Effect of spinning factors on stress-strain curves in egyptian cotton

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Abstract:
This investigation aimed to determine the effect of spinning system, yarn count and twist multiplier and their interactions on single yarn mechanical properties. Also, the Stress-Strain curves were plotted with the yield points and breaking points and their corresponding yarn properties (toughness, stiffness and Initial Young Modulus) were derived and calculated. As well as, the relative importance % of three spinning factors toward the single yarn mechanical properties was measured. Results revealed that the main effects of spinning factors *i.e.* spinning system, yarn count and twist multiplier were generally significant or highly significant on all single yarn mechanical properties except stiffness and initial Young's modulus. Regarded the first and second order interaction effects, they were no significant for all single yarn mechanical properties indicating that each one of the three spinning factors reflected similar behavior under the other two factors. It is obtained that the compact and ring spinning systems produced yarns are markedly stronger, good elasticity and more durable than the yarns spun by open-end system. Result indicates that finer yarns are weaker and have lower extension at break than coarser yarns. It is obvious that yield strain, breaking extension, breaking tenacity and toughness significantly increased as a result of increasing the twist multiplier from 3.5 up to 4.5. Results exhibited that the spinning factors explained the most single yarn mechanical properties variation expressed as coefficient of determination (R^2). The maximum relative importance % was obtained by yarn count followed by twist multiplier for yield strain, yield stress and breaking extension while the spinning system was the second important factor for breaking tenacity and toughness. On the other hand, it is appeared that the studied spinning variables accounted for least and ineffective part of the variation of stiffness and Initial Young's Modulus.

Keywords:
Spinning Factors
Stress-Strain Curves
Toughness
Stiffness
Young's Modulus

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INTRODUCTION
The tensile properties of yarns play a vital role in the manufacturing and quality of the end products. Knowledge of the Stress–Strain curves is more desirable, since it provides the whole information about the behavior of stresses under various levels of strains. The behavior of the Stress–Strain curve of spun yarns is not only a function of the nature and structural arrangement of the constituent fibers in the yarns; the variation of rate of straining and gauge length also play a key role in defining the characteristics of stress–strain curves **(Ghosh *et al*., 2005).** In fitting the stress-strain curves, it is usual to plot the stress vertically and strain horizontally. The first part of the stress-strain curve, starting at zero stress and strain, is fairly straight indicating a linear relationship between the stress and the strain.
The stress-strain curves have many practical benefits in the fields of weave research and technology. In addition to strength and extension at break, there are several other yarn properties which can be determined from these curves. Among these properties are work of rupture or toughness, secant modulus or stiffness, yield strain, yield point, Initial Young's Modulus and elasticity.
The stress-strain curve was used to determine the work of rupture or toughness as the triangular area beneath the curve (the area enclosed by the curve and the horizontal axis). Mathematically, toughness is calculated as the half product of breaking tenacity and breaking extension (expressed as a decimal). The work of rupture or toughness measures the ability of the yarn to absorb energy and as a consequence, withstand a sudden shock. Secant modulus or stiffness is the ratio of change in stress to change in strain between two points of zero and breaking stress. **Kamal *et al*. (1988)** stated that lower stiffness would produce more flexible fabrics while the yarns of high stiffness would resist deformation by any abrupt changes in tension. The Initial Young's Modulus is a measure of the force required to

produce a small extension and hence it describes the initial resistance to extension. It is calculated as the ratio of yield stress to yield strain. However, the high initial young's modulus indicates inextensibility, while low modulus denotes better extensibility.

It is an established fact that the mechanical properties of spun yarns are main determinants affecting the slope and shape of stress-strain curves. In Egypt, the reported literature toward this research point is limited. The goal of this work was to determine the effect of spinning system, yarn count and twist multiplier and their interactions on the single yarn mechanical properties.

MATERIALS AND METHODS

The commercial Egyptian cotton variety Giza 86 (follow the Long Staple category according to the local practice in Egypt) was chosen to be used as raw material for the current study. The cotton samples of this variety were taken from the 2018 crop. Cotton samples were spun using three spinning process being open-end, ring and compact spun systems. For each spinning system, three yarn counts (20'S "29.5 tex" , 30's "19.7 tex" and 40's "14.8 tex") and three twist multipliers (3.5, 4, and 4.5) were applied to study their effects on single yarn mechanical properties.

The STATIMAT automatic tensile tester was used to measure the single yarn mechanical properties and also to plot the stress-strain curves. The test was performed according to the German Standards (DIN-53-834) under controlled atmospheric conditions. The gauge length of test specimen was 50 centimeters and the time to break that specified by the ASTM was 20 ± 3 seconds. The Load-Elongation curves given by the STATIMAT tester were converted to Stress-Strain curves by changing the units without affecting the slope or shape of the curve. The stress values were expressed in terms of C.N./tex (Centi-Newton/tex) whereas the corresponding strain values were calculated by dividing the actual elongation by the original test length (50 cm) and was expressed as percentage. In accordance, the Stress-Strain curves were constructed with the yield points and breaking points. The other points in between were defined according to the values of stress corresponding to each 1% strain.

Toughness is expressed as a reliable criterion of the work of rupture and was calculated as one-half the product of breaking tenacity by breaking extension as follows:

$$Toughness = breaking\ tenacity \times breaking\ extension\ (decimal)/2$$

With respect to secant modulus or stiffness, it was calculated as the ratio of breaking tenacity to breaking extension as follows:

$$Stiffness = Breaking\ tenacity / Breaking\ extension\ (decimal)$$

The yield stress and yield strain (at the yield point) which were directly determined form the Stress-Strain curve, were used to calculate the Initial Young's Modulus as follows:

$$Initial\ Young's\ Modulus = Yield\ stress / Yield\ strain\ (decimal)$$

The collected data were subjected to analysis of variance with three factors according to the procedure outlined by **Snedecor and Cochran (1989).** Subsequently, the significance of the three main effects and their interactions were obtained. Since F test was significant, the least significant difference (L.S.D.) at 5 % level of probability was used to compare the studied treatments averages. The statistical analysis was supported by multiple linear regression analysis as outlined by **Draper and Smith (1981)** to estimate the relative importance % for each one of spinning system, yarn count and twist multiplier toward the single yarn mechanical properties expressed as coefficient of determination (R^2 %).

