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ARTHROPOD MANGEMENT

Comparison of Sticky Cotton Indices and Sugar Composition

Jay S. Bancroft*, Robert Hutmacher, Larry Godfrey, Peter B. Goodell,
Michael McGuire, Paul Funk, and Steve Wright

ABSTRACT

Sticky cotton lint contaminates equipment in gins and textile mills, and requires costly stoppages for cleaning and repair. The primary source of stickiness is sugars from insect honeydew. This manuscript assesses relationships among measurements of sugar composition and two methods used to measure stickiness. The hypothesis was that the measures of stickiness and sugar composition will be highly correlated. Variables were compared to look for patterns that could be used to improve our understanding and management of stickiness. Experimental trials were conducted in seven fields over 3 years. A total of 724 samples of cotton lint were tested for stickiness with the Lintronics Fiber Contamination Tester (LFCT) and the High Speed Stickiness Detector (H2SD). Sugar composition testing was also performed on a subset of 325 samples. Coefficients of variation, correlations, and factor analyses were used to identify relationships among the variables reported from each source of test data. The strongest relationships were between large spots on the H2SD and intermediate sized spots on the LFCT (R = 0.46). The LFCT demonstrated greater precision than the H2SD, based on coefficients of variation. Sugar composition was dominated by those found in plants (72%) with 6% from melezitose and 22% from trehalulose. The H2SD was more closely associated with aphid-derived sugars, and the LFCT was more closely associated with whitefly-derived sugars. Relationships between sugar content and stickiness indices indicate complex biochemical interactions that require further study. The factor analysis reduced the stickiness measurements to a single value that is more representative of the stickiness than total number of spots. The use of factor coefficients in linear combination is demonstrated to create enhanced indices of stickiness.

Cotton processing can be severely hindered by the presence of sticky carbohydrate exudates on cotton fibers (Henneberry et al., 1996). Cotton gins experience reduced flow and efficiency when processing sticky lint. In severe cases, they require downtime for cleaning. Lint contamination is a greater problem with roller gin processing (for extra-long staple lint) than with saw gin processing used for Upland cottons. Modern textile mills with high precision experience the most severe problems with sticky cotton, which reduces yarn spinning quality (quantified by number of "ends-down") and throughput that results in substantial economic losses. If the problem is not widespread, mills may blend sticky and clean bales to effectively dilute stickiness.

Sticky lint primarily occurs when honeydew is excreted onto exposed lint in the field by insects, mainly the cotton aphid, *Aphis gossypii* Glover, and the silverleaf whitefly, *Bemisia argentifolii* (or *B. tabaci* biotype B) Bellows and Perring (Henneberry et al., 1999; Hequet and Abidi 2002a; Naranjo and Hequet, in press; Slosser et al., 2002). These insects remove water, proteins, carbohydrates, and other nutrients from plant sap and excrete surplus carbohydrates. There may be minor contributions to stickiness from oils or proteins that are produced by microbes, which consume the sugars (Ellsworth et al., 1999, Ethridge and Hequet, 1999). Plant sugars, derived from immature fibers at harvest, may also contribute to overall stickiness (Byrne et al., 2003). The most effective way of preventing stickiness is to manage aphids and whiteflies when lint is exposed.

The sugars from cotton plants and insect pests have different effects on stickiness. The prevalent sugars in cotton plants are sucrose and glucose, which cause lower stickiness per unit volume compared

J. S. Bancroft, R. Hutmacher, M. McGuire, USDA, ARS, 17053 N Shafter Ave., Shafter, CA 93263; L. Godfrey, One Shields Ave., Davis, CA 95616; P. B. Goodell, 9240 S. Riverbend Rd., Kearney, CA 93648; P. Funk, 300 E. College Dr., Mesilla, NM 88047; S. Wright, 4437 S. Laspina St., Ste. B, Tulare, CA 93274
*Corresponding author: jsbancroft@pw.ars.usda.gov

with insect sugars because of their higher melting point (Miller et al., 1994; Ghule et al., 2004; Hequet et al., in press). Insects excrete a range of different sugars (Hendrix et al., 1992), but aphid honeydew is characterized primarily by melezitose, and whitefly honeydew is composed of approximately 40% trehalulose (Byrne et al., 2003). Both of these sugars contribute to stickiness, but trehalulose is stickier than melizitose (Hequet and Abidi, 2002a).

