American Journal of Agricultural Science, Engineering, and Technology (AJASET)

ISSN: 2158-8104 (ONLINE), 2164-0920 (PRINT)

VOLUME 10 ISSUE 3 (2026)



PUBLISHED BY

E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Agricultural Science, Engineering, and Technology (AJASET)

Volume 10 Issue 3, Year 2026
ISSN: 2158-8104 (Online), 2164-0920 (Print)
DOI: https://doi.org/10.54536/ajaset.v10i3.8815
https://journals.e-palli.com/home/index.php/ajaset

Evaluation of Reciprocal Relation Between Single and Bundle Fiber Strength of Egyptian Cotton Grades

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Article Information

Received: August 02, 2026

Accepted: October 13, 2026

Published: November 09, 2026

Keywords

Box Plot Graph, Bundle Fiber Strength, Egyptian Cotton Grades, Fiber Strength Properties, Single Fiber Strength

ABSTRACT

The four commercial Egyptian cotton varieties (Gossypium barbadense L); Extra-G 92, Extra-G 96, Super-G 97, and Giza 98 were collected from Egyptian gin mills through 2025 season. All cotton varieties were graded into three studied grades, namely; Fully Good (FG), Good (G), and Fully Good Fair (FGF). The study was carried out in Cotton Grading Department, Cotton Research Institute (CRI), Agricultural Research Center (ARC), Egypt. Using two different instruments: Fiber Classifying System (FCS); module Fibrotest for measuring bundle strength, and Fanyuan tester for measuring single fiber strength with presence of elongation at break, work to break and force to break for the two instruments. In single fiber strength for 45, 50 and 55 fiber numbers. There were highly statistically differences for all previous cotton properties. It was an obvious trend of the highest values for single fiber properties compared to bundle fiber in strength and elongation. On the contrary, the highest values of work to break and force to break in bundle fiber strength compared to single fibers measurements. Single fiber strength of 50 fiber numbers showed more stable values than others. All measures of association were more than 90% for coefficient of determination and effect sizes criteria. Practically using Fibrotest for measuring cotton bundle fiber strength is relatively quickly unlike Fanyuan tester according to saving time and efforts unlike a single fiber tester. Knowing the difference between the bundle fiber strength and the single fiber strength helps in predicting yarn strength and the expected level of quality.

INTRODUCTION

Egyptian cotton is one of the most essential fiber crops in tangible advantages of final product. It is inevitable that final cotton end in manufacturing depend on shape, competence and appearance. Each cotton variety totally differ than other rest varieties in length, fineness, maturity, strength and their criteria. All their properties in basic depending on intrinsic such as genetic and extrinsic depending on environmental factors.

Egyptian cotton varieties with their grades are a system of standardized procedures for determining all spinning values which are the core of spinning mill whether for industrial process with all their subsequences or mixing and blending process.

Fiber strength is the maximum force a cotton fiber can withstand when it is stretched before breaking. Tenacity is the fiber tensile strength per unit linear density of the cotton fiber; it shows how strong the fiber is relative to its fineness (usually expressed in cN/tex).

Fiber strength is one of the crucial physical cotton fiber properties. Its measurement can be categorized into a single fiber tester or a bundle fiber tester with numerous different instruments.

Cotton fiber strength is an important factor in determining fiber breakage during mechanical handling as presence in harvesting, ginning and spinning. For real cottons; good strength usually gives fewer problems and less neps during processing than weaker cottons. All these details explained that cotton fiber strength is generally measured on both of bundle strength and single fibers (at either zero-gauge or 1/8" =3.2mm). As it is common that bundle tenacity above 30 cN/tex is generally desired. An increase in fiber strength of 1 cN/tex increasing yarn strength by some 0.5 cN/tex or more. It is obvious by various factors contribute to fiber strength regularity, the most important of which are the presence of weak points in the fiber structure and the variation in the strength of individual fibers.

Basically; elongation is an extension of fiber before break. An increase in fiber elongation is associated with an increase in yarn by affecting all weaving efficiency processing, from level 7% is desirable and that be more illustrated at subsequences processes.