RESULTS AND DISCUSSION

1- The effect of spinning variables on single yarn mechanical properties and their interactions

1-a- The main effects

The spinning factors used in yarn construction, such as spinning system, yarn count and twist multiplier and their interaction effects, could have a considerable impact on the stress-strain relationship and its inherent properties of yarns. Results shown in Table (1) presented the mean values of some single yarn mechanical properties (yield strain, yield stress, breaking extension, breaking tenacity, toughness, stiffness and Initial Young's modulus) as affected by applied spinning system being open-end, ring and compact ring systems. Results revealed that there were marked significant differences among the used spinning systems for all single yarn mechanical properties except yield strain and stiffness indicating that the stiffness property of yarn is not influenced by the spun system.

It is apparent from Fig. (1) that the compact followed by ring spinning systems produced yarns were higher yield stress, breaking extension and breaking tenacity than the open-end spinning system. Despite these significant differences, but the general trend of the stress-strain curves for the three spun system was similar. Concerning work of rupture, expressed in terms of toughness property, also it is appeared that the yarns spun by compact and ring systems were tougher than the yarns produced by the open-end system.

Initial young's modulus is the ratio of change in stress to change in strain at the yield point. In fact, the yield stress and yield strain represent the limit within which the yarns are completely elastic. However, yarns spun by compact and ring systems were found to have a substantially greater initial young's modulus than open-end system. Thus, it appears that compact and ring spinning systems produced yarns are characterized by higher extensibility and hence they extend more easily for the same applied value of stress and ultimately have a greater extension at break than yarns spun by open-end system.

These findings indicated that the compact and ring spinning systems produced yarns are markedly stronger, good elasticity and more capable to absorb and withstand a sudden shock of energy and hence they are more durable than the yarns spun by open-end system. **Jackowski *et al.* (2002)** stated that ring-spun yarns are characterized by greater tenacity and elongation but smaller elasticity. Similar to rotor-spun yarns, ring-spun yarns with greater linear densities have a higher degree of elasticity. The higher elasticity of rotor-spun yarns is one of the main reasons why they are used for knitting purposes. **Zubair *et al.* (2017)** mentioned that the stress-strain curves for carded cotton yarn are low when compared with combed cotton yarn due to improved fiber properties during the combing process. A higher value of combed cotton yarn might be due to good fiber directional distribution, better fiber migration and longer fiber in combed yarn.

Table (1): The main effect of spinning system on single yarn mechanical properties computed from the stress-strain curves for Giza 86 cotton variety.

Spinning systems	Single yarn mechanical properties						
	Yield strain (%)	Yield stress (C.N./tex)	Breaking extension (%)	Breaking tenacity (C.N./tex)	Toughness (C.N./tex)	Stiffness (C.N./tex)	Initial Young's modulus (C.N./tex)
Open-end	0.76	2.55	6.72	14.18	0.48	214	347
Ring	0.71	2.92	7.31	15.42	0.57	211	409
Compact	0.73	2.91	7.37	16.42	0.61	224	398
LSD $_{0.05}$	NS	0.205	0.32	0.43	0.031	NS	30.91

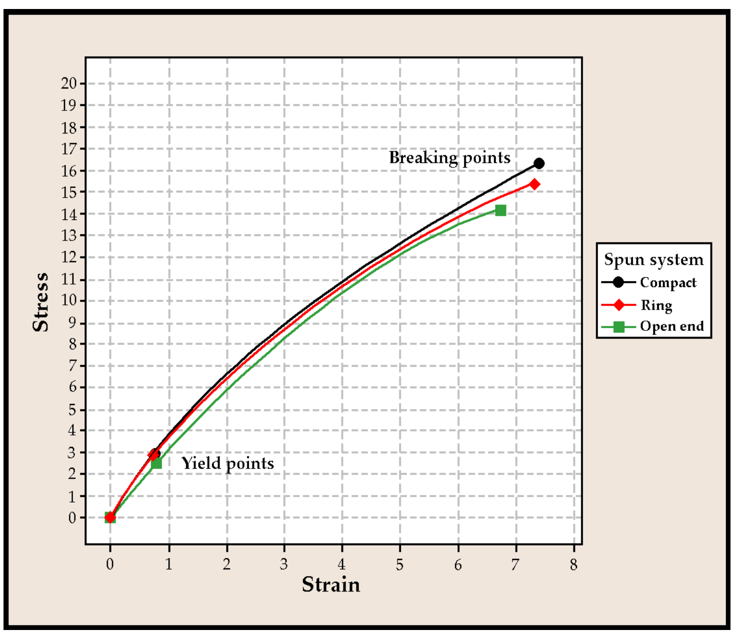

Fig. (1): Stress-strain curves of single yarn for Giza 86 cotton variety as affected by spinning system.

