1758 Cotton Quality Indices of Spun Yarn

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ABBREVIATIONS: HVI™, High Volume Instrument; AFIS, Advanced Fiber Information System; Rindex, ring spinning quality index; Oindex, open end spinning quality index; and Vindex, vortex spinning quality index; PRindex, percentile ring spinning index; POindex, percentile open end spinning index; and PVindex, percentile vortex spinning index.

ACKNOWLEDGEMENTS: We gratefully acknowledge and appreciate the help provided by producers, ginners, and numerous others. We gratefully acknowledge Don Brushwood, Nancy Carroll, Martha Duncan, Pat Fields, Don Gillespie, Robert Harrison, Curtis Heaton, Linda James, Jimmy Lewis, Bill Mahaffey, Judy Marcus, Mattie Morris, Brad Reed, Debbie Sewell, Carolyn Simpson, Derrill Stephens, Minnie Walker, and David Wessinger from United States Department of Agriculture, Agricultural Research Service, Cotton Quality Research Station for assisting with testing and set-up. We gratefully acknowledge Rose Gould and Patricia Butler from Clemson University for their statistical assistance.

Abstract Cotton was spun into yarn at the Cotton Quality Research Station by each of three spinning methods (ring, vortex, and open end spinning) to determine if a relationship exits between cotton fiber properties and the quality of spun yarn. Cotton was grown and harvested in 2001-2005 from three of the largest producing growing regions (Georgia, Mississippi, and Texas) and subsequently ginned at their respective locations. Goals of this five year project are to determine an index of overall yarn quality based on cotton fiber properties and optimize the utilization of cotton for the cotton industry. Cotton cultivars are not bred for utility value with the exception of some properties measured using the High Volume Instrument (HVI™). A portion of yarn variability is accounted for by various fiber properties which partially predict the physical properties of yarn and the success of spinning. Unfortunately, the commercialization of cotton cultivars is not contingent upon fiber quality or establishing a satisfactory fiber utility value. This manuscript explores the development of a quality index (composite measure of twelve yarn and spinning performance variables) and the means by which selection of cotton fiber qualities will help predict its ideal utilization.

Keywords: Cotton, fiber, quality, index

Introduction

Cotton fibers exhibit variation in their measured physical properties. In the past, these properties were measured and differentiated by cotton classers and later by High Volume Instrumentation (HVI™). However, the generated results are complex and multifaceted to the point that selection of optimum cotton fibers for a textile mills end product is a constant challenge and customarily more of an art than a science. This report will explore the development of a quality index and the means by which selection of cotton fiber qualities will help predict its ideal utilization. These properties are measured on different scales and may not be of equal importance. Several possible ways exist to compare and combine the predicted measures.

Index numbers are summary statistics that assign a single numerical value to represent information in several individual statistics. Micronaire is a type of index number that assigns a fineness level based on the fiber fineness distribution thus providing a single value. Indices such as the Consumer Price Index and the Dow-Jones Industrial Average (Daniel and Terrell, 1989) are widely used in economics to quantify trends in business and economic activity. The primary objective in the creation of an index number is practical utility, whether the index values can be used to make practically important distinctions among categories being compared. Fisher (1967) along with Kenny and Keeping (1962) discuss the development of index numbers and their properties in the context of economic indicators, while Weisstein (2006) lists several named price indices.

Types of index numbers include ratios, weighted averages, maximum (or minimum) values, and subjective scores. The Consumer Price Index (Anonymous, 2004) is a ratio of a current "market basket" price to the price of the same mix of products in a base year. *US News and World Report's* rankings of universities are based on weighted averages of several characteristics of the schools. The Air Quality Index (Anonymous, 2003) assigns scores to five atmospheric pollutants and uses the maximum (worse) score as the index value. Wine expert Robert Parker (2006) gives numerical points to wines based on his palate. Body Mass Index (Anonymous, 2007) is a score that indicates an individual's body fat.

