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Application of Different Statistical Methods to Estimate the Relative Importance of Fiber Properties toward Skein Strength of Egyptian Cotton Under Two Spinning Systems

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ABSTRACT

The present investigations were carried out to determine prediction equation and the relative contribution of six fiber properties to estimate skein strength for two categories of Egyptian cotton varieties (Extra long staple and long staple) under two spinning systems (ring and compact). The correlation coefficient, full model regression, stepwise multiple linear regression and path analysis were used to satisfy the target of work. The results of all supposed models differed according to the category of the used cotton variety and also the applying spinning system. All regression models (full model or stepwise procedure) were significant and reflected large part of the skein strength variation expressed as high values of R^2 and near values of the corresponding adjusted R^2 indicating the validity and goodness of fit for these models. Results showed highly significant and positive association between skein strength and each of maturity, fiber strength and fiber length while highly significant and negative correlation was found between skein strength and fiber elongation for the category of long staple under the two spinning systems. The fineness and micronaire reading were the most effective fiber properties that negatively associated with skein strength for the two spinning systems in the category of extra long staple. Stepwise multiple linear regression procedure appeared that maturity and fiber elongation were the most effective fiber properties affected skein strength overall the two spinning systems for the category of long staple cotton variety. Regarding the extra long staple cotton category, the stepwise regression approach accepted fiber elongation, fiber strength and micronaire reading as the determinant factors of skein strength across the two spinning systems. Overall the two spinning systems, path analysis revealed that fineness, maturity, fiber elongation and fiber length were the most important fiber characters that directly or indirectly contributed to skein strength of the category of long staple cotton varieties, while fiber elongation, fiber length and micronaire reading exerted the greatest influence directly or indirectly upon skein strength in the category of extra long staple cotton varieties.

Key words: Cotton, skein strength, simple correlation coefficients, full model regression, stepwise regression and path analysis.

Introduction

Cotton is a natural fiber characterized by considerable variability in its properties. Of course, most of these properties play a vital role in determining the quality of spun yarns. For example, skein strength, which is considered to be the most important property of spun yarns, is directly and indirectly affected by the fiber properties *i.e.* fineness, maturity, elongation, strength, length and micronaire reading of the constituent cotton Hegab *et al*. (1985). But the level to which various fiber properties influence yarn quality is diverse, and also changes depending on many factors such as the used cotton cultivar and yarn manufacturing technology. Accordingly, the information concerning the relative contribution of fiber properties to skein strength for various categories of cotton (extra long stable and long stable) spun under different types of spinning systems, is one of the important targets for each of cotton breeder to explore yarn quality of his large number of new selections also for the spinner in order to choose cottons that are best suited to the manufacture of specific end product.

Many authors used simple correlation coefficient, full model regression and stepwise multiple linear regression as important statistical procedures to estimate the relative contribution of the fiber properties, as independent variables, in the total variation of skein strength as dependent variable.

Amin (1971) found that fiber strength and elongation were more effective than micronaire value with regard to their contribution to skein strength. Sief (1984) found that fiber strength, micronaire values and their interaction were the prominent factors contributing to skein strength under different counts and twist. Hegab *et al*. (1985) found that fiber strength, fiber length and their interaction were the contributors to skein strength in variety of Giza 70. Abdel-Fattah (1988) found that 2.5% span length was the most contributor to skein strength.

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Fares *et al*. (2010) indicated that fiber strength and short fiber content were the most important contributing cotton fiber properties in carded ring skein strength under four counts of spinning.

Making decisions based only on correlation coefficient may not always be effective because it provides only one-dimensional information neglecting the complex interrelationships among independent variables. Consequently, the correlations may not provide deep imagine about the importance of each component in determining the variability of aimed character. A path coefficient is a standardized partial regression coefficient that measures the direct influence of predictor variables on the response variable. This permits the separation of correlation coefficient into direct effect (path coefficient) and indirect effects (that exerted through other independent variables). Path analysis was applied in predicting skein strength using the corresponding fiber properties by many investigators, such as El-Tabbakh *et al*. (1985) and Hegab *et al*. (1985).

The present investigation was carried out to determine the relative importance of six fiber properties to explain the variation of skein strength in two spinning systems (ring and compact) using two categories of Egyptian cotton varieties (extra long staple and long staple) using different statistical methods.