Table (2) and Fig. (2) illustrated how the change in yarn count affecting the stress-strain properties of single cotton yarns. There were significant differences among the three yarn counts (20's, 30's and 40's Ne) for all single yarn mechanical properties except stiffness indicating that the stiffness property is independent from the yarn count. Generally, no significant differences were obtained between yarn count of 30's and 40's regarded yield stress, breaking extension, breaking tenacity and toughness. However, it is shown that yield strain, yield stress, breaking extension and breaking tenacity significantly decreased when the yarn count increased from 20's to 40's Ne. This result indicates that finer yarns are weaker and have lower extension at break than coarser yarns. In other words, there are negative associations between yarn count and each of yield points and breaking points as shown in Fig. (2). Accordingly, the same conclusion still true for work of rupture or toughness where it is appeared that the toughness property seemed to be lower when yarns became finer. The considerable decrease in yarn tenacity, elongation and toughness, as yarn count increased, may be returned to the higher degree of irregularity usually noticed in fine yarns. Under the current study, no clear trend was obtained between initial Young's modulus and yarn count where the highest initial Young's modulus values were obtained for 20's and 40's Ne compared to 30's Ne. To obtain this relation, it is probably need to use more yarn counts. The current results are in agreement with those obtained by **Kamal *et al*. (1988)** who cleared that both breaking tenacity and breaking extension of the two studied cotton varieties consistently decreased when the count of yarns was raised from 24 (24.6 tex) to 60 (9.8 tex). They added that the coarser yarns are commonly stronger, more extensible, tougher and have lower initial young’s modulus than the finer yarns. However, secant modulus or stiffness does not appear to be strongly related to yarn count.

Table (2): The main effect of yarn count on single yarn mechanical properties computed from the stress-strain curves for Giza 86 cotton variety.

Yarn count	Single yarn mechanical properties						
	Yield strain (%)	Yield stress (C.N./tex)	Breaking extension (%)	Breaking tenacity (C.N./tex)	Toughness (C.N./tex)	Stiffness (C.N./tex)	Initial Young's modulus (C.N./tex)
20'S (29.5 tex)	0.84	3.30	7.72	16.80	0.65	218	404
30'S (19.7 tex)	0.74	2.59	6.85	14.73	0.51	216	350
40'S (14.8 tex)	0.63	2.49	6.83	14.49	0.50	214	400
LSD 0.05	0.044	0.205	0.32	0.43	0.031	NS	30.91

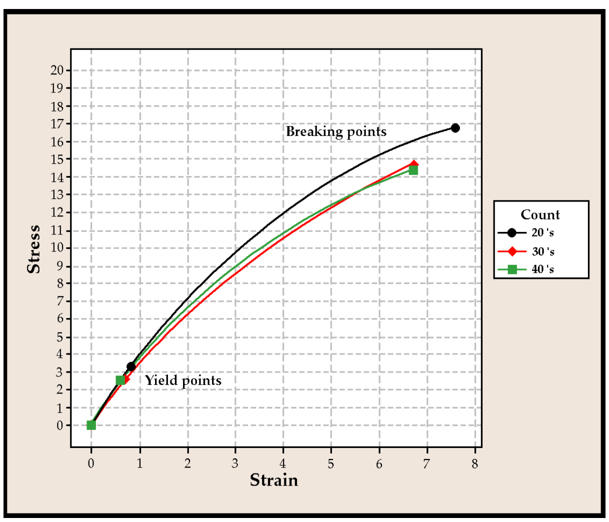

Fig. (2): Stress-strain curves of single yarn for Giza 86 cotton variety as affected by yarn count.

The main effect of twist multiplier on single yarn mechanical properties are tabulated in Table (3) and portrayed in stress-strain curve as shown in Fig. (3). Significant differences were obtained among the three twist multipliers (3.5, 4 and 5) for all single yarn mechanical properties except yield stress, stiffness and initial Young's modulus. It is clear that yield strain, breaking extension, breaking tenacity and toughness significantly increased as a result of increasing the twist multiplier from 3.5 up to 4.5. The reversed pattern was true for secant modulus or stiffness and initial Young's modulus, where they tended to decrease with the increase in twist multiplier but the decrease ratio were generally minor and no significant. However, no significant differences were obtained between twist multipliers of 4 and 4.5 for each of breaking extension, breaking tenacity and toughness indicating that these are the optimum and sufficient twist multipliers to bind the fibers together without applying excessive tension to the fibers in the outer layers of the yarn cross section. On the other hand, the progressive increase in yarn breaking extension with the increase in twist is most likely attributed to an increase in twist angle and a consequent increase in the slope of the fibers relative to yarn axis. These results are in harmony with those reported by **Kamal *et al*. (1988)** who indicated that that the breaking tenacity and secant modulus or stiffness significantly decreased with increasing the twist multiplier from 4.2 up to 5.0. They illustrated that the decrease in breaking tenacity with the increase in twist up to 5.0 may be attributed to that the used twist multiplier is most probably higher than the optimum twist required to achieve maximum yarn strength.

Table (3): The main effect of twist multiplier on single yarn mechanical properties computed from the stress-strain curves for Giza 86 cotton variety.

Twist multiplier	Single yarn mechanical properties						
	Yield strain (%)	Yield stress (C.N./tex)	Breaking extension (%)	Breaking tenacity (C.N./tex)	Toughness (C.N./tex)	Stiffness (C.N./tex)	Initial Young's modulus (C.N./tex)
3.5	0.69	2.71	6.67	14.72	0.50	223	395
4	0.74	2.78	7.24	15.47	0.56	215	384
4.5	0.78	2.89	7.50	15.83	0.60	211	376
LSD $_{0.05}$	0.044	NS	0.32	0.43	0.031	NS	NS

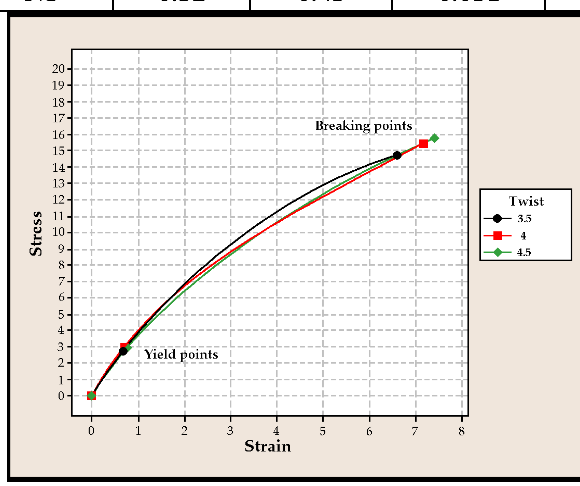

Fig. (3): Stress-strain curves of single yarn for Giza 86 cotton variety as affected by twist multiplier.