Some cotton fibers may be strong individually, but overall; strength may be weak due to lower maturity and short fiber length or the presence of impurities. Comparison reveals the true quality of cotton before processing. Then it is crucial to understand cotton fiber strength by detecting the relations of tenacity properties by using bundle fiber strength instrument (FCS) and single fiber strength tester (Fanyuan). This research linked cotton fiber strength properties for both of single fiber strength tester with a bundle fiber strength instrument. Using module Fibrotest for measuring cotton bundle fiber strength and single fiber strength tester (Fanyuan).

LITERATURE REVIEW

All cotton fiber properties play an important role in industrial process and processing performance. All details about association of cotton fiber properties and

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spinning mill were illustrated in the textile institute book series (2018). It is a vital to select cotton fiber grade as in Egyptian cotton (extra-long staple and long staple) for appropriate textile, home furnishing medical supplies and industrial by geography as detected with tracing in North America, Europe, Asia Pacific Latin, America, Middle East and Africa by Cotton fiber market share and opportunities (2025).

In cotton fiber strength testing, force represents the load required to stretch and break the fiber, while work represents the total energy absorbed by the fiber during elongation up to rupture. More studies of force and friction were conducted by Mahjoub *et al.* (2018), Fan *et al.* (2024) and Huguet *et al.* (2024).

Herein; both of a single fiber tester involve (Fanyuan) instrument and a bundle fiber instrument include medium volume instruments (Fiber Classifying System (FCS)) which provide a reasonable accurate and reliable measure of cotton properties. All sophisticated explanation of instruments was cited by McCormick *et al.* (2019). Therefore, improved fiber strength should translate into improved yarn quality and a better textile product (Ghosh *et al.* (2005).

It is a must to detect the relationships among both of strength, elongation at break, work to break and force to break to help cotton breeders to modify and enhance fiber to serve the quality of end-use as need as recommended by Thibodeaux *et al.* (1998).

Higher elongation cotton fibers resist breakage during processing. As detected by Benzina *et al.* (2007). As shown by Liu (2024) studied the relationship between fibrotest and stelometer strength on 12 cotton samples and detected that the lowest strength values were for fibrotest compared to the stelometer.

MATERIALS AND METHODS

This current study concluded four Egyptian cotton varieties (Gossypium barbadense L). These commercial varieties namely; Giza 92 (Extra-G 92; belonging to Extra-strength), Giza 96 (Extra-G 96; belonging to Extra-length), Giza 97 (Super-G 97) (belonging to long staple-Delta) and Giza 98 (G 98) (belonging to long staple-upper Egypt) were collected from gin mills around the country through 2025 season. Cotton fiber samples of the three studied grades were Fully Good (FG), Good (G), and Fully Good Fair (FGF).

All studied samples were tested in Cotton Grading Department, Egyptian & International Cotton Classification Center (EICCC), Cotton Research Institute (CRI), Agricultural Research Center (ARC), Giza, Egypt. Using two different instruments concluded:

1. Fiber Classifying System (FCS) which stands for medium volume instrument. FCS has several modules for cotton lint properties. Herein the used module was Fibrotest for measuring bundle strength parameters of cotton. All standard test method was in compliance with (ASTM D 1445M- 12) (2021) for breaking fiber strength and elongation.

2. Fanyuan tester for measuring single fiber strength in compliance with ASTM D3822 (2020). The number of fibers tested were 45, 50, and 55 fibers.

Fibrotest measures multiple fiber properties, including strength properties as following:

1. Absolute bundle fiber strength; Abs. (BFS) which is represent direct mode, expressed in g/tex.
2. Bundle fiber strength (BFS), expressed in g/tex.
3. Elongation at break, expressed in %.
4. Work to break which is the amount of energy that a cotton will absorb before it breaks, expressed in cN.cm.
5. Force to break: which is the ability to break a bundle, expressed in cN.

Fanyuan determined several properties including:

1. Single fiber strength (SFS), expressed in cN/d tex
2. Elongation at break, expressed in %.
3. Work to break. which is the amount of energy that a cotton will absorb before it breaks, expressed in Joule.
4. Force to break: which is the ability to break a single fiber, expressed in cN.

Any different of single fiber strength tester properties units were inverted to bundle fiber strength instrument units to unite them to give the ability to do values comparisons.

Before performing any cotton fiber sample measurement, it was well conditioned at a constant relative humidity of 65 ± 2% and a temperature of 21 ± 2o by non-condensing using UnflairTM (2023) equipment (Air Technology System).