Materials and Methods

The present investigation was carried out on two categories of Egyptian cotton varieties, that are, long staple (Giza 86, Giza 89, Giza 85, Giza 80 and Giza 90) and extra long staple (Giza 70, Giza 88 and Giza 92) during 2013 at laboratories of Cotton Technology Division of the Cotton Research Institute under controlled atmospheric conditions of $20^{\pm}$ $1.1^{C^{\circ}}$ temperature and $65^{\pm}$ 2% relative humidity. Cotton samples were obtained from the commercial cotton samples of 2013 crop that belong to Cotton Maintaince Research Section. Cotton samples were spun into two spinning systems (Ring and Compact) at one count being 60's carded yarns with 3.6 twist multiplier.

Lab labour:

In the current study, yarn skein strength (Y) was used as a dependent variable and was measured on the Good Brand Lea Tester to determine the lea strength in pounds (D- 1578-67, 1998). Data of six fiber properties were recorded as independent variables *viz.* fineness (x_1), maturity (x_2), fiber elongation (x_3), fiber strength (x_4), upper half mean length (x_5), and micronaire reading (x_6).

Fiber properties were tested according to the following methods:

H.V.I Instrument System was used according to ASTM (D- 4603-86-1776-98) to determine upper half mean length by mm., uniformity index, micronaire value (microgram/inch), and fiber strength (cn/tex), while fiber elongation (FE%) was used according to the A.S.T.M.(D-1440-65).

Statistical analysis methods:

Four classical statistical procedures were used to evaluate the relative contribution of the aforementioned six fiber properties (x_1, x_2,…,x_6) as explanatory variables toward yarn skein strength as a dependent variable. These statistical methods were summarized as follows:

1. Simple correlation coefficients among yarn skein strength and fiber properties were computed as applied by Snedecor and Cochran (1989).
2. Full model regression was applied as outlined by Draper and Smith (1981) to predict the yarn skein strength using their corresponding fiber properties and also to estimate the relative importance of the tested fiber properties expressed as coefficient of determination (R^2 value) in the total variation of yarn skein strength.
3. Stepwise multiple linear regression analysis was used to determine the fiber properties that account for the majority of total variation of yarn skein strength according to Draper and Smith (1981).
4. Path analysis was also used, as proposed by Dewey and Lu (1959), to partition the simple correlation coefficient into direct and indirect effects.

Results and Discussion

The average values of fiber properties and skein strength for Egyptian extra long and long staple cotton varieties spun under ring and compact spinning systems are presented in Table (1).

Correlation matrix:

The simple correlation coefficients among skein strength and its respective six fiber properties, for the two categories of Egyptian cotton varieties (long and extra long staple) spun under two spinning systems (ring and compact), are shown in Table (2).

Table 1: Average values of six fiber properties and skein strength for two categories of Egyptian cotton varieties under two spinning systems (ring and compact).

Variety	X1	X2	X3	X4	X5	X6	Skein strength	
							Ring	Comp.
Long staple cottons								
Giza 80	166.00	0.93	7.17	38.50	31.80	4.30	2050.00	2125.00
Giza 85	140.00	0.93	6.80	40.93	30.30	3.77	2166.70	2251.70
Giza 86	160.00	0.97	6.60	45.00	33.23	3.97	2303.30	2376.70
Giza 89	157.67	0.94	6.50	40.00	32.00	4.20	2323.30	2386.70
Giza 90	155.00	0.87	7.30	36.00	30.07	3.90	2071.70	2140.00
Mean mean	155.73	0.93	6.87	40.09	31.48	4.03	2183.00	2256.00
Extra long staple cottons								
Giza 70	142.67	0.94	6.33	47.33	35.67	4.00	2445.00	2566.70
Giza 88	135.67	0.95	6.17	49.17	35.60	3.80	2655.00	2773.30
Giza 92	133.33	0.95	6.07	50.33	35.60	3.70	2765.00	3050.00
Mean mean	137.22	0.95	6.19	48.94	35.62	3.83	2621.70	2796.70

Abbreviations:

Fineness (x_1), maturity (x_2), fiber elongation (x_3), fiber strength (x_4), fiber length (x_5), and micronaire reading (x_6).