1- b - The first-order interaction effects

When twist multiplier was held constant, the average values of single yarn mechanical properties as influenced by the first-order interaction effect between spinning system and yarn count are shown in Table (4). Also, Stress-strain curves of single yarn of Giza 86 cotton variety for the three yarn counts under the applied spun systems are diagrammatically plotted in Fig. (4).

Results presented in Table (4) revealed that the interaction effect was only significance for yield strain and initial Young's modulus. This result indicated that the effect of yarn counts on yield stress, breaking extension, breaking tenacity was relatively similar under the used spun systems. Subsequently, under all used spun systems, it is shown that yield strain, yield stress, breaking extension and breaking tenacity were generally decreased when the yarn count increased from 20's to 40's Ne as shown in Fig. (4). This result indicates that coarser yarns are more strong and extension than finer yarns. It is clear from stress-strain curves that the point of 40's located very close to 30's point indicating no significant difference between them. In the same context, the toughness property tended to decrease with the finer yarns. With respect to initial Young's modulus, the significant interaction means that they are differently responded for increasing yarn count under different the spun systems. For instance, under the open-end system, the initial Young's modulus values increased by 15.44 and 33.89 % with increasing the yarn count from 20's up to 30's and 40's, respectively, while under the compact spinning system, their corresponding values decreased by 19 and 11.08 % with increasing the yarn count from 20's up to 30's and 40's, respectively. The present results are in parallel line with those obtained by **Jackowski *et al*. (2002)**, **Ghosh *et al.* (2005) and Zubair *et al*. (2017).**

Table (4): The first-order interaction effect between spinning system and yarn count on single yarn mechanical properties computed from the stress-strain curves for Giza 86 cotton variety.

Spinning systems	Yarn count	Single yarn mechanical properties						
		Yield strain (%)	Yield stress (C.N./tex)	Breaking extension (%)	Breaking tenacity (C.N./tex)	Toughness (C.N./tex)	Stiffness (C.N./tex)	Initial Young's modulus (C.N./tex)
Open-end	**20's (29.5 tex)**	0.95	2.81	7.23	15.43	0.56	215	298
	30's (19.7 tex)	0.73	2.50	6.43	13.58	0.44	215	344
	40's (14.8 tex)	0.60	2.35	6.50	13.53	0.44	212	399
Ring	**20's (29.5 tex)**	0.79	3.72	7.87	17.28	0.68	220	471
	30's (19.7 tex)	0.73	2.54	7.17	14.73	0.53	206	348
	40's (14.8 tex)	0.62	2.51	6.90	14.23	0.49	207	408
Compact	**20's (29.5 tex)**	0.77	3.37	8.07	17.70	0.72	220	442
	30's (19.7 tex)	0.77	2.74	6.96	15.86	0.55	228	358
	40's (14.8 tex)	0.67	2.61	7.10	15.70	0.56	222	393
LSD $_{0.05}$		0.077	NS	NS	NS	NS	NS	53.53

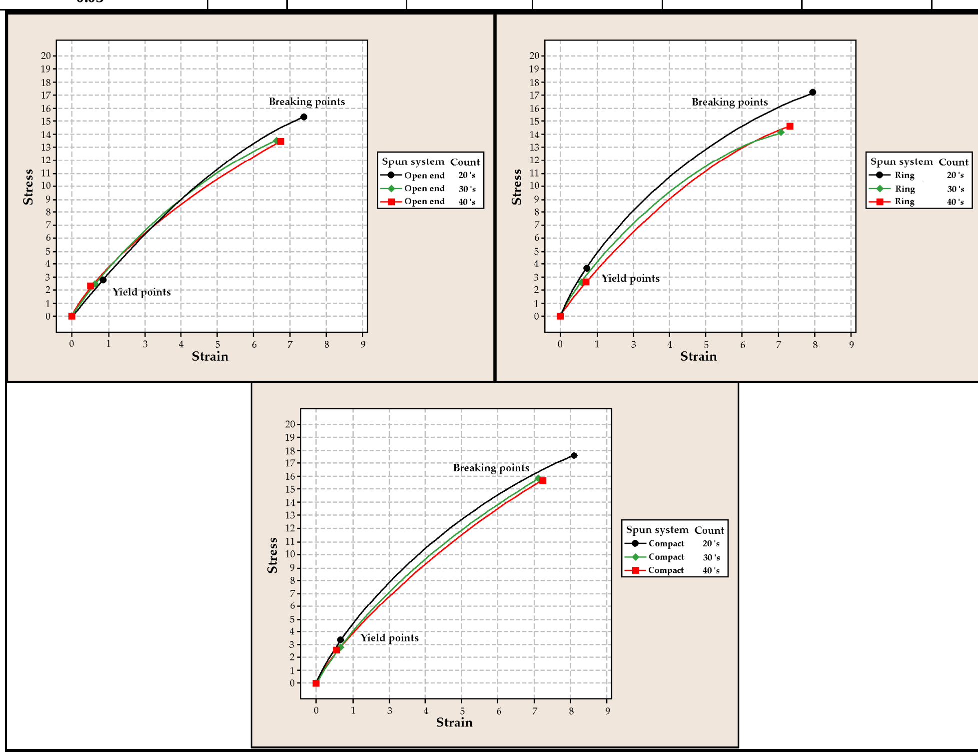

Fig. (4): Stress-strain curves of single yarn for Giza 86 cotton variety as affected by the interaction effect between spinning system and yarn count.