The techniques used to measure lint contamination generally rely on the stickiness of constituent sugars. Two common methods are used for measuring lint stickiness. In both methods, samples are held at a constant 25 °C with 55% relative humidity for at least 12 hr prior to testing. Hequet et al. (in press) argued that the High Speed Stickiness Detector (H2SD) may be the most suitable. H2SD forms a 3.5-g lint sample into a 190-mm^2 pad. The lint sample is pressed onto a 53 °C aluminum sheet and held for 25 s at 1500 Newtons. The sample is depleted of sugars by the process, and the foil is optically scanned to score sticky spots. The Lintronics Fiber Contamination Tester (LFCT) also relies on destructive sampling to measure sticky spots. A 6-g sample is pressed between metal cylinders that are warmed to a constant temperature and read with an optical scanner (Mor et al., 2005, Hequet et al., 2005).

The LFCT and H2SD methods were used to measure stickiness in this study. Both methods can process a sample in less than a minute and are common standards that were used in previous research on lint stickiness (Naranjo and Hequet, in press). Stickiness problems are believed to develop when total H2SD sticky spot counts exceed approximately 15, but this threshold may vary depending on the type of processing equipment, humidity, and temperature (Hequet et al., in press). In comparison, LFCT produces a "stickiness grade" based on total counts and average spot size. LFCT grades under 100 have low stickiness, those above 200 are sticky, and those in between 100 and 200 have moderate stickiness (Mor et al., 2005).

Two hypotheses are proposed. One hypothesis predicted that measurements from the two machines would correlate highly with each other. The second hypothesis was that the sugars associated with insect pests or plant fiber would correlate with the stickiness measurements.

This study arose from a larger study designed to determine the effects of late season cotton management (insecticide and harvest-aid applications) on cotton lint stickiness. The opportunity was taken to examine the stickiness measurements by two methods, analyzed on both H2SD and LFCT. The purpose of this study was to look for patterns in stickiness in a large set of lint samples. Factor analysis was used to improve the index value used to represent stickiness of a lint sample, although factor analysis also uses correlation and no causal inference can be ascribed. Finally, biological processes occurring in cotton fields are related to lint sugars and stickiness.

MATERIALS AND METHODS

The field sites were located in the southern San Joaquin Valley, California. In 2002, two fields were used in Tulare county and one in Kern county. In 2003 and 2004, one field was used in both Kern and Tulare counties. A total of 8 ha were used in the seven fields, and all cottons were commercial Acala cultivars grown on beds spaced 1 m apart. All of the cotton was furrow irrigated. Lint samples were acquired from the set of field experiments that were used to test the effects of various defoliants and insecticides on lint stickiness. Plots at each site were 22.9 m long and 6.2 m wide. Chemical treatments, along with untreated control plots, were used to create uniform lint stickiness within plots and variability in lint stickiness between plots. For the purpose of this paper, the resulting correlations of stickiness measurements rely only on successful creation of variability between plots that is reflected in stickiness among lint samples. A total of 724 plots were used to collect 3-kg samples of seed cotton. Each sample was prepared by hand-picking all bolls from 20 plants in an even spacing along the center of the plots, leaving a 2 m buffer between plots. The sampling was meant to mimic mechanical harvesting.

Samples were processed to acquire stickiness and sugar measurements. All samples were saw-ginned at the Shafter Research and Extension Center, and the ginning process was assumed to mix the bolls within the sample. The lint was kept in paper bags and stored below 30% RH to prevent microbial activity. Lint subsamples of 50 g were placed in small paper bags for testing at three facilities.

Duplicated subsamples were taken from some samples to determine the variability within samples for each analytic method. Most subsamples were duplicated 3 times, and none were duplicated more than 10 times. For H2SD, 2200 duplicated subsamples were analyzed from 543 samples, and 191 samples

were not subsampled multiple times. For the LFCT, 334 duplicated subsamples were analyzed from 153 samples, and 571 samples were not sub-sampled multiple times. For the sugar composition, 93 subsamples were analyzed from 25 samples, and 699 samples were not subsampled multiple times. This provided three sets of subsamples for stickiness or sugar analysis.

