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Effect of Fibre Maturity on fibre microscopic and mechanical properties of two Egyptian cotton varieties

[1]El-Seidy, E. H.; [2]Abeer S Arafa; [2]Younis, M.A.SH.
[1]Agronomy Dept. Faculty of Agric, Tanta University Egypt.
[2]Cotton Research Institute, Agricultural Research Center- Giza- Egypt

Abstract
The present study was carried out in Cotton Technology Res. Department Cotton Res. Institute, Agric. Res. Center at Giza in 2018 season. Aiming to Investigation the relationship between fibre microscopic properties and fibre mechanical properties. Lint cotton samples of four micronaire levels (Mic levels) from two Egyptian cotton genotypes; namely; Giza 94 and Giza 95 representing Delta and Upper Egypt LS genotypes were tested by HVI and Image analysis methods. The results indicated that over maturity level shown the highest values of each Perimeter (P), area of cross section (ACW), area of secondary wall (ASCW) degree of thickening (Ɵ), Maturity ratio, maturity percent (M%) and Elongation%. While, the very immature fibres gave the lowest values of the same characters respectively in addition to fibre length (mm) and fibre strength (g/tex). Whilst, the normal maturity fibres shown highest fibre length and strength. On the other hand, the over maturity showed lowest values of the reversals number and convolutions number. While, the very immature fibres gave largest number of reversals, and the normal maturity level shown more number of convolutions. Correlation coefficients between fibre maturity measurements and fibre mechanical and physical properties were highly significant. The stepwise analysis regression coefficients proved that, Perimeter, degree of thickening and number of convolutions were the three best variables for pridect fibre strength, R2 = 0.97

Keyword: *cotton – fibre maturity – microscopic properties – fibre strength*

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I. Introduction

Quality is the ultimate goal of the cotton manufacturer because raw material costs are 50% of the total manufacturing costs at the spinning mill .This cost decreased or increased depends on their fibre quality.

The quality is a set of attributes some of them are related to the bundle physical and mechanical characters each measured with fast and easy instruments like AFIS and HVI and the others is a time consuming attributes such as single fibre fine structure which need some complicated instruments like microscope and Image analyzer. In fact, the qualities of the fibre fine structure characters is a result of some genetic factors like fibre perimeter or diameter, cellulose deposition method, the angle of deposition, some others are associated with the growing conditions like the amount of cellulose deposited inside the fibre which represents the fibre body;[1,2,3] also the fibre fine structure is an indicator for the bundle physical and mechanical characters.. Add [4,5] and [9]that Mature fibres usually have greater strength and better flexibility, while, immature cottons result in large processing wastes in large number of spinning and weaving breaks, which may reduce yarn strength and end down in spinning, and causes neps that led to not dye uniformly and show up as white specks in dyed fabric, mm.

It is worth that, Micronaire measurement alone not good predictors of fibre maturity, is a measure for Gravimetric fineness that depends on both of fineness and maturity together. [6]indicated that linear-density could be refered to biological fineness if fibre maturity is known. In addition, low micronaire cotton may be due to immature fibres or genetically fine fibres and may also indicate fine fibres with adequate maturity[7], and a higher micronaire value indicates either coarser fibres or thinner fibres with thick cell walls[8]**.** Add [9] that micronaire value does not adequately assess varying fibre perimeter for different genetic cotton verities and thus is not satisfactory as a real measure of fibre maturity. although Micronaire is being used as the official cotton standard for fibre fineness and maturity measurement [10]**.**

Fibre maturity refers to the degree of thickening of the fibre cell wall relative to the perimeter or effective diameter of the fibres**,** [5,11]**.**

In the USA method of measuring maturity as Indian Standard Methods[12] recommended, maturity had apportionment to just two classes, mature and immature fibres, and the percentage of mature fibres is calculated from the total number of observations, and the results is expressed as percentage of mature fibres: $P_M = [m/ t] \times 100$; where, m = total number of mature fibres, and t = total number of observations.

According to BS 3085:1968[13], and Indian Standard Methods [12] the maturity ratio (MR) is degree of wall thickening. The swelling fibres classified into normal, dead and thin walled fibres, and calculated from: MR= [N%-D%/200] + 0.7, where N is the percentage of normal fibres; D is the percentage of dead fibres. And that, cotton with maturity ratio in the interval 0.7 to 0.8 are immature, fibres of a MR in the interval 0.8 to 1 – are mature, and fibres of a MR > 1 have been very rarely met.