The three commercial spinning processes, ring, open end, and vortex spinning, differ in production rates and in characteristics of the spun yarn. Spinning performance of each method depends in part on fiber properties of the raw stock. It has been stated that key properties for the three spinning systems are as follows: length, strength, fineness, and friction (ring-spinning); strength, fineness, length, cleanliness, friction (open end-spinning); and length, fineness, strength, friction, cleanliness (vortex-sp 1 inning) (Deussen, 1993). Some cottons are better utilized by one spinning method than another. This report describes the use of quality indices (index numbers) to make relative comparisons of spinning performance of the three processes for a lot of cotton based on fiber properties. For a bale of cotton, yarn characteristics for each type of spinning need to be predicted. The goal is to utilize fiber property information to classify the cotton in terms of how it will perform in open end, ring, and vortex spinning.

Yarn Quality Index

In the five years Commercial Variety Spinning Study, 154 lots of blended cotton were spun into yarn by each of the three methods (Foulk et al., 2007a). One yarn count per spinning systems was selected to represent the most commonly produced weaving yarn (a 20/1 count for ring and open end spinning and a 35/1 for vortex spinning). Spinning performance was measured by 16 variables. Foulk et al. (2007b) details the descriptions of the HVI™ and AFIS fiber properties of the raw stock and corresponding yarn characteristics. Foulk et al. (2007c) further details the multiple regression relationships of supplementary and classic fiber properties and yarn characteristics. Four "benchmark" HVI™ fiber properties (micronaire, strength, length, and length uniformity) were utilized to illustrate the development of a quality index. From the HVI fiber properties it is possible to predict the spinning performance measures of a new lot of cotton for each of the three spinning methods. The question then is which spinning method is optimal for that lot of cotton. As an illustration, the yarn characteristics of one lot of cotton in the study are shown in Table 1.

As a summary or composite measure of overall spinning performance of a lot of cotton, a "quality index" will be calculated for each spinning method. Relative comparisons of spinning performance can then be made by comparing indices. Three yarn quality indices are described in this report, one for each of the three spinning methods. The indices are composite or summary measures of the twelve spinning performance variables listed in Table 1. A weighted average procedure analogous to that used by *US News and World Report* (Anonymous, 2006) to rank universities is employed to produce index numbers which are composite measures of spinning performance. Separate indices are calculated for each spinning processes, and values of the indices are to be computed for the 154 lots in the Commercial Spinning Study. Index values are also converted to percentile index scores where a higher value indicates better overall spinning quality.

Spinning performance variables considered for inclusion in the formula f 1 or an index are listed in Table 1, together with an indication of whether a higher value of the variable implies better quality. Because the variables are measured in different units, each variable is standardized to have a mean of zero and standard deviation of 1, using the mean and standard deviation of that variable from the 154 lots in the study in order to calculate the z scores. A weighted average of the standardized values (z-scores) of the variables is then calculated, assigning weights of -1 to variables for which a lower value is better and +1 to those for which a higher value is better. Thus larger values of the index indicate better overall spinning performance. For new lots of cotton, the yarn properties must be predicted from fiber properties. In that case, the yarn quality index is computed as a weighted average of z scores with coefficient of determination (R2) values of the prediction models as weights, using negative weights for variables for which a lower value is better.

Yarn Quality Index Values

For each of the 154 lots in the Commercial Variety Study, a yarn quality index value was calculated for each spinning method. The indices for ring, open end, and vortex spinning are denoted Rindex, Oindex, and Vindex respectively. Each is calculated from 12 standardized yarn properties: ends down in production, Statimat yarn strength, Statimat strength coefficient of variation, DS-65 Digital Evenness Tester neps, DS-65 Digital Evenness Tester thick, DS-65 Digital Evenness Tester low, DS-65 Digital Evenness Tester yarn coefficient of variation, Classimat major, Classimat minor, Classimat long thick, Classimat long thin, and yarn board appearance. Z-scores for these variables, with negative weights for all variables except strength and yarn board, were averaged to produce an index for which higher values indicate better yarn quality.