All duplicates from one set of subsamples were analyzed on a LFCT in Buttonwillow, CA. Duplicates from the other subsamples were tested at the International Textile Center in Lubbock, TX, where both H2SD and sugar compositional analyses were performed. On the H2SD, each subsample was measured three times. The H2SD quantified the number of small (≤1.9 mm^2), medium (>1.9 and ≤18 mm^2), large (>18 mm^2) spots and the total number of spots. Sugar composition analysis with high performance liquid chromatography measured the percentage of the subsample that was inositol, trehalose, glucose, fructose, trehalulose, sucrose, turanose, melezitose, maltose, and the total percentage of sugar (Hequet and Abidi, 2002a). The LFCT measured the number of spots for five spot size classes within each 6-g subsample. During processing, sticky spots interrupt a laser, which is capable of detecting single fibers adhering to the spot. Spot sizes correspond to the number of fibers on the sticky spot, counted in groups of about 10 fibers. The five size classes are as follows: ≤ 10, >10 ≤ 20, >20 ≤ 30, >30 ≤40, and >40 fibers per spot. The values for the five sizes were used to calculate average spots per gram and average size classification of the spots. The average size and average number of spots were then multiplied to get a stickiness grade for each subsample. The LFCT reported a standard output consisting of the number of sticky spots in the five size classes, along with total spots, average spot size, grade, neps, and micronaire. The three separate analyses provided standard variable measurements, and the data sets were included in the following analyses.

The measurement techniques destroyed the lint subsamples; therefore, subsamples were used to compare variation within samples, variance among samples, and the relationships among the 25 variables measured. Three statistical methods were used to analyze the data. The coefficient of variation (CV) was used to characterize variation within samples (CV = standard deviation/mean). The CV of the samples was calculated as a weighted average to account for the number of repeated subsamples taken from each sample.

In the second statistical method, factor analyses (Statistica, ver. 5.5; Statsoft Inc.; Stillwater, OK) further characterized the relationships among variables. In this analysis, eigenvalues, factor coefficients, factor scores, and factor correlations are produced. Factor coefficients are used with variable measurements to create a factor score like multiple regression. The factor coefficients are slopes of axes that are rotated through the values of variable points in multi-dimensional space. Matrix algebra is used to create a single eigenvalue for each set of factor coefficients (an eigenvector), which conceptually represents the amount of variance captured in the data. One set of coefficients does not usually capture all of the variance in a given set of data. The number of factors may be objectively determined by the number of eigenvalues greater than one, and these are called principle factors (Kaiser, 1960). Factors with lower eigenvalues explain little additional variability and are excluded. Principal factors are fitted to encompass the greatest variance in the values of a set of variables, maximizing multiple R^2. The factor coefficients may be used to calculate a single factor score for each set of variable values. To interpret the results, the factor scores are then correlated with the variable values to gain insight into which variables contribute to the variance in the factor analysis. A specific example will clarify exactly what was done.

For a set of lint stickiness measurements from the H2SD, a single principle factor was calculated by Statistica software (Statistica, ver. 5.5; Statsoft, Inc.). The principle factor had a set of coefficients, one for each variable, such as the size classes of sticky spots. The variable values for each lint subsample were used in a linear combination with the factor coefficients to calculate a factor score. The factor score represented all H2SD measurements from within a single subsample and was an objective way to summarize the values of all variables in that measurement. Finally, Pearson correlations were calculated between the variable values and factor scores. This correlation for each variable in the analysis provided a measure of the strength of contribution to the factor. The factor correlations facilitated the interpretation of the relationships among variables.

Factor analyses were performed separately for measurements from sugar, H2SD, and LFCT, and on the combined data from all three data sets. For samples that had duplicate subsamples analyzed, the average value was used. Sugar analysis was performed on 325 of 724 total samples; therefore,

a subset of 325 samples was used in the sugar and combined factor analyses. The results of an analysis for all 724 samples using only the stickiness measurements, H2SD and LFCT, did not alter the results significantly and are omitted for brevity.

