 hours.

Preliminary tests were run on ring spinning before testing the mixes. Thirty pounds of lint from each bale was carded and drawn. If noticeable problems occurred at the draw frame, the process was stopped. If not, the drawing slivers were transformed into roving. If noticeable problems occurred at the roving frame, the process was stopped. If not, the roving was transformed into yarn at the ring spinning frame. If noticeable problems occurred at the ring spinning frame, the process was stopped. If not, 100 pounds of lint was processed for the large-scale test. Whenever noticeable problems occurred at any step of the process, the cotton was mixed with 50% of non-sticky cotton and the process was repeated. Using this procedure led to the execution of 17 large-scale tests. Four bales were spun without mixing the lint

TABLE I. HVI results on twelve contaminated bales and one uncontaminated module.

Bale ID	UHML (mm)	UI (%)	Strength (cN/tex)	Micronaire	Reflectance (%)	Yellowness
2	28.7	82.9	30.2	4.51	75.5	10.7
3	29.5	82.7	29.7	4.63	76.9	10.5
4	29.2	84.3	29.9	4.88	77.5	10.2
5	26.9	81.9	24.3	5.35	72.6	9.7
6	29.0	82.8	31.9	4.18	77.1	10.4
7	26.7	82.0	26.9	4.39	72.4	8.7
8	27.4	80.6	25.1	5.49	70.1	8.3
9	28.4	83.6	30.1	4.61	76.9	10.7
10	29.0	83.1	29.4	4.55	77.1	10.5
11	28.2	81.3	29.6	4.44	77.1	10.0
12	27.2	79.9	24.6	5.30	70.8	8.6
13	26.9	80.0	24.9	5.39	69.1	8.5
Average	28.1	82.1	28.0	4.81	74.4	9.7
Minimum	26.7	79.9	24.3	4.18	69.1	8.3
Maximum	29.5	84.3	31.9	5.49	77.5	10.7
1*	27.7	81.7	28.1	4.88	75.9	10.6

* Corresponds to the non-sticky module.

TABLE II. HPLC and H2SD results on twelve contaminated bales and one uncontaminated module.

Bale ID	Glucose (a)	Fructose (a)	Trehalulose (a)	Sucrose (a)	Melezitose (a)	Total Sugars (b)	H2SD
2	45.3	32.9	1.7	6.8	12.8	0.234	2.0
3	47.6	32.5	1.7	4.3	13.9	0.231	1.9
4	42.9	15.2	2.7	8.9	29.5	0.112	2.3
5	18.4	19.0	30.1	0.6	31.9	0.163	12.6
6	25.6	36.5	15.5	2.3	19.7	0.386	18.9
7	44.4	33.1	3.0	0.8	18.8	0.133	14.5
8	18.8	15.3	39.8	0.0	26.1	0.176	22.4
9	19.2	27.0	18.1	7.2	28.7	0.792	38.2
10	18.4	27.9	18.3	8.1	27.1	0.705	42.8
11	42.8	29.3	6.5	6.9	14.5	0.276	41.5
12	13.6	22.8	34.7	0.2	28.9	0.536	64.7
13	17.6	23.3	34.8	0.0	24.2	0.541	69.9
Average	29.5	26.2	17.2	3.8	23.0	0.357	27.6
Minimum	13.6	15.2	1.7	0.0	12.8	0.112	1.9
Maximum	47.6	36.5	39.8	8.9	31.9	0.792	69.9
1*	44.4	23.6	3.2	10.6	18.1	0.216	2.5

* Corresponds to the non-sticky module.

(a) Expressed in percent of total sugars.

(b) Expressed in percent of the fiber weight.

FIGURE 1. Outline of the mechanical process for the spinning trials.

with the non-sticky cotton. Four bales were spun after mixing the lint with 50% of non-sticky cotton. Four bales were spun after mixing the lint with 75% of non-sticky

cotton. Three bales were spun after mixing the lint with 87.5% of non-sticky cotton. Finally, two bales were spun after mixing the lint with 93.75% of non-sticky cotton.

TABLE III. HPLC and H2SD results on the card slivers of seventeen cotton mixes. G = Glucose, F = Fructose, T = Trehalulose, S = Sucrose, Me = Melezitose.