Descriptive statistics, completely Randomized Design (CRD) and measures of association were calculated according to Steel and Torrie (1980).

To get better decision-making, and more effective scientific communication using a boxplot graph which summarizes data using quartiles which is clarified:

- Median (line in the box)
- Spread (length of the box = interquartile range)
- Median closer to bottom → positive skew
- Median closer to top → negative skew
- Outliers (dots or stars)

SPSS (2012) and Luzmo (2025) was used for statistical analyses and Box plot graph

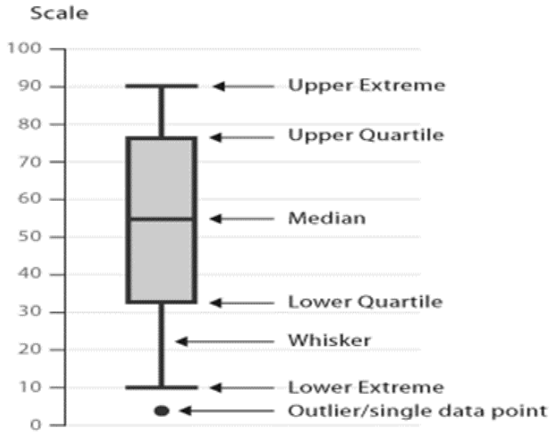


Figure 1: standard box plot cited from Luzmo 2025

RESULTS AND DISCUSSION

The results of cotton fiber strength properties as bundle fiber strength (BFS) and single fiber strength (SFS) obtained from Fibrotest and single fiber strength tester (Fanyuan) instruments; respectively are shown in Tables 1,2,3,4 and 5.

Results were demonstrated using descriptive statistics to provide and clarify a clear, simple, and summary the data difference among the two instruments.

Tables 1, 2, 3 and 4 represented means of each cotton fiber strength properties for G 92, G 96, G 97 and G 98 grades FG, G and FGF; Abs. (BFS) as shown only for FCS is the actual breaking force measured. Absolute bundle fiber strength reflects mechanical resistance where it adjusts strength according to fiber fineness (linear density), but it is not ideal for comparing varieties with different fineness. Generally higher mean values were for the highest grade (FG) followed by (G) and finally the lowest grade (FGF) of the studied cotton varieties. Nearly, the same trend of results was discussed by Mona Shalaby *et al.* (2022) and Rady *et al.* (2025).

Bundle fiber strength (SF-BF) is the called normalized strength. The highest mean values were for single fiber strength (45, 50 and 55) fiber numbers compared to bundle fiber strength for G 92, G 96, G 97 and G 98. Bundle fiber strength is the standard value used in cotton classification as used in U.S. Department of Agriculture HVI system.

Table 1: Means values of bundle and single fiber strength measurements of Giza 92 cotton variety

Grade	Instrument		Abs. (BFS)	(BFS)	E%	Work	Force
FG	Fibrotest		26.21	48.25	6.11	1420	503
	Fanyuan	45n	--------	52.26	8.20	1346	469
		50n		50.89	8.24	1350	468
		55n		52.63	8.11	1356	478
		Mean	--------	51.93	8.18	1350	471
G	Fibrotest		24.38	43.51	6.15	1290	401
	Fanyuan	45n	--------	48.57	8.23	1098	343
		50n		49.18	8.53	1103	350
		55n		48.89	8.67	1110	355
		Mean	--------	48.88	8.48	1103	349
FGF	Fibrotest		22.79	40.59	6.17	1188	292
	Fanyuan	45n	--------	42.76	8.87	987	210
		50n		42.98	8.57	1001	215
		55n		42.44	8.60	1033	217
		Mean	--------	42.73	8.68	1007	214

45n, 50n, and 55n are the number of fibers tested by Fanyuan

Table 2: Means values of bundle and single fiber strength measurements of Giza 96 cotton variety