The third statistical method used the combined data set to examine the Pearson correlations among all variables in the sugars, H2SD, and LFCT data sets. A sequential Bonferroni correction was applied to account for repeated correlation tests (Rice, 1989). Finally, comparison of a variable's ability to discriminate among samples was facilitated by calculating the CV across all 325 samples and subtracting the within-sample CV.

RESULTS

The levels of stickiness ranged widely, but most were in the moderate or borderline levels for causing problems in lint processing. Both the H2SD and LFCT indicated that about half the samples were moderately sticky, 20% were non-sticky, and 30% were very sticky. These results indicate that the analysis was conducted on an appropriate range of stickiness data, and supports the application of the factor coefficients.

Factor analysis of the stickiness measurements from the H2SD showed similar correlation levels across the three size classes of sticky spots (Table 1). The CV was greatest for large spots indicating the poorest precision. The factor analysis resulted in one eigenvalue greater than one (eigenvalue = 3.4), and factor correlations reflected the high correlation among size class variables. The single eigenvalue greater than one accounted for 82% of the variance in the data set.

The LFCT had CVs that were lower than those for H2SD for smaller sized sticky spots, but other variables had CVs roughly equal to those of H2SD (Table 2). Factor analysis for the LFCT showed one eigenvalue greater than one, and factor correlations were dominated by middle-sized sticky spots. The stickiness grade was the most highly correlated variable with the factor score, and rounded to 1.00. The single eigenvalue of 4.2 accounted for 61% of the variance in the data set.

Levels of sugars in the analysis were inositol (23%), trehalulose (22%), fructose (21%), maltose (11%), turanose (8%), melezitose (6%), glucose (4%), and trehalose (1%). The CVs of sugar composition showed slightly lower values among con-

Table 1. Coefficients of variation within samples and results of factor analysis for classes of sticky spots from the High Speed Stickiness Detector (H2SD)

Sticky class[x]	CV	Factor 1 coefficients[y]	Factor 1 correlations[z]
Small	0.58	0.276	0.94
Medium	0.38	0.247	0.79
Large	1.38	0.268	0.89
Total	0.55	0.295	0.99
Explained variance			82%

[x] Small, medium, and large sticky spots are ≤1.9 mm^2, >1.9 to ≤18 mm^2, and >18 mm^2, respectively. The explained variance shows the proportion of the overall variance in all of the variables that was explained by the linear combination of factor coefficients and stickiness measurements.

[y] The value represents the index of stickiness for the lint sample. The coefficients may be multiplied by the number of sticky spots in the output from H2SD and summed to calculate the more representative index of stickiness.

[z] Factor correlations show the correspondence of the factor coefficients with the four variables. The correlations are used to gauge the influence of the variable on the factor coefficients and may used to compare variables.

Table 2. Coefficients of variation within samples and the results of the factor analysis for sticky spot classes for Lintronics Fiber Contamination Tester (LFCT)

Variable[x]	CV	Factor 1 coefficients[y]	Factor 1 correlations[z]
Size 1	0.04	0.137	0.84
Size 2	0.03	0.154	0.95
Size 3	0.03	0.152	0.94
Size 4	0.03	0.148	0.91
Size 5	0.76	0.145	0.89
Counts	0.55	0.159	0.99
Grade	0.59	0.161	1.00
Mean size	0.30	0.020	0.11
Neps	0.40	0.030	0.16
Micronaire	0.58	0.009	0.05
Explained variance			61%

[x] The five size classes are ≤ 10, >10 ≤ 20, >20 ≤ 30, >30 ≤40, and >40 fibers per spot. The explained variance shows the proportion of the overall variance in all of the variables that was explained by the linear combination of factor coefficients and stickiness measurements.

[y] The value represents the index of stickiness for the lint sample. The coefficients may be multiplied by sticky spots in the output from LFCT and summed to calculate the more representative index of stickiness.

[z] Factor correlations show the correspondence of the coefficients of variation with the ten variables. The correlations are used to gauge the influence of the variable on the factor coefficients and may used to compare variables.

stituent variables (Table 3). Factor analysis showed two eigenvalues greater than one (eigenvalues = 4.2 and 1.7) that accounted for 62% of the variance. Factor scores showed strong negative correlations with levels of trehalulose, maltose, and fructose in factor one and a positive correlation with melezitose in factor two.