Descriptive statistics for the three indices are shown in Table 2 for the 154 lot in this study. The mean of Vindex differs slightly from zero because 3 lots had missing values. Distributions of the three indices are similar in shape and location; all are left-skewed as shown is Figure 1. However, there is little correlation between Oindex values and those of Rindex (r = 0.002) and between Oindex and Vindex (r = -0.065) while Rindex and Vindex values are significantly positively correlated (r = 0.748). Associations are displayed graphically in Figure 2. Lots which plot on the "tails", in the upper left or lower right corners, are ones for which yarn quality indices differs markedly for two spinning systems. To illustrate how the Rindex values discriminate between lots, data from two lots with widely different Rindex values are displayed in Table 3. Lot 55 (Rindex = 1 -3.286) produced very low quality yarn among the 154 lots while lot 128 (Rindex = 0.86) produced very high quality yarn. Corresponding data from open end spinning for these same two lots are displayed in Table 4, followed by similar data for vortex spinning in Table 5. The cotton in lot 55 was of too low a grade to process by the vortex spinning method. A missing value in any tables is indicated by "—".

Percentile Indices

The three yarn quality indices permit relative comparisons of lots within a type of spinning, but the scales of these statistics are meaningless. An alternative is to convert the index values to percentiles. This was done by expressing each index as a percentile of a normal distribution with mean zero and standard deviation equal the standard deviation of the index. The resulting percentile indices are denoted PRindex, POindex and PVindex for ring, open end, and vortex spinning, respectively. Values of these indices range between 0 and 1 (or 0% to 100%). For example a value of PRindex = 0.60 or 60% would indicate the ring spinning quality of yarn from that lot of cotton would exceed that of about 60% of the lots in this study and would be exceeded by about 40% of them. For lots 55 and 128 described in Tables 4 and 5, the values of PRindex are 0 and 90% respectively. Those of POindex are 43% and 92% respectively, and the value of PVindex for lot 128 is 94% (lot 55 could not be processed).

Yarn Quality Index Values

To obtain yarn quality index values for a new lot of cotton, estimates of the twelve spinning performance variables that compose the index must be made from fiber properties using multiple regression equations (Foulk et al., 2007; Foulk et al., 2007). Some of the variables can be predicted with greater precision than others, and should carry greater weight in calculating index values. Table 6 lists multiple R2 values for predicting spinning performance variables for a new lot of cotton from the four "benchmark" HVI™ fiber properties (micronaire, strength, length, and length uniformity) of that lot. These R2 values are used as weights in computing predicted index values based on HVI™ properties. For a type of spinning, the predicted index value of a lot of cotton is a weighted average of its twelve standardized predicted yarn characteristics, a sum of the form Σ (±Ri 2)(standardized predicted property i) / Σ Ri 2 where negative weights are given to properties for which a lower value indicates better quality. To illustrate calculation of a predicted index value, suppose two new lots of cotton have HVI™ properties identical to those of lots 55 and 128, as shown in Table 7.

From the four "benchmark" HVI™ properties, spinning properties are predicted for each of the three kinds of spinning, from which predicted yarn quality index values are computed. The R2 values shown in Table 6 are used as weights. Because of missing values, some of the Vortex properties were not predicted for lot 128. Those missing properties were given weights of zero in computing the vortex quality index for that lot. Table 8 gives the predicted and actual values of twelve yarn properties for lot 55, with actual values in parentheses. There are no actual values for Vortex spinning because lot 55 could not be processed by that method. Predicted index and actual index values are given along with predicted and actual percentile index values. The negative predicted index values indicate that a lot with the same HVI™ properties as lot 55 will perform poorly in spinning relative to most of the 154 lots in this study regardless of the spinning method. Relatively, the best spinning method for this very poor quality lot is open end spinning, with overall yarn quality predicted to be in the 8th percentile of all open end spun lots. Table 9 provides statistics for lot 128 analogous to those in Table 7 for lot 55. The positive predicted index values indicate that a lot with the same HVI™ properties as lot 128 will perform well in spinning relative to the most of the 154 lots in this study regardless of the spinning method. Relatively, the ring and vortex methods are about equal and are marginally better than the open end method based on the percentile index values.