Grade	Instrument		Abs. (BFS)	(BFS)	E%	Work	Force
FG	Fibrotest		23.67	47.50	6.44	1344	424
	Fanyuan	45n	--------	50.56	8.43	1156	363
		50n		50.43	8.33	1161	377
		55n		46.70	8.50	1163	378
		Mean	--------	49.32	8.42	1160	372
G	Fibrotest		21.29	43.17	5.93	1126	296
	Fanyuan	45n	--------	47.89	7.83	965	235
		50n		47.41	7.87	984	244
		55n		47.52	7.67	988	250
		Mean	--------	47.61	7.79	979	243
FGF	Fibrotest		19.41	39.79	6.33	987	204
	Fanyuan	45n	--------	44.63	7.50	936	155
		50n		44.16	8.27	954	162
		55n		44.39	8.63	962	114
		Mean	--------	44.39	8.13	951	143

45n, 50n, and 55n are the number of fibers tested by Fanyuan

Table 3: Means values of bundle and single fiber strength measurements of Giza 97 cotton variety

Grade	Instrument		Abs. (BFS)	(BFS)	E%	Work	Force
FG	Fibrotest		22.40	44.59	6.43	1204	398
	Fanyuan	45n	--------	47.53	8.53	1116	374
		50n		47.11	8.70	1110	374
		55n		47.53	8.60	1116	379
		Mean	--------	47.39	8.61	1114	375
G	Fibrotest		20.85	42.73	6.70	1044	384
	Fanyuan	45n	--------	45.44	8.63	996	343
		50n		45.31	8.40	990	351
		55n		45.52	8.57	995	356
		Mean	--------	45.42	8.53	993	353
FGF	Fibrotest		19.06	40.77	6.30	904	347
	Fanyuan	45n	--------	43.53	8.13	887	320
		50n		43.50	8.27	890	301
		55n		43.83	8.53	913	306
		Mean	--------	43.62	8.31	896	309

45n, 50n, and 55n are the number of fibers tested by Fanyuan

Table 4: Means values of bundle and single fiber strength measurements of Giza 98 cotton variety

Grade	Instrument		Abs. (BFS)	(BFS)	E%	Work	Force
FG	Fibrotest		18.03	37.73	6.93	1100	**302**
	Fanyuan	45n	--------	40.48	8.83	975	238
		50n		40.07	8.80	983	245
		55n		40.62	8.87	981	247
		Mean	--------	40.39	8.87	980	243
G	Fibrotest		16.67	35.53	6.94	886	221
	Fanyuan	45n	--------	38.84	8.80	777	191
		50n		38.53	8.83	788	199
		55n		37.50	8.76	788	199
		Mean	--------	38.29	8.79	784	196
FGF	Fibrotest		13.57	33.43	6.97	693	199
	Fanyuan	45n	--------	36.47	8.92	599	111
		50n		36.40	8.72	600	114
		55n		36.53	8.92	602	115
		Mean	--------	36.47	8.85	600	113

45n, 50n, and 55n are the number of fibers tested by Fanyuan

Meanwhile; absolute fiber strength values were lower than normal strength values. Where absolute strength reflects the total breaking force of the fiber bundle, and normal strength provides a more accurate assessment of intrinsic fiber quality.

Single fiber strength measurements revealed the true mechanical integrity of the fiber cell wall, eliminating bundle interaction effects as seen the values of strength were larger for single fiber compared to bundle fiber. The observed differences between bundle and single fiber strength suggest variation in fiber alignment and structural homogeneity among samples as detected by Zhu *et al.* (2024).

Elongation at break; single fiber tester had the highest mean values compared to bundle fiber strength. It was obvious from gradient from FG to FGF grades. In table 5, G 98 gave the highest elongation percentage versus G 92, G 96 and G 97 which exhibit higher elongation due to lower molecular orientation, higher amorphous cellulose content, and reduced maturity allow greater deformation and chain mobility under tensile stress compared with longer fibers as explained by Scheffler and Bai (2024), and Liu *et al.* (2014). As a result, cottons with high elongation may be tend to have lower bundle tenacity. Stronger fibers tend to have higher elongation which results is more work to break, this could lead to lower fiber breakage during processing. An increase in elongation at break with a reduction in maximum force indicates enhanced fiber

extensibility.

The values assured the importance of fiber elongation, as quality factor where highly fiber elongation leads directly to higher yarn elongation and show lower ends-down rates on spinning mill. Therefore; it is crucial to get improvement by integration fiber elongation into cotton breeding programs to let the opportunity of cotton fibers compete with the man-made fibers in the textile industry as regarded by Backe (1996), Mathangadeera *et al.* (2020) and Huguet *et al.* (2024).