Table 3. Coefficients of variation for the various sugars from the sugar content analyses and total sugar within samples

Variable	CV	Factor 1 correlations[y]	Factor 2 correlations[y]
Inositol	0.085	-0.58	-0.05
Glucose	0.156	0.68	0.51
Fructose	0.205	-0.85	0.34
Trehalulose	0.507	-0.87	0.39
Sucrose	0.625	-0.25	0.45
Turanose	0.434	-0.47	-0.49
Melezitose	0.160	-0.02	0.73
Maltose	0.465	-0.85	-0.47
Trehalose	0.429	-0.47	0.05
Total sugars	0.137	-0.95	0.24
Explained variance[z]		44%	18%

[y] Factor correlations show the correspondence of the coefficients of variation with the ten variables. The correlations are used to gauge the influence of the variable on the factor coefficients and may used to compare variables.

[z] The explained variance shows the proportion of the overall variance in all of the variables that was explained by the linear combination of factor coefficients and stickiness measurements.

The factor analysis of all data combined showed the relationship among the three sources of data. The CVs for each variable (Table 4) were generally greater than those within samples (Tables 1-3). This was demonstrated by the CV differences for each variable, where CVs within samples were subtracted from those calculated across samples. The factor analysis calculated four eigenvalues (8.7, 2.9, 2.5, and 1.7) that accounted for 66% of the variance in the data set (Table 4). The increase to four factors showed the data held more heterogeneity than previously described by factor analyses. The factor loadings show how variables were grouped to maximize variance within the data set. The first factor was correlated strongly with the LFCT variables, and the second factor was highly correlated with the H2SD variables. The third factor was highly correlated with melezitose, and the fourth factor was correlated strongly with several of the sugars, most notably trehalulose.

Pearson correlation values (Table 5) showed patterns of relationships among variables. Within sugars, fructose and trehalulose were the most highly correlated ($R = 0.95$). Maltose, inositol, and trehalose were strongly correlated with total sugar ($R > 0.71$). Glucose was not significantly associated with any sugars except melezitose, a key honeydew sugar ($R = 0.49$). Stickiness measurements generally showed high correlation ($R \approx 0.90$) within measurements from LFCT or H2SD. Correlations between LFCT and H2SD were much lower with the largest value of 0.46 between LFCT size two and H2SD large size spots.

DISCUSSION

The relationships among stickiness and sugar measurements show distinct patterns. The correlation was strongest between large spots from the H2SD and medium spots (sizes 2, 3 and 4) from LFCT. The first factor (Table 4) showed correlations, not only with LFCT spots, but with trehalose and trehalulose. Byrne et al. (2003) found that aphids are a primary source of melezitose, which makes up about 11% of aphid honeydew, while trehalulose makes up over half of whitefly honeydew. The characteristic ratio of melezitose to trehalulose is 1:1 for aphid honeydew and 1:3 for whitefly honeydew. This factor correlation implies that whiteflies were a more prevalent source of stickiness than aphids in this study.

The correlations among variables (Table 5) showed LFCT to be more strongly associated with trehalulose than the H2SD, but the association was reversed with melezitose. This suggests that the LFCT and H2SD are more sensitive to sugars associated with whiteflies and aphids, respectively. The correlation of trehalulose with total sugar showed the predominance of this whitefly-derived sugar; however, the results are undoubtedly affected by the condition of the plant and all of the environmental influences this entails. Further studies may clarify the mechanisms that result in the biochemical relationships among lint sugars and stickiness measurements.

Factor analysis was used to account for variance in the stickiness data, because an algebraic relationship is not known. The coefficients (Table 1) provide

a good method to represent stickiness on the H2SD versus total spots. The stickiness grade on LFCT incorporates spot size, but the factor coefficients are an objective summarization of the data, which accounts for the maximum amount of variance in one stickiness index. The coefficients may be used with stickiness measures from either H2SD or LFCT and will better represent stickiness than total spots, which is often used (Ethridge and Hequet, 1999; Hequet and Abiti, 2002b).