In addition to recently, the image analysis of the fibres cross sections provides reliable unbiased accurate technique for determining fibre fineness and maturity. This technique depends entail on using a computer program to obtain direct measurements of cotton fibre cross sectional characteristics as wall thickness, ribbon width (cross-sectional diameter), maturity ratio and degree of thickening. Although image analysis technique is very slow due to the long time and efforts of preparing fibres cross-sections, it could be used as a reference method for evaluating the other methodology and technique of measuring fibre fineness and maturity parameters of the dry cotton fibre which are commonly used with the large numbers of samples in cotton breeding programs, cotton trading and cotton spinning industry as well.

The impact of fibre maturity or immaturity on bundle strength tests is a point of controver, in spite of a single mature fibre is inherently stronger than a single immature because of its fine structure as crystallite orientation, fibrillar orientation, fibre maturity, crystalline cellulose structure, degree of polymerization and the spiral angle in addition to convolutions, reversals and other features of the fibre structure. 14,15,16,17 has cleard that high bundle strength can be obtained from a bundle of more numerous immature fibres, each of which could be weak on an individual fibre basis. Immature fibres have thin secondary walls, while mature fibres have secondary walls approaching maximum thickness. Moreover, a bundle of fibres consisting of a large amount of fine and mature fibres may have higher bundle strength than a bundle of coarser and very mature fibres. It is may be due to the number of fibres participating in the fibre bundle test. in fact, a bundle of coarse and very mature fibres has fewer fibres participating in the bundle test specimen and between-fibre frictions and cohesion forces will be lower in the very mature fibres. 18Illustrated that the stiff and bristle nature of over-mature fibers make them undesirable in the spinning process. The over-mature fibres result in the formation of virtually closed lumen by extra growth of cell wall and ultimately creates high resistance to bending during the spinning process. All these changes make it mandatory to measure the cotton fiber maturity prior to spinning in order to avoid drop in yarn and fabric quality. cotton fiber fineness until and unless immature or over-mature fibers put forth their impact upon the measured value of cotton fiber fineness. This scenario indicates that the measurement of cotton fibre maturity is highly influential for the accurate determination of fibre fineness.

The objective of this research work is studying:

- The impact of fibre micronaire value Levels (maturity Levels), perimeter and degree of thickening, reversals and number of convolutions on fibre strength of two Egyptian cotton variety.
- Investigation the relationship between fibre microscopic properties and fibre mechanical properties.
- estimate the relative importance of the mentioned fibre microscopic properties contributing to fibre strength.

II. Material and Method

The main objective of this study was investigation the effect of fibre fine structural and physical and mechanical properties and relation between them. Two Egyptian cotton genotypes namely; G.94 as Delta long staple variety (Delta LS) and G.95 as Upper Egypt long staple variety (Upper Egypt LS) were used in this study. The lint samples were selected from the 2018 season yield traits of maintenance of varieties genetic purity programs of cotton research institute delivered to HVI Lab, cotton fibre research section, cotton research institute (CRI), Agricultural Research Center (ARC).

Based on HVI micronaire values, the different sample of each variety were divided into four level of micronaire (four level of maturity) every level was represented by three different repetitions. The samples of each variety (4 levels of maturity x 3 repetitions) were used to determine fibre fine structural properties in (fibre structural lab) and physical and mechanical properties in HVI lab [19]. All tests carried out under control conditions of 65% ±2 of relative humidity and 21 ± 2C˚ temperature.

- Studied characters:-

1- Fibre microscopic properties

1. Ribbon width and Maturity ratio (MR), determined by using sodium hydroxide method according to [20]. Some of the dry fibres of each sample were placed on a glass slide about 200 fibres then treated with 18% sodium hydroxide and tested using the image analysis system.

MR= [N%−D% /200] + 0.7, where N is the percentage of normal; D is the percentage of dead fibres. Degree of thickening was calculated according to the formula [21]

2. Calculate fibre perimeter with micron [μ], fibre perimeter (P) = 3.14 x fibre diameter (D)

3. Area of cross section μ² (ACS), ACS= $\pi[\ ^1/_2\ D]^2$, where π = 3.14, (area of a circle having the same perimeter)
4. Area of secondary cell wall (ASCW) with [μ]² = ACS-LA
5. Degree of thickening %(θ). Where θ = ASCW/Area of a circle having fibre perimeter
6. Number of reversals per mm
7. Number of Convolutions per mm

2- Fibre physical properties

1- Micronaire value
2- Fibre Upper Half Mean (UHM) mm
3- Fibre uniformity Index (UI)
1. 8-Fibre strength (g/tex)
2. 9-Fibre elongation percentage.