Fibrotest had the highest mean value of work to break and force to break compared to single fiber tester. The same trend was shown among grades from the highest to the lowest. The work to rupture remains relatively high, suggesting that cotton short fibers absorb considerable energy through deformation despite their lower tensile strength as detected by Mathangadeera *et al.* (2020).

In so much that Table (5) displayed cotton fiber properties for the three cotton grades. In general; standard deviation (SD) of single fiber tester was the highest compared to bundle fiber instrument which means greater variability; indicating less consistency.

Table 5: Descriptive statistics for bundle and single fiber strength measurements of G 92, G 96, G 97 and G 98 cotton varieties over grades

Varieties	Properties		Abs. FS	SF		E%		Work		Force	
	Instruments		BFS	BFS	SFS	BFS	SFS	BFS	SFS	BFS	SFS
G 92	Mean		25.06	45.09	47.84	6.14	8.18	1302	1154	408	345
	Range		4.22	4.97	11.4	0.12	0.41	235	377	139	269
	CI	Lower	23.98	43.27	45.28	6.10	8.11	1224	1095	358	303
		Upper	26.13	46.92	49.41	6.18	8.18	1379	1212	457	388
	SD			2.38	3.96	0.051	1.09	100	147	64	107
G 96	Mean		21.46	43.49	47.52	6.13	8.11	1152	1030	308	253
	Range		4.99	8.87	7.43	0.50	2.90	367	234	229	362
	CI	Lower	20.02	40.89	46.49	5.99	7.85	1032	992	234	214
		Upper	22.89	44.08	48.55	6.27	8.38	1272	1068	382	292
	SD		1.78	3.37	4.59	0.178	1.667	155	195	96	156
G 97	Mean		20.77	42.69	45.48	6.48	8.48	1027	1013	376	345
	Range		4.32	4.20	4.75	0.80	0.80	240	280	56	87
	CI	Lower	19.62	41.40	44.85	6.24	8.37	950	974	358	333
		Upper	21.92	43.99	46.10	6.73	8.60	1104	1051	394	357
	SD		1.50	1.68	2.59	0.317	2.29	100	196	23	129
G 98	Mean		15.76	35.57	37.68	6.95	8.82	893	723	248	169
	Range		4.70	5	3.61	0.09	0.52	411	191	106	90
	CI	Lower	14.26	34.11	37.19	6.92	8.77	757	688	204	153
		Upper	17.25	37.03	38.17	6.98	8.88	1029	758	277	184
	SD		1.94	1.89	3.268	0.038	2.137	176	211	47	139

BFS refers to bundle fiber strength and SFS refers to single fiber strength

The measurements of cotton fiber strength properties of single cotton fiber instruments clarified high variations for cotton varieties among grades compared to bundle strength in so much as the values of range, lower and upper values of confidence interval.

All in all; the results indicated a decreasing trend in both absolute strength and strength between the two instruments over grades. Absolute strength values ranged from 15.76 to 25.06 g, while strength ranged from 35.57 to 45.09 g/tex. Meanwhile; the highest mean values of single fiber strength were 37.68 and 47.84 for G 98 and G 92, respectively.

G92 exhibited the highest strength values, indicating superior intrinsic fiber quality and mechanical resistance. Where its consistently suggest excellent spinning performance potential and well-developed fiber cell wall structure.

The role of Box plot which presents medians to give middle value, length of the box as indicator of the degree of spread, skeweness as the deviation from normality by extremes and outliers. All studied cotton varieties; G 92, G 94, G 97 and G 98 gave the same trend. Then herein the presented cotton variety graphs were for G 92 as shown by Figures 1,2,3,4 and 5. There were no extreme or outliers' points.

In Figures 1 and 2, the box plot illustrates differences in Fibrotest for absolute and strength properties across the three grade levels which demonstrated the median with limited dispersion as seen with narrow box and short whisker which indicate relatively homogeneous performance.