LFCT had greater CV differences than those for H2SD (Table 4). This suggests a stronger ability to discriminate samples. Large differences in CVs were also calculated for sugars, including those associated with whitefly (trehalulose) and aphids (turanose and melezitose) (Byrne et al., 2003). Recent sampling research (Naranjo and Hequet, in press) was used to plan this experiment, and CV differences help show the relationships within and between lint samples. CV differences may be lower in lint grown commercially,

Table 4. Coefficients of variation and factor analyses from the Lintronics Fiber Contamination Tester (LFCT), High Speed Stickiness Detector (H2SD), and the sugar analysis data sets combined

	Variable[x]	CV	CV difference[y]	Factor 1 correlation[z]	Factor 2 correlation[z]	Factor 3 correlation[z]	Factor 4 correlation[z]
1	Size 1	1.73	1.70	0.80	0.10	0.09	0.04
2	Size 2	1.33	1.30	0.88	0.20	0.08	0.20
3	Size 3	1.28	1.25	0.87	0.16	0.05	0.27
4	Size 4	1.39	1.36	0.84	0.16	0.02	0.23
5	Size 5	1.60	0.84	0.85	0.13	-0.05	0.17
6	Counts	1.35	0.80	0.94	0.16	0.07	0.16
7	Grade	1.31	0.73	0.94	0.16	0.04	0.21
8	Mean size	0.19	-0.12	-0.01	-0.04	0.10	-0.03
9	Neps	1.05	0.65	0.09	0.02	-0.01	0.21
10	Micronaire	0.21	-0.37	0.03	0.06	0.46	0.02
11	Small	0.70	0.12	0.22	0.90	-0.09	0.13
12	Medium	0.77	0.39	0.11	0.85	-0.03	0.04
13	Large	0.90	-0.49	0.26	0.86	0.08	0.16
14	Total	0.73	0.17	0.22	0.95	-0.03	0.13
15	Inositol	0.21	0.12	0.02	-0.03	0.27	0.57
16	Glucose	1.26	1.10	0.15	0.01	0.74	0.35
17	Fructose	0.69	0.48	0.30	0.17	0.07	0.80
18	Trehalulose	1.16	0.65	0.31	0.20	0.03	0.83
19	Sucrose	0.77	0.15	0.11	0.02	-0.28	0.39
20	Turanose	1.46	1.03	0.04	0.11	0.62	0.22
21	Melezitose	0.71	0.55	0.06	-0.25	0.69	-0.36
22	Maltose	0.72	0.25	0.24	0.09	0.78	0.51
23	Trehalose	0.65	0.22	0.44	0.05	0.12	0.32
24	Total sugars	0.50	0.36	0.28	0.21	0.18	0.89
Explained variance				36.4	12.1	10.2	7.0

[x] Variables 1-10 from H2SD, 11-14 from LFCT, and 15-24 from sugar analysis. Total variance explained by the 4 factors was 66%.

[y] CV differences (CV among – CV within samples) show the resolution of the differences among samples.

[z] Factor correlations show the correspondence of the coefficients of variation with the 24 variables. The correlations are used to gauge the influence of the variable on the factor coefficients and may used to compare variables.

because untreated control plots with high stickiness and plots with optimal insect control were present. This enhances the argument for using a maximally discriminating method like factor analyses. With less variation among samples, the most sensitive method available becomes more important for improved resolution of stickiness estimates. Although the factor coefficients reported here (Tables 1 and 2) may vary with production region and management practices, the use of factor coefficients should provide better discrimination among lint samples. We encourage the testing of factor analysis and eventual adoption of factor scores for assessing lint stickiness.

Several sources of variation were not controllable. A primary source was temperature, which exceeded 35 °C on an average of 54 d per year during the three-year study. The high temperatures in the San Joaquin Valley may reduce problems associated with plant sugars (Byrne et al., 2003) but may facilitate aphid and whitefly populations. The predominance of aphids and whiteflies varied among fields, with the Tulare sites having greater whitefly abundance and the Kern sites having more aphids. Variation in the level of infestation would alter stickiness results, and future studies will attempt to clarify the role of each species to the creation of certain size ranges of sticky spots. Another concern that may explain the variation in these results is dispersal of aphids and whiteflies among plots. The plots were 23 x 6 m and required approximately 8 ha in seven separate fields, but some insect movement among plots undoubtedly occurred. Defoliation and pesticide treatments were likely to reduce insect movement among treatment plots.