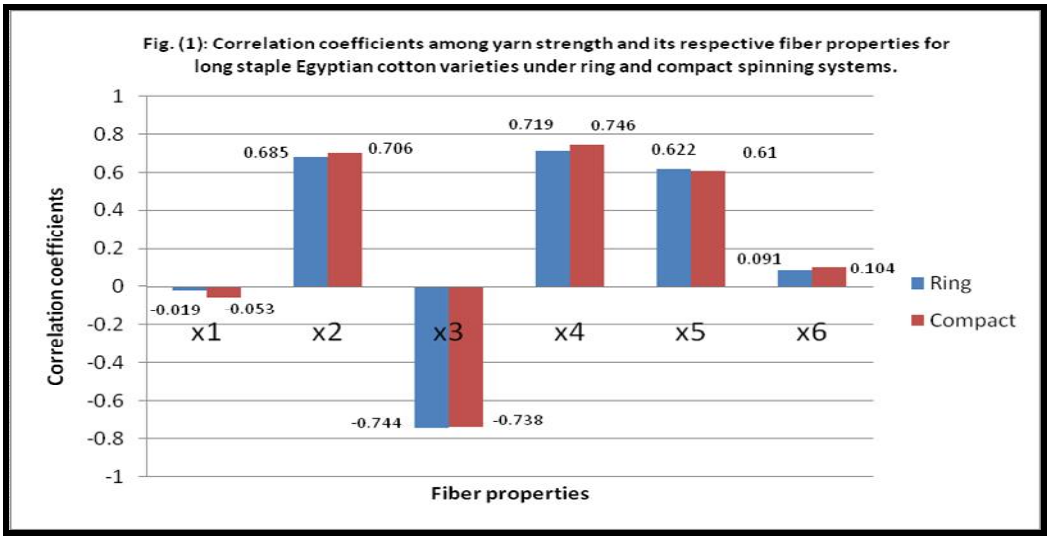
Results showed that the most effective relationships to spinner, for long staple cotton fibers, were those between skein strength and each of maturity (0.685** and 0.706*), fiber elongation (-0.744** and -0.738**), fiber strength (0.719** and 0.746**), and fiber length (0.622** and 0.610**) under ring and compact spinning systems, respectively. On the contrary, for extra long staple cotton varieties, highly significant and negative associations were only obtained between skein strength and each of fineness (-0.748** and -0.678**) and micronaire reading (-0.791** and -0.717**) under ring and compact spinning systems, respectively.

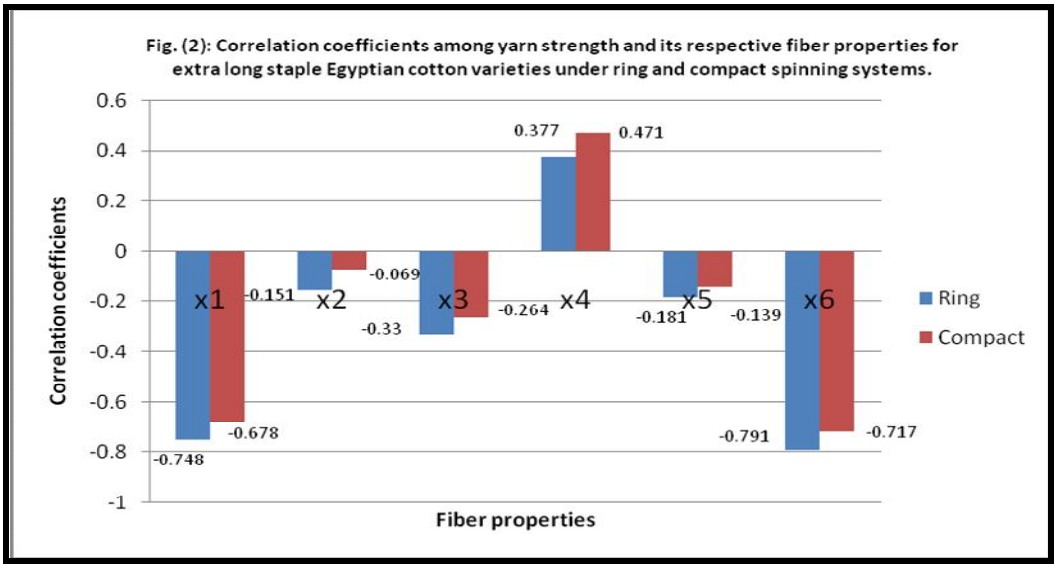
Table 2: Correlation coefficients among skein strength and its respective fiber properties for two categories of Egyptian cotton varieties *i.e.* long staple (above diagonal) and extra long staple (below diagonal) under ring and compact spinning systems.