On the other hand; Figs 3 and 5 showed a lower medium, long box and long whisker for 45 and 55 fiber numbers accompanied by greater variability compared to absolute

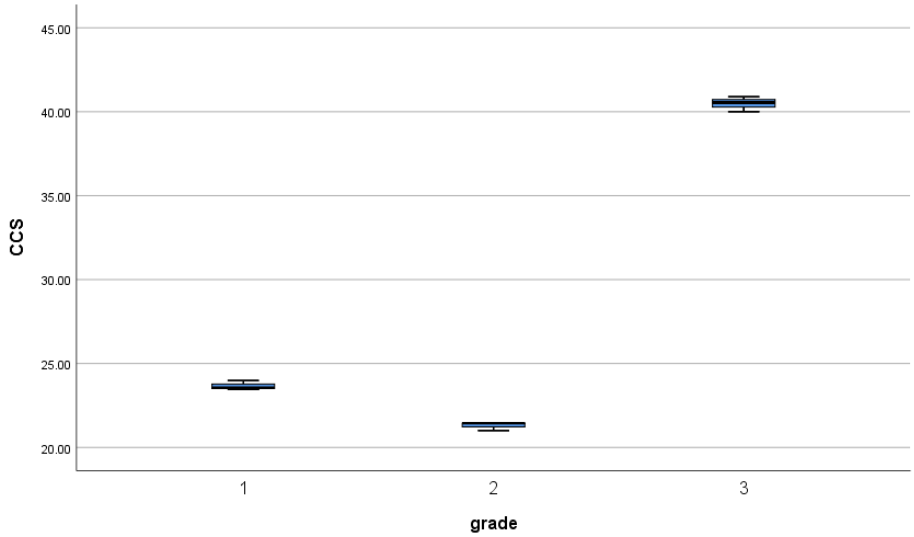


Figure 1: Relation among absolute BFS and grades with highly data similarity in G 92

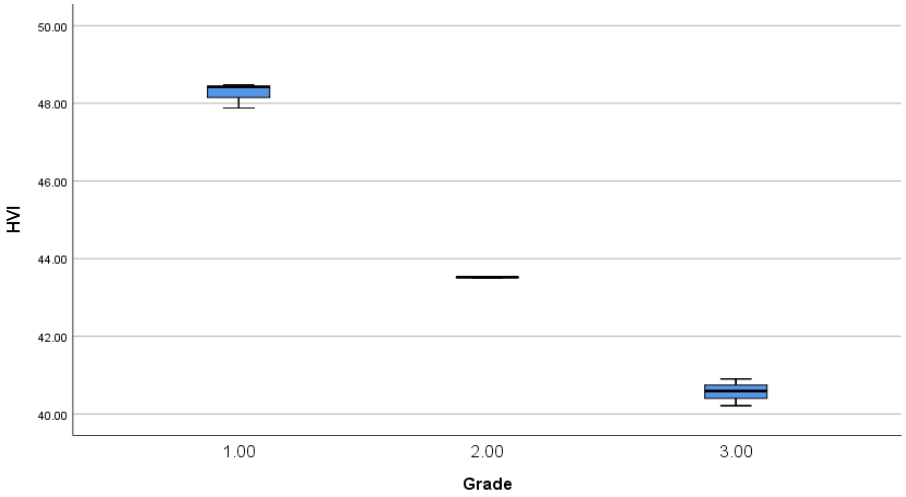


Figure 2: Relation among strength and grades with data similarity in G 92

and strength bundle which means heterogeneous with high spread of data whisker performance within these groups. Meanwhile, Fig. 4 for 50 fiber numbers tended to be in harmony with cotton strength bundle in absolute fiber and strength fiber bundle as shown in Figures. 1 and 2.

According to 45, 50, 55 single fibers numbers data; 50 single fiber numbers tended to give nearly similarity in homogeneity with bundle fiber strength data of FCS strength properties.