Table 5. Results of Pearson correlation analysis among the 25 variables

Variable	Variable[z]																					
	S2	S3	S4	S5	Cnt	Grd	Msz	Nep	Mic	Sm	Med	Lrg	Tot	I	G	F	Tu	S	Tn	M	MA	Ta	Sugar
Size 1	0.81	0.69	0.64	0.64	0.91	0.81	-0.20	0.07	0.08	0.28	0.18	0.33	0.29	0.07	-0.22	0.34	0.34	0.08	0.10	-0.04	0.30	0.33	0.33
Size 2		0.90	0.85	0.81	0.96	0.95	-0.03	0.11	0.06	0.42	0.28	0.46	0.43	0.16	-0.27	0.48	0.50	0.19	0.17	0.02	0.41	0.46	0.51
Size 3			0.89	0.88	0.92	0.96	0.08	0.15	0.08	0.38	0.26	0.43	0.40	0.19	-0.26	0.52	0.54	0.20	0.19	0.05	0.43	0.56	0.55
Size 4				0.86	0.87	0.93	0.14	0.12	0.06	0.37	0.25	0.41	0.38	0.18	-0.23	0.46	0.49	0.20	0.15	0.05	0.37	0.51	0.49
Size 5					0.86	0.92	0.15	0.14	0.01	0.34	0.25	0.37	0.35	0.11	-0.16	0.42	0.44	0.16	0.06	0.06	0.28	0.48	0.42
Counts						0.98	-0.04	0.12	0.07	0.38	0.25	0.43	0.39	0.14	-0.25	0.47	0.48	0.16	0.15	0.01	0.38	0.48	0.48
Grade							0.04	0.13	0.06	0.40	0.27	0.44	0.41	0.16	-0.25	0.49	0.51	0.19	0.15	0.04	0.39	0.52	0.51
Mean size								0.09	0.02	0.05	0.06	0.03	0.05	0.03	0.09	-0.07	-0.02	0.08	0.05	0.13	-0.06	0.06	0.00
Neps									-0.03	0.08	0.01	0.08	0.08	0.11	-0.07	0.22	0.21	0.04	0.06	0.08	0.15	0.18	0.22
Micronaire										0.05	0.03	0.10	0.07	0.13	-0.47	0.06	0.05	-0.03	0.25	-0.30	0.40	0.13	0.10
Small											0.83	0.89	0.98	0.02	-0.04	0.32	0.37	0.16	0.06	0.34	0.13	0.19	0.36
Medium												0.80	0.88	0.02	-0.02	0.19	0.23	0.05	0.12	0.28	0.11	0.11	0.25
Large													0.95	0.07	-0.17	0.41	0.43	0.07	0.18	0.19	0.30	0.21	0.44
Total														0.03	-0.08	0.34	0.38	0.12	0.11	0.30	0.19	0.19	0.38
Inositol															-0.33	0.28	0.34	0.32	0.57	0.15	0.52	0.31	0.57
Glucose																-0.48	-0.46	0.02	-0.35	0.49	-0.84	-0.23	-0.48
Fructose																	0.95	0.27	0.09	0.19	0.60	0.31	0.91
Trehalulose																		0.29	0.12	0.27	0.56	0.38	0.93
Sucrose																			-0.15	0.38	0.01	0.23	0.31
Turanose																				-0.24	0.65	0.23	0.42
Melezitose																					-0.39	0.04	0.25
Maltose																						0.40	0.71
Trehalose																							0.44

[z] Abbreviations across the top follow the same order as the column on the left. Values greater than |0.15| are significantly correlated at the $P = 0.05$ (N = 325).

The timing of boll opening and cumulative lint exposure to aphids and whiteflies is critical for the development of stickiness. This study has shown that stickiness measurement is still problematic, because methods do not correlate very highly. Continued improvement is still needed to acquire rapid and representative measures of stickiness. In turn, this will aid further research on stickiness management issues, including final irrigation, nitrogen fertilization, defoliation and harvest-aid application, foliar regrowth, and especially aphid and whitefly control. This study has shown the correlations among commonly used measures of stickiness and how these relate to sugars produced by aphids and whiteflies. Finally, coefficients from factor analysis provide a way to improve the discrimination of stickiness among samples.

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