Data in Table (5) presented the mean values of single yarn mechanical properties as affected by the first-order interaction effect between twist multiplier and the used spinning system considering the yarn count was held constant. This interaction effect was not significant for all single yarn mechanical properties indicating that the effect of twist multiplier on single yarn mechanical properties followed similar trend under all used spun system. Looking at the stress-strain curves (Fig. 5), for all spun systems, it is obvious that yield strain, yield stress, breaking extension and breaking tenacity, work of rupture or toughness increased with each increment in twist multiplier from 3.5 up to 4 and 4.5. In accordance, there are positive associations between twist multiplier and each of yield points and breaking points as shown in Fig. (5). In conclusion, irrespective of the applied spun system, it could be stated that the good single yarn mechanical properties were obtained with increasing the twist multiplier to the optimum level. The reversed pattern was true in case of initial Young's modulus, since their values tended to decrease when twist multiplier was increased. With respect to secant modulus or stiffness, its values were weakly affected by the change of both spun system and twist multiplier.

Table (5): The first-order interaction effect between spinning system and twist multiplier on single yarn mechanical properties computed from the stress-strain curves for Giza 86 cotton variety.

Spinning systems	Twist multiplier	Single yarn mechanical properties						
		Yield strain (%)	Yield stress (C.N./tex)	Breaking extension (%)	Breaking tenacity (C.N./tex)	Toughness (C.N./tex)	Stiffness (C.N./tex)	Initial Young's modulus (C.N./tex)
Open-end	3.5	0.71	2.45	5.87	13.34	0.39	232.09	357.13
	4	0.76	2.52	7.03	14.49	0.51	207.09	346.73
	4.5	0.82	2.69	7.26	14.72	0.54	202.73	337.50
Ring	3.5	0.68	2.86	7.07	14.97	0.53	211.87	417.55
	4	0.72	2.93	7.28	15.38	0.56	212.69	408.50
	4.5	0.74	2.98	7.59	15.91	0.61	209.35	401.58
Compact	3.5	0.69	2.81	7.06	15.86	0.56	225.17	409.15
	4	0.74	2.90	7.42	16.54	0.62	224.33	395.89
	4.5	0.78	3.01	7.64	16.85	0.65	221.17	388.55
LSD 0.05		NS	NS	NS	NS	NS	NS	NS

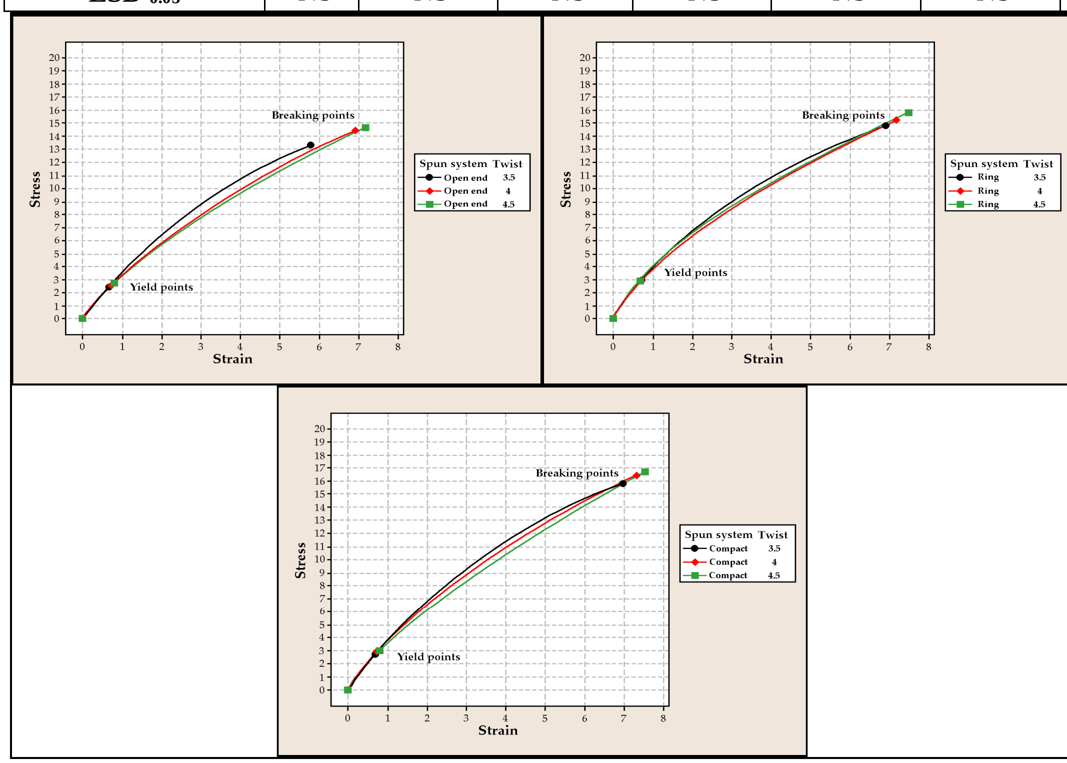

Fig. (5): Stress-strain curves of single yarn for Giza 86 cotton variety as affected by the interaction effect between spinning system and twist multiplier.

Results of the first-order interaction effect between yarn count and twist multiplier on the single yarn mechanical properties are presented in Table (6). Also, stress-strain curves of single yarn for the three twist multipliers under the applied yarn counts are graphically plotted in Fig. (6). It is shown that the interaction effect was not significant for all single yarn mechanical properties. This result indicated that the effect of twist multiplier on yield strain, yield stress, breaking extension, breaking tenacity and toughness was relatively similar regardless the used yarn count. Testing the stress-strain curves for any yarn count, it is appeared that the maximum yarn strength and higher energy-absorbing capacity would be attained by increasing the twist multiplier from 3.5 up to 4.5 confirming the positive relationships between twist multiplier each one of the abovementioned single yarn mechanical properties. On the other hand, the effect of twist multiplier on the secant modulus or stiffness and Initial Young's modulus was weak at any yarn count**. Patil *et al*. (2017)** noticed that, as twist multiplier increases into certain limits, then tenacity and strength get increases. When the twist multiplier increases above the optimum limit, the tenacity and strength may be decreased.