Mix ID	Bale ID	Non-sticky Module %	G (a)	F (a)	T (a)	S (a)	Me (a)	Total Sugars (b)	H2SD† Meas.	H2SD‡ calc.
A	1	100	42.5	21.7	3.4	14.5	17.9	0.207	3.2	2.5
B	2	0	44.9	33.5	2.4	5.7	13.1	0.245	2.0	2
C	3	0	49.1	33.6	1.8	5.0	10.5	0.220	2.3	1.9
D	4	0	40.7	10.6	1.8	5.3	40.7	0.113	3.2	2.3
E	5	50	29.8	20.8	14.3	9.5	25.6	0.168	8.3	7.6
F	5	75	36.3	21.2	9.8	11.9	20.7	0.193	6.5	5.0
G	6	50	30.0	32.9	10.7	7.2	19.2	0.307	8.9	10.7
H	6	75	36.1	29.1	4.1	10.7	19.7	0.244	4.5	6.6
I	7	50	42.5	28.1	1.3	5.6	21.9	0.160	10.2	8.5
J	7	75	41.5	24.5	2.1	11.2	20.7	0.188	4.8	5.5
K	8	50	27.7	17.8	16.8	6.9	30.7	0.202	15.1	12.5
L	8	75	34.0	19.8	9.9	10.8	25.5	0.212	6.0	7.5
M	9	87.5	29.8	23.8	9.8	14.0	22.5	0.315	4.7	7.0
N	10	87.5	34.2	24.1	7.5	14.3	19.5	0.266	5.3	7.5
O	11	87.5	42.6	23.8	2.5	13.4	17.8	0.202	15.7	7.4
P	12	93.75	35.0	21.0	9.7	12.1	21.8	0.257	9.3	6.4
Q	13	93.75	40.3	23.6	6.9	11.2	18.5	0.233	9	6.7
Average			37.5	24.1	6.8	10.0	21.5	0.219	7.0	6.3
Minimum			27.7	10.6	1.3	5.0	10.5	0.113	2.0	1.9
Maximum			49.1	33.6	16.8	14.5	40.7	0.315	15.7	12.5

† H2SD readings measured on card slivers.
 (b) Expressed in percent of the fiber weight.

‡ H2SD calculated from the raw material.

(a) Expressed in percent of total sugars.

After mixing of each bale, samples were taken for testing with H2SD (three replications, three times) and the HPLC (three replications) (Table III). The yarns were tested on UT3 (400 m/minute and 2.5 minutes on 10 bobbins) on Tensorapid (200 breaks), and on Scott Tester (10 skein). The ring spinning was done on a Saco-Lowell SF-3H, and the rotor spinning was done on a Rieter R20.

To validate the hypothesis of selective accumulation of trehalulose, card tests were performed on a selected range of 160 moderately sticky cotton samples that were independent from the cottons used for the spinning tests. The distribution of the H2SD readings for the 160 samples is shown in Figure 2 and HPLC results are summarized in Table IV. Each of the 160 tests consisted of 50 pounds (22.7 kg) of raw material. Around 8000 pounds (160 tests × 50 lb) of lint were processed through a Rieter C4 card. The production speed of the card was set at 100 pounds/hour (45.4 kg/hour).

Results and Discussion

Table II shows the HPLC and the H2SD results on the twelve contaminated bales and the non-sticky module. It reveals that trehalulose content ranged from 1.7% to 39.8% and melezitose content ranged from 12.8% to 31.9% (expressed as a percentage of the total sugars). The H2SD readings ranged from 1.9 to 69.9 sticky points.

FIGURE 2. H2SD readings on 160 samples for card tests.

TABLE IV. HPLC on 160 samples for spinning trials.

	% of the fiber weight			% of the total sugars		
	Average	Mini	Maxi	Average	Mini	Maxi
Glucose	0.081	0.030	0.168	63.1	37.8	83.3
Fructose	0.031	0.004	0.101	19.9	7.5	33.0
Trehalulose	0.002	0.000	0.006	1.7	0.1	11.1
Sucrose	0.008	0.000	0.046	5.2	0.0	17.4
Melezitose	0.013	0.002	0.036	10.2	2.9	24.2
Total	0.135	0.036	0.357			

TABLE V. Expected percentage sugar and H2SD readings versus measured percentage sugar and H2SD readings.

HPLC (% of the fiber weight)					
Variable	Slope	± 95% Cnf. Lmt	Offset	± 95% Cnf. Lmt.	Adjusted R^2
Glucose	1.060	[0.923, 1.197]	-0.012	[-0.025, 0.001]	0.944
Fructose	1.137	[1.058, 1.217]	-0.010	[-0.015, -0.005]	0.983
Trehalulose	0.961	[0.757, 1.164]	-0.001	[-0.004, 0.004]	0.863
Sucrose	1.749	[1.457, 2.040]	-0.009	[-0.014, -0.003]	0.911
Melezitose	0.993	[0.554, 1.433]	0.003	[-0.016, 0.022]	0.582
Total sugars	1.086	[0.924, 1.248]	-0.022	[-0.058, 0.015]	0.927