Summary

The yarn quality index numbers defined above are composite measures of twelve spinning performance variables. Index values are calculated using statistics (means and standard deviations) from the 154 lots of cotton processed during the Commercial Variety Spinning Study. In essence, an index value for a lot of cotton compares its spinning performance (for ring, open end or vortex spinning) with that of the 154 lots in the study, under the processing conditions of the study. Robustness of the indices to changes in processing parameters is not known. In calculating an index from known spinning performance values (as for lots in 1 the study) the twelve measures (ends down, yarn strength, neps, etc.) are assumed to be equally important. When predicted spinning performance values are used for a new lot of cotton, the twelve measures are weighted by the R2 values of the prediction equations. Other weighting schemes for example assigning more weight to ends down than to neps could be used.

In illustrating the calculation of predicted index values for a new lot, only the four "benchmark" HVI™ properties were used to predict the spinning performance measures. Other fiber properties such as the AFIS, supplementary, or classic properties could be added to improve predictions. The index numbers are computed from standardized spinning performance variables, and their scales are not meaningful. Interpretation of index values is facilitated by converting them to percentile index values. These values can be used to place the (predicted) spinning performance of a lot by a specified spinning method in the distribution of performance values of all lots in the study. For example, a lot with a percentile index value of 90% for vortex spinning will spin as well or better than 90% of the lots processed by the vortex method in this study. Data collected from this five year study allows percentile index values to be expanded beyond the "benchmark" HVI™ properties. These percentile index values could potentially be predicted from selected HVI™ fiber quality measurements, selected AFIS fiber quality measurements, and from classic and supplementary fiber quality measurements. These values would allow mills to better optimize bale purchasing, bale laydown, processing efficiency, and product quality.

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Table 1.
Spinning performance variables and typical yarn properties of a single lot of cotton

Variable	Ring	Open end	Vortex	Higher Number Better
Ends down (Cnt/1000 hrs)	63	215.2	22.87	No
Strength (g/Tex)	18.91	14.12	13.4	Yes
Statimat Strength Coefficient of Variation (%)	8.84	8.59	9.84	No
Neps (Cnt)	309	14.0	10.38	No
DS-65 Digital Evenness Tester Thick (Cnt)	765	50	12.34	No
DS-65 Digital Evenness Tester Low (Cnt)	24	1	343	No
DS-65 Digital Evenness Tester Yarn Coefficient of Variation (%)	16.5	12.6	21.7	No
Classimat Major (Cnt per 100,000 yds)	8.0	1	22	No
Classimat Minor (Cnt per 100,000 yds)	330	30	29654	No
Classimat Long Thick (Cnt per 100,000 yds)	14	2	18	No
Classimat Long Thins (Cnt per 100,000 yds)	490	86	5207	No
Yarn Appearance Board	71	100	67	Yes

Table 2.
Descriptive statistics: Rindex, Oindex, Vindex

Variable	N	Mean	StDev	Min	Median	Max
Rindex	154	0	0.6857	-3.2866	0.1555	0.8859
Oindex	154	0	0.4779	-2.2353	0.0859	0.8230
Vindex	151	-0.00532	0.6878	-2.4171	0.1037	1.0789

Table 3.
Ring spinning performance and Rindex values for two lots

Lot	Ends down	Statimat strength	Statimat CV	Neps	Thick	Low	Yarn CV	Major	Minor	Long thick	Long thins	Yarn Appearance	Rindex
55	484	11.15	17.25	274	2168	2038	26.4	15	4778	107	20208	60	-3.2866
128	0	18.39	6.74	33	349	41	16.5	2	58	0	113	93	0.86094