Fiber properties	X_1	X_2	X_3	X_4	X_5	X_6	Skein strength (YS)	
							Ring	Compact
Fineness (X_1)		0.211	0.196	-0.001	0.597**	0.536**	-0.019	-0.053
Maturity (X_2)	0.650**		-0.360	0.813**	0.698**	0.279	0.685**	0.706**
Elongation (X_3)	0.821**	0.956**		-0.510**	-0.435*	0.213	-0.744**	-0.738**
Strength (X_4)	0.064	0.754**	0.565**		0.714**	0.131	0.719**	0.746**
Length (X_5)	0.472*	0.860**	0.791**	0.637**		0.403*	0.622**	0.610**
Micronaire (X_6)	0.983**	0.641**	0.807**	0.093	0.503*		0.091	0.104
YS (Ring)	-0.748**	-0.151	-0.330	0.377	-0.181	-0.791**		
YS (Compact)	-0.678**	-0.069	-0.264	0.471*	-0.139	-0.717**		

** and **: Significant and highly significant at 0.05 and 0.01 probability levels, respectively.*

The correlation coefficients between skein strength and its related fiber properties, for ring and compact spinning systems, are graphically illustrated in Figures 1 (long staple) and 2 (extra long staple), respectively.





On the other hand, the fiber properties exhibited various trends of associations among themselves. Considering the long staple category, there were considerable positive associations between fineness and each of fiber length (0.597**), and micronaire reading (0.536**). Also, the maturity was highly significant and positively correlated with fiber strength (0.813**) and fiber length (0.698**). Fiber elongation exhibited significant and negative associations with each of fiber strength (-0.510**) and fiber length (-0.435*). However, significant and positive correlation coefficients were reported between fiber length and each of fiber strength (0.714**) and micronaire reading (0.403**).

With respect to extra long staple, there were considerable positive associations between fineness and each of maturity (0.650**), fiber elongation (0.821**), fiber length (0.472*), and micronaire reading (0.983**). Also, the maturity recorded highly significant and positive associations with each of fiber elongation, fiber strength, fiber length and micronaire reading recording (0.956**), (0.754**), (0.860**), and (0.641**), respectively. In the same context, fiber elongation was highly significant and positively associated with each of fiber strength (0.565**), fiber length (0.791**), and micronaire reading (0.807**). However, highly significant and positive correlation coefficients were obtained between fiber length and each of fiber strength (0.637**) and micronaire reading (0.503**).

On the other hand, the remainder correlation coefficients among studied fiber properties were negligible and insignificant. These findings are in agreement with those obtained by El-Tabbakh *et al* (1985), Hegab *et al* (1985) and Hager *et al* (2011) who confirmed that the interrelationships among fiber properties and yarn quality are depending on many factors such as the used cotton cultivar and yarn spinning technology.

Multiple linear regression analysis:

The results of multiple linear regression analysis between skein strength as dependent variable and six fiber properties as explanatory variables under ring and compact spinning systems for two categories of cotton varieties are presented in Table (3). The results revealed that the four supposed multiple regression models significantly explained the most variability of skein strength over the two types of cotton variety and two spinning systems where the coefficients of determination (R^2 %) ranged from 77.2 to 98.5%. This result indicated that the most skein strength variation was attributed to the tested fiber properties. The residuals content (1- R^2 %) may be returned to some errors during measuring the fiber and yarn properties, some fiber properties were not into account under the current investigation and/or unknown variation (random error).

Table 3: Analysis of full model regression to predict skein strength using six fiber properties for two categories of Egyptian cotton varieties (long and extra long staple) under two spinning system (ring and compact).