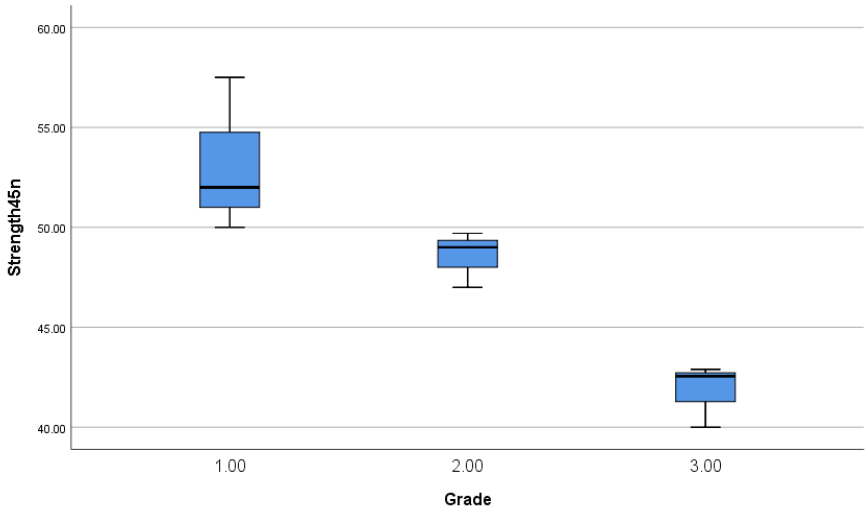


Figure 3: Relation among 45 single fibers and grades with data fluctuation in G 92

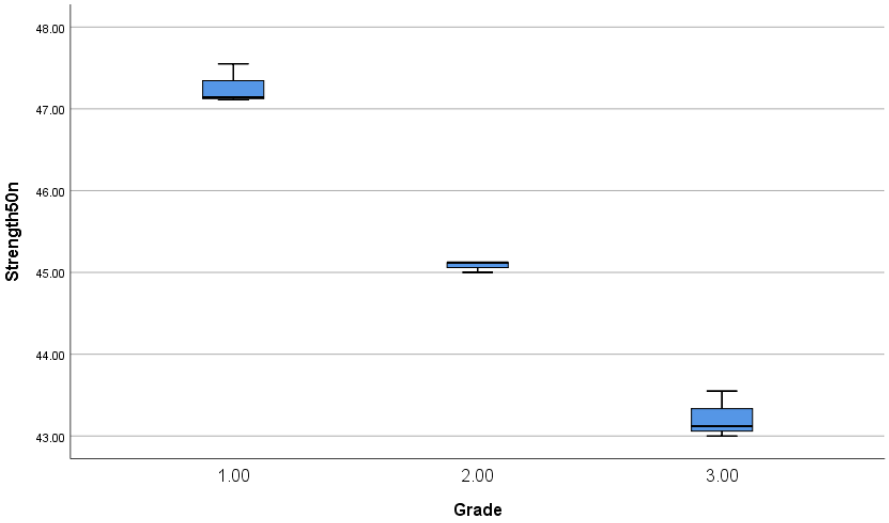


Figure 4: Relation among 50 single fibers and grades with less fluctuation in G 92

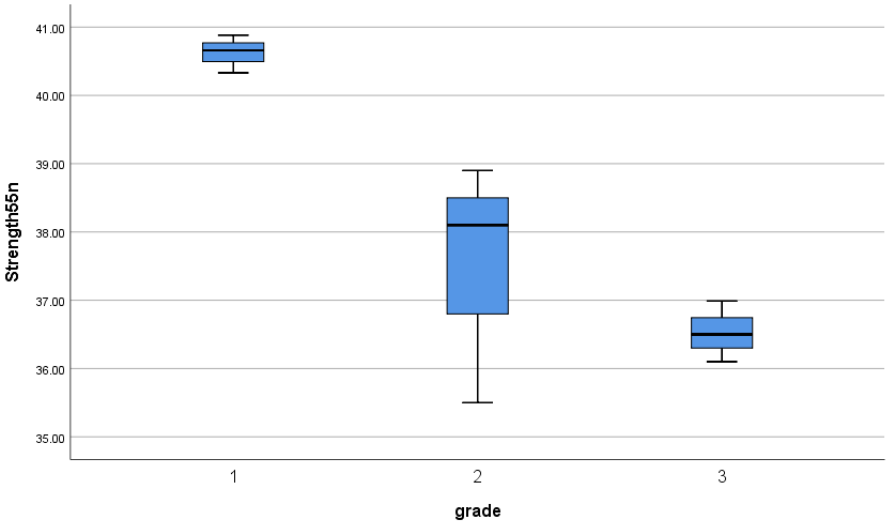


Figure 5: Relation among 50 single fibers and grades with much more fluctuation in G 92