Table 4.
Open end spinning performance and Oindex values for two lots

Lot	Ends down	Statimat strength	Statimat CV	Neps	Thick	Low	Yarn CV	Major	Minor	Long thick	Long thins	Yarn Appearance	Oindex
55	0	10.85	8.22	3	76	34	14.9	1	2	0	5	100	-0.085
128	0	14.72	6.89	2	43	17	13.8	0	3	0	88	97	0.6912

Table 5.
Spinning performance and Vindex values for two lots

Lot	Ends down	Statimat strength	Statimat CV	Neps	Thick	Low	Yarn CV	Major	Minor	Long thick	Long thins	Yarn Appearance	Vindex
55	—	—	—	—	—	—	—	—	—	—	—	—	—
128	3.711	14.74	9.80	159	227	51	16.2	2	460	0	305	97	1.0789

Table 6.
Multiple coefficient of determination (R^2) values based on HVI™ "benchmark" properties

Yarn Property	Ring	Open end	Vortex
Ends down	0.02	0.31	0.35
Statimat yarn strength	0.79	0.085	0.079
Statimat Strength CV	0.33	0.03	0.30
Neps	0.26	0.02	0.57
Thick	0.68	0.49	0.68
Low	0.5	0.71	0.55
Yarn CV	0.57	0.28	0.68
Major places	0.12	0.01	0.29
Minor places	0.33	0.04	0.51
Long thick places	0.01	0.02	0.06
Long thin places	0.37	0.07	0.36
Yarn appearance	0.54	0.03	0.25

Table 7.
HVI™ "benchmark" properties of lots 55 and 128

Lot	Micronaire	Strength (g/tex)	Length (in)	Uniformity (%)
55	4.7417	22.6256	1.095	79.4167
128	4.1167	32.333	1.1492	82.2083

Table 8.
Predicted and actual yarn properties by spinning method for lot 55 with predicted and actual index and percentile index values

Property	Predicted Ring	Actual Ring	Predicted Open end	Actual Open end	Predicted Vortex	Actual Vortex
Ends down	95.26	484	20.94	0	184.3	—
Statimat yarn strength	11.84	11.15	10.01	10.82	9.02	—
Statimat strength CV	13.86	17.25	8.3	8.22	14.81	—
Neps	190.3	274	8.33	3.0	671.8	—
Thick	1567	2168	85.58	76	748	—
Low	1076	2038	48.37	34	767	—
Yarn CV	23.69	26.4	14.85	14.9	22.5	—
Major places	8.51	15	0.06	1.0	3.15	—
Minor places	1440	4778	11.9	2.0	1278	—
Long thick places	28.5	167	5.15	0	-32.94	—
Long thin places	9125	20208	41.47	5.0	41.59	—
Yarn appearance	53.3	60	99.96	100	59.35	—
Index	-2.05	-3.29	-1.44	-0.08	-1.60	—
Percentile (%)	0.2	0+	8.0	43.2	1.10	—

Table 9.
Predicted and actual yarn properties by spinning method for lot 128 with predicted and actual index and percentile index values

Property	Predicted Ring	Actual Ring	Predicted Open end	Actual Open end	Predicted Vortex	Actual Vortex
Ends down	147.5	0	61.38	0	-11.56	3.71
Statimat yarn strength	19.13	18.39	14.41	14.72	13.94	14.74
Statimat strength CV	8.15	6.74	8.5	6.89	10.67	9.80
Neps	74.9	33	9.35	2.0	—	159
Thick	329	349	78.97	43	270.7	227
Low	-49	41	34.74	17	—	51
Yarn CV	16.81	16.5	14.77	13.8	16.1	16.2
Major places	2.75	2.0	0.11	6.0	3.59	2.0
Minor places	-158	58.0	25.19	3.0	—	460
Long thick places	10.78	0	2.36	0	—	0
Long thin places	-876	113	48.33	88	264.8	305
Yarn appearance	84.7	93.0	101.13	97	73.6	97
Index	0.97	0.86	0.50	0.69	0.89	1.07
Percentile (%)	92	89.7	84	91.7	90	93.8

Figure 1. Histograms of Index values for 154 lots of blended stock.