Spinning system / Cotton Categories		Partial regression coefficients							Goodness of fit	
		Constant	X_1	X_2	X_3	X_4	X_5	X_6	R^2 %	Adj. R^2
Long Staple	Ring	2017.9	-2.43	1008	-171.57	-0.17	20.23	38.87	77.2	71.3
	Compact	2135.5	-2.56	1016.9	-166.82	265	13.04	51.14	79.4	74.0
Extra Long Staple	Ring	8711.1	16.21	-7978	466.03	54.48	-1.64	-1599.1	98.5	97.7
	Compact	7149	55.38	-11076	421.8	122.57	4.75	-2672.6	92.2	87.9

Statistically, the values of adjusted R^2 were very close to their corresponding R^2 values giving evidence on the goodness of fit for the supposed regression models. Similar trend of results was obtained by Sief (1984), Abdel-Fattah (1988), Fares *et al* (2010) and Hager *et al* (2011).

Stepwise multiple linear regression:

The stepwise multiple linear regression was usually used to determine the more effective fiber properties that explained the most variation of skein strength. The accepted fiber properties and their regression parameters according to stepwise multiple linear regression under each of ring and compact spinning systems are shown in Table (4).

Concerning the long staple cotton category, the stepwise multiple linear regression indicated that both maturity (X_2), and fiber elongation (X_3) were the accepted limiting cotton fiber properties that were significantly accounted for the most variation of skein strength under the two spinning systems. The two proposed models were responsible for 75.4 and 76.7% of the total variation of skein strength (expressed as R^2 %) under ring and compact spinning systems, respectively. According to the previous results, it could be concluded that maturity (X_2), and elongation (X_3) were the most effective fiber properties overall the two spinning systems for the category of long staple cotton variety.

Regarding the extra long staple cotton category, the stepwise regression approach accepted maturity (X_2), and fiber elongation (X_3), fiber strength (X_4) and micronaire reading (X_6) as the most effective fiber properties in skein strength under ring spinning system. Using compact spinning system, the stepwise model selected only elongation (X_3), fiber strength (X_4) and micronaire reading (X_6) as the determinant factors of skein strength. The two models accounted for 97.4 and 82.9 % expressed as R^2 of the total variation of skein strength, respectively.

Table 4: Analysis of stepwise multiple linear regression to predict skein strength using six fiber properties for two categories of Egyptian cotton varieties (long and extra long staple) under two spinning system (ring and compact).

Spinning system / Cotton categories		Regression coefficients							Goodness of fit	
		Constant	X_1	X_2	X_3	X_4	X_5	X_6	R^2 %	Adj. R^2
Long Staple	Ring	2269.6	--------	1328.9	-192.01	--------	--------	--------	75.4	73.6
	Compact	2238.7	--------	1389.9	-185.14	--------	--------	--------	76.7	74.9
Extra Long Staple	Ring	9638.9	--------	-7826	486.55	42.43	--------	-1225.22	97.4	96.7
	Compact	5072	--------	--------	120.04	31.89	--------	-1195.5	82.9	79.2

The above results indicated that elongation (X_3), strength (X_4) and micronaire reading (X_6) were the most important fiber characters contributing to skein strength under the category of extra long staple variety. Because all postulated stepwise regression models were significant and reflected the most variation of skein strength expressed as high values of R^2, the previous results proved the validity of these models; in addition, the clear closeness between R^2 values and their corresponding adjusted R^2 values gave other evidence. Accordingly, the present regression equations would be accurately applied to predict the skein strength using fiber properties.

Remarkable conclusion was obtained from the previous result, is that, fiber properties which significantly contributing to yarn properties differed according to the category of the used cotton variety and the applied spinning system (El-Hariry *et al* 1990, Sawires *et al*., 1990, Fares *et al* 2010 and Hager *et al* 2011).

Path analysis:

The relative importance (RI %) for six fiber properties toward skein strength for two categories of Egyptian cotton varieties (long and extra long staple) under two spinning systems (ring and compact) are presented in Table (5).

Regarding to the category of long staple cotton varieties, it is evident that the most skein strength variation (using ring or compact spinning system) was explained by the direct effects of fiber elongation (20.88 and 19.63 %) followed by maturity (10.52 and 11.07 %), fineness (2.66 and 3.25 %) and fiber length (3.65 and 1.82 %). The studied six characters directly explained 38.69 and 37.74 % of skein strength variation when the fibers were spun under ring and compact spinning systems, respectively.

The great values of joint effect components toward skein strength were expressed by maturity through their associations with each of fiber elongation (10.67 and 10.61 %) and fiber length (8.65 and 6.27 %), as well as by fiber elongation *via* fiber length (7.59 and 5.2 %) for ring and compact spinning systems, respectively.