There were highly significant differences between strength properties and grade using ANOVA. Then it is the aim of complete measures of association which quantify the strength of the relationship between variables such as in coefficient of determination (R^2), Pearson's Correlation Coefficient (R), Eta (η), and Eta squared (η^2) which are commonly reported depending on the level of grades. The coefficient of determination (R^2) quantifies the proportion of variance in the strength properties that is explained by the three grades in a regression model. In G 97; the highest regression analysis yielded a coefficient of determination of R2 = 1 indicating that approximately

Table 6: Measures of association for strength properties in G 92 and G 96

Varieties	Strength	R2	R	H	η^2
G 92	Abs. BFS	0.776	-0.881	0.890	0.792
	BFS	0.997	-0.989	0.998	0.995
	45n	0.953	-0.976	0.984	0.969
	50n	0.885	-0.941	0.990	0.980
	55n	0.968	-0.984	0.996	0.992
G 96	Abs. BFS	0.645	0.803	0.999	0.999
	BFS	0.980	-0.990	0.992	0.982
	45n	0.986	-0.993	0.995	0.989
	50n	0.999	-1	1	1
	55n	0.970	-0.985	0.985	0.970

Abs. BFS refers absolute bundle fiber strength and BFS refers bundle fiber strength in Fibrotest

Table 7: Measures of association for strength properties in G 97 and G 98

Varieties	Strength	R2	R	η	η^2
G 97	Abs. BFS	0.930	-0.964	0.965	0.931
	BFS	0.972	-0.986	0.985	0.972
	45n	0.958	-0.979	0.979	0.958
	50n	1	-1	1	1
	55n	0.962	-0.981	0.982	0.964
G 98	Abs. BFS	0.994	-0.997	0.998	0.995
	BFS	0.966	-0.983	0.983	0.967
	45n	0.956	-0.978	0.983	0.966
	50n	0.991	-0.995	1	1
	55n	0.732	-0.856	0.894	0.800

Abs. BFS refers absolute bundle fiber strength and BFS refers bundle fiber strength in Fibrotest

100% of the variance in the single fiber 50 numbers is explained by the three grades. Meanwhile, the lowest R2 indicating the lowest variance for G 92 as seen in Table 6. The Pearson correlation coefficient (R) indicates the strength and direction of the linear relationship between the strength and grades were negative strong relations for the two instruments and varieties.

The eta coefficient (η) measures the strength of association between the grades and strength methods. All eta values were more than 0.80 which indicated strong association.

Eta squared (η^2) represents the proportion of variance in the strength methods that is attributable to the grades. All eta squared values were with large effect size which was more than 90% except in 0.792 and 0.800 for abs. BFS in G 92 and 55 single fibers in G 98, respectively. These findings indicate that the grades were strongly related to strength measurements for bundle fiber and single fiber (45, 50 and 55 fiber numbers).

All previous mentioned Tables and figures represented strength property which had higher value for single fiber tester (except for work and force to break) compared to bundle fiber instrument, as much that, it may due to the bundle has discrepancies with containing fibers which ranged from strong to weak and their gradients.

CONCLUSION

The most important of single fibers to predict the spun yarn tenacity which is one important property in determining yarn quality, since it directly affects the winding weaving and knitting production efficiency as well as the fabric. Generally stronger fiber gives trend to better yarn strength, fewer breakages in spinning and suitable for fine counts whether single or bundle method. Both of absolute and strength of FCS are related but not the same physical quantity and that is why the absolute value is numerically lower. All in all; higher value of fiber strength tends to fiber bundle resists higher force.

Therefore; it is a must to study both of cotton bundle fiber strength and single fiber strength; absolute fiber strength is used for mechanical behavior study. Meanwhile in quality classification, cotton grading, spinning performance and research; bundle strength is the correct in use. In addition, single fiber strength reflects true cell wall integrity, cellulose crystallinity, secondary wall development, microfibril angle. Because bundle strength is affected by fiber alignment, fiber length distribution, friction between fibers and slippage before break which, it gives all vital information for cotton breeder.

Bundle fiber strength is commonly compared with single fiber strength because both parameters are expressed per unit linear density, reflecting the intrinsic mechanical resistance of cotton fibers. In contrast, absolute fiber strength represents the total breaking force of a fiber bundle and is strongly affected by bundle mass and fiber fineness, making it unsuitable for direct comparison with single fiber measurements.

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