Table (6): The first-order interaction effect between yarn count and twist multiplier on single yarn mechanical properties computed from the stress-strain curves for Giza 86 cotton variety.

Yarn count	Twist multiplier	Single yarn mechanical properties						
		Yield strain (%)	Yield stress (C.N./tex)	Breaking extension (%)	Breaking tenacity (C.N./tex)	Toughness (C.N./tex)	Stiffness (C.N./tex)	Initial Young's modulus (C.N./tex)
20's (29.5 tex)	3.5	0.80	3.19	7.41	16.12	0.60	218.19	406.87
	4	0.82	3.26	7.76	16.93	0.66	219.88	406.45
	4.5	0.89	3.45	8.00	17.36	0.70	217.40	397.87
30's (19.7 tex)	3.5	0.70	2.54	6.37	14.27	0.46	226.76	361.41
	4	0.75	2.59	6.99	14.85	0.52	213.01	347.54
	4.5	0.78	2.65	7.20	15.06	0.54	209.39	341.57
40's (14.8 tex)	3.5	0.58	2.39	6.23	13.78	0.43	224.18	415.55
	4	0.64	2.50	6.97	14.62	0.51	211.22	397.13
	4.5	0.67	2.58	7.31	15.07	0.55	206.46	388.19
LSD $_{0.05}$		NS	NS	NS	NS	NS	NS	NS

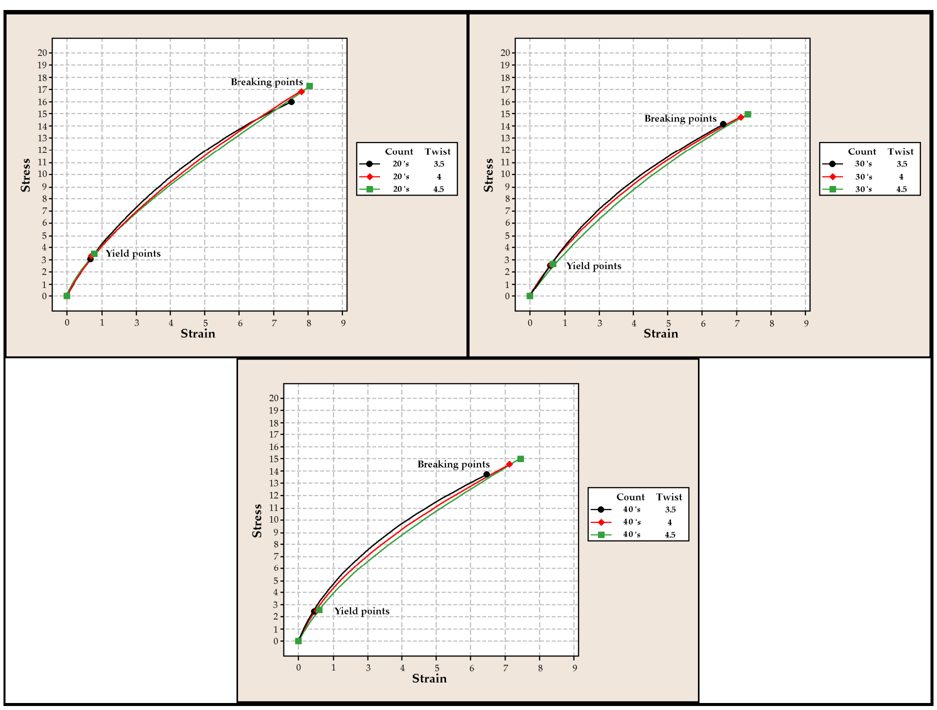

Fig. (6): Stress-strain curves of single yarn for Giza 86 cotton variety as affected by the interaction effect between yarn count and twist multiplier

1- c - The second-order interaction effect

Results of the second-order interaction effect among the three spinning factors (spun system, yarn count and twist multiplier) on single yarn mechanical properties is presented in Table (7). In addition, the stress-strain curves of single yarn for the interaction among the three spinning variables are plotted in Fig. (7). Results revealed that the interaction effect was no significant for all single yarn mechanical properties. This means that each one of the three spinning variables reflect similar behavior under the other two variables. Overall yarn counts and twist multipliers, it is apparent that the elite single yarn mechanical properties were obtained by compact followed by ring spinning systems compared to the open-end spinning system. In the same context, it is shown that the yarn strength and yarn elasticity decreased when the yarn count increased from 20's to 40's Ne under any spinning system and twist multiplier. Also, it is clear that the maximum values of single yarn mechanical properties were significantly increased as a result of increasing the twist multiplier from 3.5 up to 4.5 under all spun systems and yarn counts. Generally, it is possible to say that the effect of the three spinning variables on the secant modulus or stiffness and Initial Young's modulus was low and ineffective. **Kotb (2012)** reported that the cotton type, yarn count and twist multiplier have the higher effect on all the properties studied also the yarn tensile strength.

Table (7): The second-order interaction among spinning system, yarn count and twist multiplier on single yarn mechanical properties computed from the stress-strain curves for Giza 86 cotton variety.