Statistical analysis:

Because of the study will be carried out at the Labs of fibre department, cotton Research Institute the experiments will be in complete randomized design with three replicates. The obtained data were computed using SAS program. Analysis of variance outlined by[22] LSD at 5% level of probability. Simple correlation coefficient and regression equation will be performed using latest available software.

III. Results and Discussions

The effect of maturity level on fibre fine structural from Image analysis system and fibre length, fibre strength and elongation properties from HVI data in Egyptian cotton variety G.94 and G.95:-

Data in table (1) presented the cotton variety, Mic value levels (maturity levels) and their interaction cleared significant differences between micronaire value (Mic), maturity ratio (MR) and maturity percentage% (MP) of custic soda, fibre perimeter μ (P), area cross section μ^2 (ACS), secondary cell wall μ^2 (ASCW), degree of thickening (ɵ), Number of reversals and number of convolutions, fibre length (UHML) mm, fibre strength g/tex and elongation%.

The results in table 1 cleared that, fibre perimeter showed significant different between the four mature levels and genotypes being (46.7μ and 51.5μ) in G.94 and G.95 respectively. While, ranged in (47.3 to 46.1μ) in the over mature level to the very immature fibre of the G.94 variety and (52.3 to 50.5μ) of G.95 variety. Although, it is know that the perimeter is genetically stable parameter, but, the noticed increase in fibre perimeter of normal maturity and over mature fibre, may be due to the stress of the secondary wall layers on the stretchable primary wall resulting the perimeter increase in the over maturity. Area cross section take the same tend of fibre perimeter, the values being (171.7 and 222.7 μ^2) of G.94 and G.95 variety respectively. Whilst, the value of maturity levels recorded (175.0 and 226.0 μ^2) in the over mature level to (168.5 and 218.5 μ^2) in the very immature level of G.94 and G.95 variety respectively. According to secondary cell wall of G.94 lower than G.95 variety to be (81.1 ant 103.6 μ^2) this variation due to the different fibre Perimeter between them. The values of different mature levels ranged in (100.5 to 64.0 μ^2) of the G.94 variety and (130.0 to 80.0 μ^2) in G.95 variety for the over mature level to very immature level respectively. It is know that secondary cell wall is a trait highly affected by environment and management practices which affect cotton growth and development. Degree of thickening taken the same trend of ASCW and ACS among the differently mature levels; this is normal because it calculated from them. The values of MR and MP from custic soda method in table (1) shown the same tend but the different between them in the calculate equation of both them; this is clear in the material and method part, the values ranged in (0.80 and 73.5%) to (0.81 and 74.2%) of MR and MP for two variety respectively. Moreover, maturity ratio and maturity percent showed more variation between the different maturity levels to be (0.57 and 0.58) in the over mature level to (0.38 and 0.37) in the very immature fibre of MR in G.94 and G.95 variety respectively. MP shown the same trend of MR in the two varieties under study and this is clear in the table.

With regard to number of reversals, the values were (16.2 and 14.9) of G.94 and G.95 variety respectively. It is worth mention that, the reversals considered as weak point along the fibre where the fibre exposed to breakage when force applied along. Because it the point where the cellulose deposition layers reservels the direction from clock wise to anti-clock wise. It affected by both genetic and environmental condition. Maturity levels also affected on the number of reversals, the values were (14.7 to 17.2) in the over mature level to immature level of the variety G.94 and (13.0 to 16.1) of the variety G.95. As for number of convolution parameter, it is know well that is reflected positively on the strength. The over mature level exhibited the higher convolutions number than low maturity fibre. also the longer fibre is higher in convolution number than shorter fibre, this is clear in table (1), which it The cotton variety G.94 gave the higher convolution number than the variety G.95 to be (24.9 and 22.9) respectively. Also, the values ranged in (33.5 and 30.9) in mature level to (18.0 and 16.5) in very immature level of G.94 and G.95 variety respectively.