H2SD					
Variable	Slope	± 95% Cnf. Lmt.	Offset	± 95% Cnf. Lmt.	Adjusted R^2
H2SD	1.050	[0.562, 1.539]	0.4	[-3.0, 3.7]	0.556

The "stickiness profiles" in Table II are diverse. For instance, the bale number 2 was non-sticky even if the HPLC measured a very low contamination with aphid honeydew. Bale number 6 was sticky due to contamination by whitefly and aphid honeydew. Bale number 8 was probably sticky from whitefly honeydew, although the level of melezitose contamination indicates that some aphid honeydew contamination was likely. Bale number 9 was fairly heavily contaminated with honeydew from both aphids and whiteflies; yet, it also had high levels of physiological sugars, including sucrose. Bale number 12 was very heavily contaminated with whitefly honeydew and probably with a small amount of aphid honeydew. Therefore, there was no bale that could be classified as contaminated exclusively by whitefly honeydew.

From the 12 contaminated and the five non-sticky bales, 17 mixes (referenced A through Q) were evaluated. The HPLC and H2SD results obtained on the card slivers are presented in Table III. Testing was performed on card slivers because of the intimate blend between the two bales composing the mix at this stage. Expected HPLC and H2SD results were also calculated from the raw material values. For example if one mix was constituted of equal percentages of two bales, the average value of the two bales would be the expected values of the mix. A comparison between the expected value of the mix (raw material) to its measured value (card sliver) should indicate the effectiveness of our mixing procedure. Table V summarizes the results of the relationship of the percentage of sugars in the mix (expected) versus the percentage of sugar in the card sliver (measured). These results show that our mixes match nearly perfectly the expected values, with very high coefficients of determination between measured values and expected values obtained for all sugars except melezitose. Melezitose is the dominant insect sugar for all seventeen mixes.

Insect populations are not uniformly distributed within a field and neither are their excreta; therefore, higher variability within a bale is expected for insect sugars. Obviously this higher variability translated into a lower coefficient of determination. It should be noted that measured and expected H2SD readings (measuring insect honeydew sticky spots) also show lower correlation coefficients.

As expected, the sugar contents and H2SD readings on the mixes indicate slight-to-moderate levels of stickiness. The fiber characteristics of the bales involved in these trials were fairly typical for Upland cottons (Table I). The yarns were spun to a finer count (30Ne for the ring spun yarn and 22Ne for the rotor spun yarn) than appropriate for the fiber, in order to maximize the probability of contact between the sticky spots and the spinning components.

FIGURE 3. UT3 CV%: variability between doffs for the ring spun yarn 30 Ne: $UT3\ CV\% = 24.47 + 0.0496 (\text{Doff number}) - 0.00251 (\text{Doff number})^2$, Adjusted $R^2 = 0.731$ $F(2,10) = 17.27$, $p < 0.001$ Std error of estimate = 0.038.

FIGURE 4. UT3 Thin places: variability between doffs for the ring spun yarn 30 Ne: Thin places = $866.9 + 12.31 (\text{Doff number}) - 0.556 (\text{Doff number})^2$, Adjusted $R^2 = 0.892$ $F(2,10) = 50.70$, $p < 0.001$ Std error of estimate = 6.55.

FIGURE 5. UT3 Thick places: variability between doffs for the ring spun yarn 30 Ne: Thick places = $1902 + 7.08 (\text{Doff number}) - 0.335 (\text{Doff number})^2$, Adjusted $R^2 = 0.763$ $F(2,10) = 20.31$, $p < 0.001$ Std error of estimate = 5.58.

The results obtained on the yarn quality tests are presented as the average of 17 mixes. Figure 3 shows the changes in the CV% of the ring-spun yarns with successive doffs. It shows that the accumulation of sticky deposits on the ring spinning frame had a slight but significant impact on the UT3 CV%. Similar observations were made for the UT3 thin places (Figure 4) and UT3 thick places (Figure 5). However, no significant effect was found on the neps count or on the yarn hairiness. Neither was there an effect on yarn tenacity nor count strength product (CSP). As the yarn produced was quite fine, the number of ends down was rather high,

FIGURE 6. H2SD versus number of ends down for 1000 spindle hours.

FIGURE 7. UT3 Neps (280%): variability between doffs for the rotor spun yarn 22 Ne: Neps 280% = $3.72 + 0.094 (\text{Doff number})$ Adjusted $R^2 = 0.632$ $F(1,6) = 13.01$, $p < 0.011$ Std error of estimate = 0.17.

but it was not related to the stickiness level of the mix, as shown in Figure 6.