Factors			Single yarn mechanical properties						
Spinning system	Yarn count	Twist multiplier	Yield Strain (%)	Yield Stress (C.N./tex)	Breaking extension (%)	Breaking tenacity (C.N./tex)	Toughness (C.N./tex)	Stiffness (C.N./tex)	Initial Young's Modulus (C.N./tex)
Open-end	20's (29.5 tex)	3.5	0.89	2.65	7.01	14.36	0.50	205.97	299.55
		4	0.92	2.71	7.28	15.86	0.58	220.59	302.12
		4.5	1.05	3.06	7.39	16.07	0.60	217.63	291.20
	30's (19.7 tex)	3.5	0.69	2.45	5.30	13.05	0.35	248.34	357.76
		4	0.74	2.49	6.90	13.80	0.48	200.11	342.75
		4.5	0.77	2.55	7.10	13.90	0.49	195.96	332.69
	40's (14.8 tex)	3.5	0.54	2.24	5.30	12.60	0.34	241.96	414.07
		4	0.61	2.37	6.90	13.80	0.48	200.58	395.32
		4.5	0.64	2.45	7.30	14.20	0.52	194.60	388.60
Ring	20's (29.5 tex)	3.5	0.78	3.70	7.51	16.80	0.63	224.58	473.54
		4	0.79	3.72	7.90	17.13	0.68	217.83	474.04
		4.5	0.80	3.75	8.20	17.92	0.74	218.67	466.19
	30's (19.7 tex)	3.5	0.70	2.50	7.00	14.20	0.50	203.15	356.27
		4	0.73	2.53	7.13	14.80	0.53	209.13	346.41
		4.5	0.76	2.59	7.38	15.20	0.56	205.87	342.14
	40's (14.8 tex)	3.5	0.57	2.39	6.70	13.90	0.47	207.88	422.83
		4	0.63	2.53	6.80	14.20	0.48	211.10	405.06
		4.5	0.66	2.61	7.20	14.60	0.53	203.51	396.42
Compact	20's (29.5 tex)	3.5	0.72	3.22	7.70	17.20	0.66	224.02	447.51
		4	0.76	3.36	8.10	17.81	0.72	221.22	443.19
		4.5	0.82	3.54	8.40	18.08	0.76	215.89	436.22
	30's (19.7 tex)	3.5	0.72	2.67	6.81	15.56	0.53	228.78	370.21
		4	0.78	2.74	6.95	15.94	0.56	229.80	353.47
		4.5	0.81	2.80	7.11	16.08	0.57	226.34	349.88
	40's (14.8 tex)	3.5	0.62	2.54	6.68	14.83	0.50	222.72	409.75
		4	0.67	2.60	7.20	15.86	0.57	221.99	391.02
		4.5	0.71	2.68	7.42	16.40	0.61	221.27	379.54
$LSD_{0.05}$			NS	NS	NS	NS	NS	NS	NS

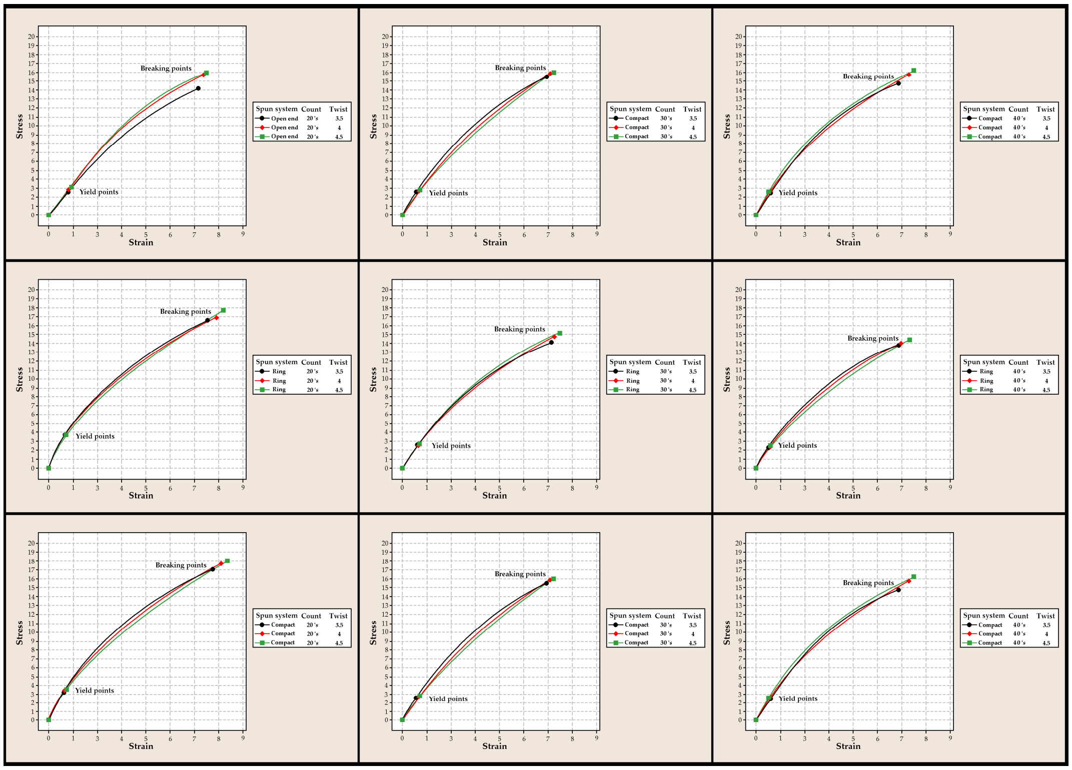

Fig. (7): Stress-strain curves of single yarn for Giza 86 cotton variety as affected by the interaction effect among spinning system, yarn count and twist multiplier.

2- The relative importance of spinning variables on single yarn mechanical properties.