In general, the over maturity level shown the highest values of each P, ACS, ASCW, MR and MP to be (52.3 µ, 226.0 μ^2, 115.3 μ^2, 0.57 and 86.6%) respectively, while the lowest values shown in very immature level to be (50.5 µ, 218.5 μ^2, 72.0 μ^2, 0.37, 0.66 and 60.9%) respectively. On the other hand, the over maturity showed the lowest number of reversals and number of convolutions to be (13.0 and 16.5) respectively, while the highest values of number of reversals being 16.1 in the very immature level and 30.9 of number of convolutions in maturity level. **These results confirmed by**[23,24,25]

Table (1): effect of maturity levels on fibre fine structural properties and fibre physical properties in Egyptian cotton variety G.94 and G.95.

		HVI Data				Data from Image analysis and polarized microscope							
Varieties	maturity levels	mic	fibre length	Fibre str.	elong	P	ACS	ACSW	DEGREE	MR	MP	No. of Reversal /cm	No. of Convol ution
G.94	Very immature	2.63	32.1	35.3	5.51	46.1	168.5	64.0	0.38	0.65	59.5	16.5	18.1
	immature	3.22	33.9	40.6	6.10	46.5	170.6	72.1	0.42	0.72	67.0	17.2	33.5
	mature	3.96	34.3	42.8	6.80	46.9	172.7	87.7	0.51	0.87	80.7	16.7	30.1
	over mature	4.53	33.6	37.8	7.45	47.3	175.0	100.5	0.57	0.96	86.9	14.7	18.0
	G.Mean	3.59	33.5	39.1	6.47	46.7	171.7	81.1	0.47	0.80	73.5	16.2	24.9
G.95	Very immature	2.99	27.9	32.7	7.01	50.5	218.5	80.0	0.37	0.66	60.9	14.9	16.7
	immature	3.44	28.3	36.0	7.55	51.1	221.9	93.4	0.42	0.73	68.1	16.1	30.9
	mature	4.54	31.0	37.6	8.00	52.2	224.2	111.2	0.50	0.88	81.0	15.5	27.6
	over mature	5.05	29.2	35.4	8.53	52.3	226.0	130.0	0.58	0.96	86.6	13.0	16.5
	G.Mean	4.01	29.1	35.4	7.77	51.5	222.7	103.6	0.46	0.81	74.2	14.9	22.9
Maturity Levels	Very immature	2.81	30.0	34.0	6.26	50.5	218.5	72.0	0.37	0.66	60.9	16.1	16.7
	immature	3.33	31.1	38.3	6.83	51.1	221.9	82.7	0.42	0.73	68.1	16.4	30.9
	mature	4.25	32.7	40.2	7.40	52.2	224.2	99.4	0.50	0.88	81.0	16.0	27.6
	over mature	4.79	31.4	36.6	7.99	52.3	226.0	115.3	0.57	0.96	86.6	13.0	16.5
	G.Mean	3.80	31.3	37.3	7.12	51.5	222.7	92.3	0.47	0.81	74.2	14.9	22.9
LSD 5%													
Variety (V)		0.07	0.21	0.25	0.10	0.9	2.01	0.17	0.01	0.02	0.28	0.07	0.21
Maturity level (M)		0.11	0.30	0.33	0.11	1.2	2.84	0.20	0.03	0.03	0.32	0.11	0.30
V x M		0.14	036	0.41	0.21	1.4	2.98	0.27	0.03	0.04	0.45	0.14	036

Concerning data from HVI in table (1) the results cleared that, the variety G.94 shown the higher fibre length and fibre strength than G.95 to be (33.5 mm and 39.1 g/tex) and (29.1mm and 35.4g/tex) respectively. It is cleared that the results of each variety affected by maturity levels the ranged in fibre length (34.3 mm to 32.1mm) and (31.0 to 27.9mm) in mature level to very immature level of the variety G.94 and G.95 respectively. The values of fibre strength ranged in (42.8 to 35.3g/tex) and (37.6 to 32.7g/tex) in mature level to very immature level of the variety G.94 and G.95 respectively. The decrease of fibre length may be due to that immature fibre is easily to be broken during ginning, subsequently affects and decrease the length fibre. Furthermore, the short fibre content is increased. The fibre strength is related by micronaire value and maturity which is increased by increasing maturity. The maturity is always accompanied with high strength. However the fibre strength also seems to be high with immature fibre, this may be due to that the increasing of the fibre number in bundle cross section compensated the decreasing of cellulose deposition. It is worthy to mention that there is a certain extent, and the increase or decrease on it reflects on the fibre strength negatively. Therefore, the over maturity led to decrease in fibre strength may be due to that the decrease the fibre number in bundle cross section accompanied with excess of cellulose deposition in fibre , this making the fibre stiff more and its easy to rupture during the yarn processing. the same thing in the very immature level, very decrease of cellulose deposition in fibre led to decrease of fibre strength, because even though the increase in the fibre number in the bundle cross section but this did not compensate for the decrease of maturity and therefore, makes the fibre easy to cut off during the yarn . The results agree with [18,22,23,24].