For rotor spinning, no such time-related impacts were seen for the UT3 CV%, number of thin places, or number of thick places. For the number of neps (+280% sensitivity) in the yarn, there was an extremely slight but statistically significant increase (Figure 7). However, the analysis of the neps using the +200% sensitivity setting on the UT3 did not indicate a significant change. Yarn hairiness, yarn tenacity, and yarn CSP do not seem to be affected by these low levels of stickiness.

The mixes tested had card-silver H2SD readings that ranged between 2 and 15.7 (Table III). At these levels a very slight, but significant, short-term effect on spinning

150×

300×

300×

600×

FIGURE 8. SEM of the residues collected from the Rieter C4 card.

performance was detected for quality but not for productivity (as measured by ends-down levels). The slight deterioration of the yarn quality of the ring spun yarn after 72 hours of spinning indicates a possible long-term

effect on both quality and productivity even at these very low levels of stickiness.

In conclusion, in the short term and based on H2SD measurements only, less than 12 sticky spots (within a

mix, on raw material), with the stickiness coming predominantly from aphid honeydew contamination, does not seem to influence the productivity for either ring- or rotor-spun yarns. However, a slight, but significant, longer term negative effect on the ring spun yarn quality was detected even at the very low levels of stickiness tested. Over long periods of manufacturing, it seems likely that the gradual accumulation of sugars on the textile equipment could negatively impact both productivity and yarn quality. The only way to alleviate such effects would be careful and time-consuming cleaning of the machinery.

To study the long-term behavior of sugar accumulation on the textile equipment, card tests were performed as described in the materials and methods section. As shown in Table IV, all samples were contaminated with insect honeydew to some degree. All ratios of trehalulose to melezitose were well below 1 indicating a predominantly aphid honeydew contamination. The average H2SD reading was 10 spots. After the completion of all card tests, the residues stuck on the Rieter C4 card transfer tray were collected and examined with a scanning electron microscope (Figure 8). These micrographs clearly show crystals and fibers embedded in an amorphous matrix. In addition, X-ray microanalysis tests were performed on these sticky deposits. As shown in Figure 9, silica (Si) is the dominant compound in the residues collected. It represents 46.2% of the area under curve (average of three replications). The quite elevated amounts of potassium (K), 13.6% of the area under curve, and aluminum (Al), 9.5% of the area under curve are also noteworthy. Silica and potassium probably come from the soil collected during cotton harvesting, while aluminum probably comes from the opening line and the card. Indeed, it is quite likely that the fine particles of aluminum come from the machinery. This could explain why the spinners, in some cases, complain about the

abrasive character of sticky cottons. The sugars in the sticky residues were extracted and the HPLC tests were conducted. The results showed a total percentage for sugars of 0.920%, which indicated a high sugar concentration in the residues. More importantly, the percentage of entomological sugars (expressed as a percentage of the total sugars) is very high with 50% of trehalulose and 17.4% of melezitose, compared with only 1.7% of trehalulose and 10.2% of melezitose in the raw fiber. This indicates that among the sugars detected on the raw fiber, trehalulose has the tendency to accumulate most on the textile equipment. This makes trehalulose a primary suspect as the main source of process disruption, productivity loss, and poor-quality products. Consequently, the threshold level above which a textile mill would experience problems could be lower for whitefly honeydew (trehalulose-rich) contamination than for aphid honeydew contamination. This issue is the subject of another study, the results of which will be reported in the near future.

Conclusions

The spinning experiments showed that in the short term, and based on the H2SD measurements only, less than 12 H2SD spots (within a mix on raw material), caused little-to-no loss in productivity for either ring-spun (Saco-Lowell SF-3H) or rotor-spun (Rieter R20) yarns. A slight, but significant, negative effect on the ring spun yarn quality was detected even at the very low levels of stickiness tested. Thus, in the long term it appears that even very small amounts of trehalulose might slowly contaminate the equipment; first sticking to surfaces, then catching dust, silica, etc. This could increase the friction forces within the machinery and lead to excessive wear and temperature increase. This accumulation of sugars could have a negative impact on both

FIGURE 9. X-ray microanalysis of the residues collected from the Rieter C4 card.

productivity and yarn quality over the long term. The threshold level above which a textile mill would experience problems could be lower for whitefly honeydew (trehalulose-rich) contamination than for aphid honeydew contamination. This issue is the subject of another study, the results of which will be reported in the near future.

ACKNOWLEDGMENT

The authors would like to acknowledge Cotton Incorporated and the Texas Food and Fibers Commission for their financial support.

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