The relative importance %, coefficient of determination (R^2) and multiple correlation coefficient (R) of spinning systems, yarn count and twist multiplier toward the single yarn mechanical properties are presented in Table (8) and graphically shown in Fig. (8). Results exhibited that the three spinning factors explained the most variation of single yarn mechanical properties expressed as coefficient of determination (R^2 %) except for stiffness and initial young's modulus. The coefficient of determination (R^2 %) of the three spinning factors toward the single yarn mechanical properties ranged from 68.80 for breaking extension to 87.11 for breaking tenacity indicating that the used spinning parameters were effectively affecting the yarn strength and elasticity. The maximum relative importance % was obtained by yarn count followed by twist multiplier for yield strain, yield stress and breaking extension while the spinning system was the second important factor for breaking tenacity and toughness. On the other hand, it is appeared that the studied spinning variables accounted for least and ineffective part of the variation of stiffness and initial young's modulus expressed as coefficient of determination ($R^2 < 30$ %). However, the residuals content ($1-R^2$ %) may be attributed to other spinning parameters were not take into account under the current study and/or also to unknown variation (random error).

Results revealed that the multiple correlation coefficients (R) between the spinning factors of one side and each one of the single yarn mechanical properties of the other side were greater than 0.8 indicating strong associations between them. In fact, these conclusions confirmed the abovementioned results obtained from Tables 1 to 7.

Table (8): The relative importance %, coefficient of determination (R^2) and multiple correlation coefficient (R) of spinning system, yarn count and twist multiplier affecting the single yarn mechanical properties.

Single yarn mechanical properties	Relative importance				
	Spinning system	Yarn count	Twist multiplier	Coefficient of determination (R^2)	Multiple correlation coefficient (R)
Yield strain (%)	1.00	62.82	11.22	75.00	0.87
Yield stress (C.N./tex)	10.73	56.70	20.87	70.31	0.84

Breaking extension (%)	**15.44**	**28.40**	**24.96**	**68.80**	**0.83**
Breaking tenacity (C.N./tex)	**37.59**	**40.33**	**9.19**	**87.11**	**0.93**
Toughness (C.N./tex)	**25.93**	**38.52**	**16.67**	**81.11**	**0.90**
Stiffness (C.N./tex)	**9.20**	**2.05**	**14.32**	**25.27**	**0.50**
Initial Young's modulus (C.N./tex)	**16.39**	**0.07**	**2.23**	**18.70**	**0.43**

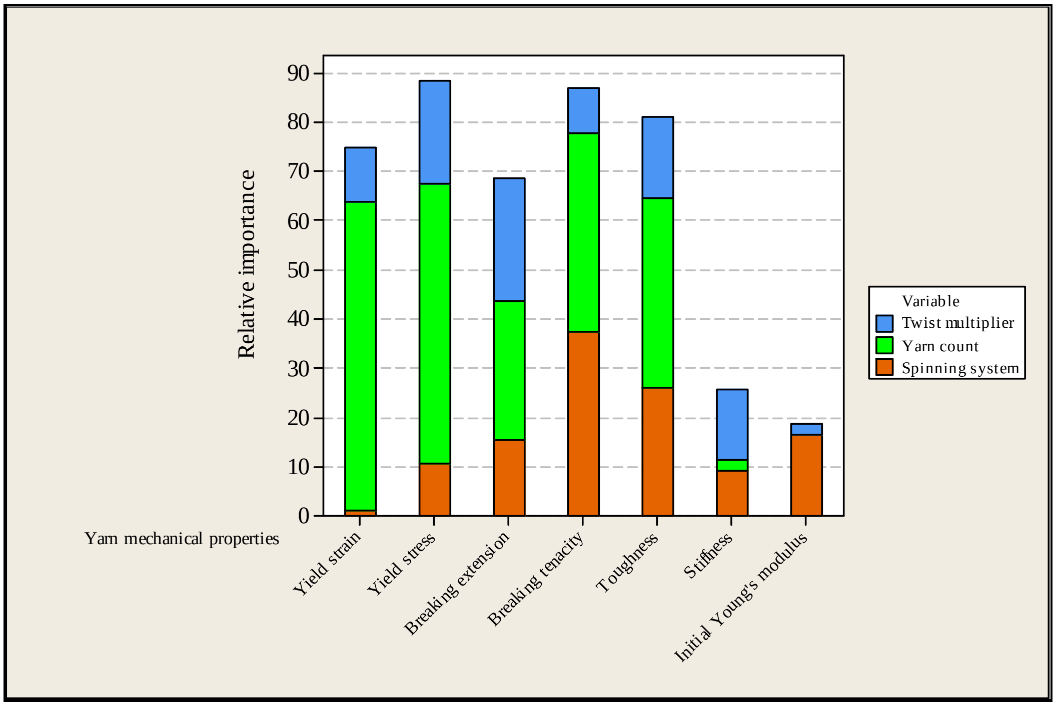

Fig. (8): The relative importance % of spinning systems, yarn count and twist multiplier toward single yarn mechanical properties.

CONCLUSION

The current work carried out to study the effect of three spinning factors (spinning system, yarn count and twist multiplier) and their interactions on the single yarn mechanical properties using stress-strain curves. Results indicated that the spinning factors being; spinning system, yarn count and twist multiplier had significant or highly significant effects on all single yarn mechanical properties except stiffness and initial Young's modulus. However, most the interaction effects were no significant for all single yarn mechanical properties meaning that each one of the three spinning variables reflect similar behavior under the other two variables. It is obvious that the favorable single yarn mechanical properties were obtained by compact followed by ring spinning systems compared to the open-end spinning system. Result indicates that finer yarns are weaker and have lower extension at break than coarser yarns. The maximum values of single yarn mechanical properties significantly increased as a result of increasing the twist multiplier from 3.5 up to 4.5. It is exhibited that the studied spinning factors reflected the most variation of single yarn mechanical properties expressed as coefficient of determination (R^2). The highest relative importance was obtained by yarn count followed by twist multiplier for yield strain, yield stress and breaking extension while the spinning system was the second important factor for breaking tenacity and toughness.

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