Trivial values of relative importance were observed by the other direct and indirect effects ranged from 0.0004 to 3.72. Totally, the studied six fiber properties explained 81.70 and 83.75 % of skein strength variation using ring and compact spinning systems, respectively.

Considering the extra long staple category, when the cotton fibers were spun using ring system, the maximum direct effects were observed by micronaire reading (15.65 %) followed by fiber elongation (12.41 %), fineness (2.27 %) and then fiber length (2.05 %). The direct effect for micronaire reading (19.74 %) was ranked the first using compact spinning system followed by fiber elongation (8.15 %), fiber strength (4.24 %) and fiber length (3.46 %). Consequently, it is stated that the used spinning system affected the interrelationships among the skein strength and fiber properties for the Egyptian extra long staple varieties. The tested six characters directly reflected 33.01 and 35.91 % skein strength variation when the fibers were spun under ring and compact spinning systems, respectively.

Regarding the relative importance for the components of joint effects, it appeared that the valuable indirect effects were observed by fineness through micronaire reading recording 11.42 and 4.62 % under the two spinning systems, respectively. Also, considerable values of relative importance were listed for the joint effects of fiber elongation *via* each of fiber strength (3.02 and 6.51 %), fiber length (7.78 and 8.23 %), and micronaire reading (21.94 and 20.07 %), as well as for the fiber length *via* micronaire reading (5.56 and 8.14 %) for two spinning systems, respectively.

Table 5: The relative importance (RI %) for six predictor characters toward skein strength for two categories of Egyptian cotton varieties (long and extra long staple) under two spinning systems (ring and compact).

Cotton categories / Fiber properties		Long staple		Extra long staple	
		Ring	Compact	Ring	Compact
Direct effect					
Fineness (X_1)		2.66	3.254	2.267	0.291
Maturity (X_2)		10.52	11.073	0.029	0.035
Elongation (X_3)		20.88	19.627	12.408	8.149
Strength (X_4)		0.0004	0.292	0.603	4.24
Length (X_5)		3.65	1.822	2.048	3.458
Micronaire (X_6)		0.98	1.672	15.65	19.735
Total (direct)		38.69	37.74	33.01	35.91
Indirect effects					
Fineness (X_1) *via*	X_2	2.231	2.533	0.326	0.128
	X_3	2.919	3.133	8.496	2.48
	X_4	0.0001	0.002	0.146	0.14
	X_5	3.716	2.908	1.984	0.929
	X_6	1.73	2.501	11.424	4.621
Maturity (X_2) *via*	X_3	10.671	10.614	1.123	1.00
	X_4	0.106	2.926	0.195	0.568
	X_5	8.645	6.271	0.411	0.585
	X_6	1.792	2.401	0.846	1.042
Elongation (X_3) *via*	X_4	0.094	2.443	3.017	6.512
	X_5	7.591	5.203	7.780	8.233
	X_6	1.928	2.440	21.943	20.066
Strength (X_4) *via*	X_5	0.055	1.042	1.382	4.783
	X_6	0.005	0.183	0.558	1.668
Micronaire (X_5) *via*	X_6	1.524	1.407	5.556	8.147
Total (indirect)		43.007	46.007	65.187	60.902
Total (direct + indirect)		81.70	83.75	98.20	96.81
Residuals		18.30	16.25	1.80	3.19
TOTAL		100	100	100	100

The underline cells indicate to the highest values.

High indirect effect was recorded by fineness through fiber elongation (8.50 %) using only ring spinning system and by fiber strength *via* fiber length (4.78 %) applying compact spinning system. The other values of direct and indirect effects were very small and negligible. The tested fiber properties accounted for directly and indirectly 98.20 and 96.81 % of skein strength variation using ring and compact spinning systems, respectively. The current results are in harmony with those obtained by EL-Tabbakh *et al* (1985) and Hegab *et al* (1985).

Finally, the current investigation stated the following conclusions:

1- The results of the supposed statistical models differed according to the category of the used cotton variety and also the type of the applying spinning system.
2- The current results helps the spinner to predict the spinning performance using the available fiber properties as well as choosing cotton that are best suited to the manufacture of the end products.
3- Statistically, goodness of fit was satisfied for all proposed models under the present investigation.
4- The stepwise regression procedure determined the minimum number of fiber characters that are accounted for the most variation of skein strength which save the time and effort.

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