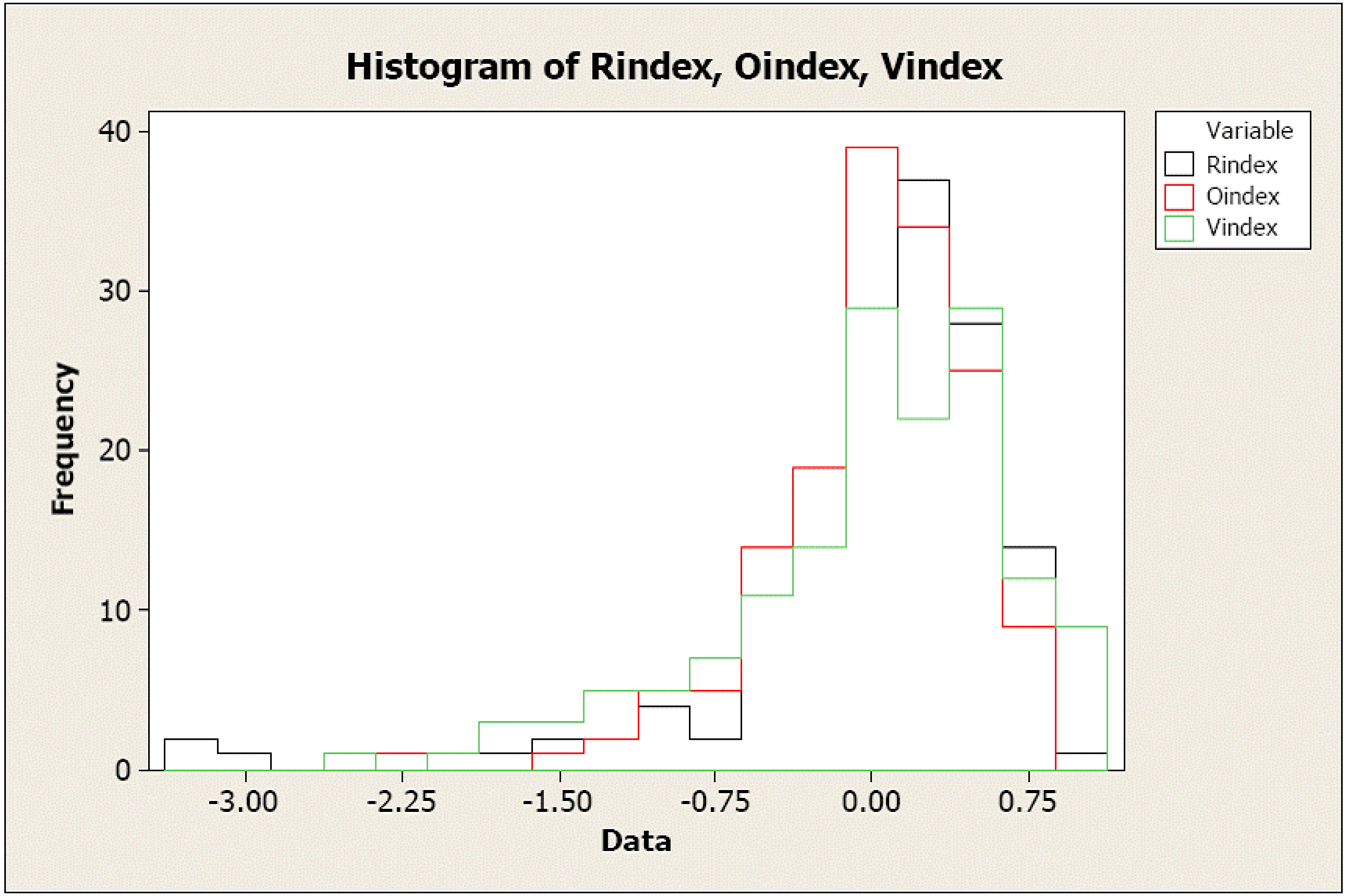

Figure 2. Scatterplot matrix of index values for 154 lots