According to fibre elongation% parameter the variety G.95 shown the higher value than G.94 to be (7.77 and 6.47%) respectively, this is a genetically trait of the variety but it affected by the maturity levels such as the fibre strength and fibre length, the values being (8.53 to 7.01%) and (7.45 to 5.51%) in the over mature level to very immature level in the variety G.94 and G.95 respectively. These results confirmed by [18,22,23]**.**

In general, the maturity level shown the highest values of each Fibre length (mm) and fibre strength (g/tex) to be (32.7mm and 40.2g/tex) respectively, while the lowest values shown in very immature level to be (30.0 mm and 34.0g/tex) respectively.

Relationship of fibre fine structural with fibre mechanical and physical properties:

Simple correlation coefficients between the different measurements of fibre fine structural (from Image analysis system) and mechanical and physical properties (fibre strength, fibre length and elongation) that measured by HVI are shown in table (2). These correlations could be summarized as follows:

Fibre perimeter (express on fibre intrinsic fineness) showed highly significant negative correlation with fibre length, fibre strength and number of reversal. The negative relationship could be due to that the smaller perimeter is always finer and stronger. In other words, the decrease of the fibre perimeter accompanied by increase of the strength and fibre length. While, the relationship between the fibre perimeter shown highly significant positive correlation with elongation%. This may be due to that, most of coarse cottons (high perimeter) having higher short fibre of lower tenacity easily to be broken during the ginning this led to more short fibre. One the other hand, the coarse fibres contains more amorphous cellulose and characterized by higher fibre elongation than fine variety. This the results confirmed by[24,26].

Table (2): Relationship of fibre fine structural with fibre mechanical and physical properties:

	mat	fibre Len	stre	Elong	P	ACS	ACSW	DEGREE	MR	MP	Revearsal	Convolu tion No
Mic	0.977**	0.701**	0.780**	0.970**	-0.986**	-0.972**	0.950**	0.982**	0.995**	0.990**	0.606**	0.059
Mat		0.643*	0.689**	0.953**	-0.952**	-0.963**	0.922**	0.974**	0.978**	0.973**	-0.900**	-0.048
Length			0.888**	0.588*	-0.728**	-0.524	0.848**	0.659*	0.675*	0.711**	-0.349	0.601*
Strength				0.759**	-0.807**	-0.668*	0.861**	0.732**	0.772**	0.805**	-0.516	0.669*
Elong					-0.951**	-0.983**	0.892**	0.957**	0.980**	0.977**	-0.625**	0.058
P						0.942**	0.969**	-0.984**	-0.987**	-0.982**	0.889**	0.788**
ACS							-0.865**	-0.961**	-0.977**	-0.964**	0.965**	-0.139
ACSW								0.952**	0.950**	0.960**	-0.773**	0.042
DEGREE									0.991**	0.985**	-0.920**	0.035
MR										0.996**	-0.918**	0.037
MP											-0.886**	0.102
REV												0.670*

According to relationship between fibre maturity (degree of thickening, Area secondary cell wall, maturity ratio and maturity percent) and fibre mechanical and physical properties. The correlation Showed highly significant positive relationship with fibre strength, fibre length and elongation%. It worthy to mention that Both of micronaire values and maturity measurements are affected by the amount of cellulose deposited in the fibre and this reflected on length and strength.

The relative importance of fibre fine structural to fibre strength:-

Applying the stepwise analysis regression coefficients, the partial correlation determined the excluded character to build up the best model describes the relationship between fibre strength and other characters in this study. It is clear from table (3) that number of convolutions proved to be the best one variable contributing to fibre strength, R^2 = 0.53. Perimeter and number of convolutions were the two best variable, R^2 = 0.74. Perimeter, degree of thickening and number of convolutions were the three best variables, R^2 = 0.97 compared to 0.98 in the full model. This the results confirmed by [24].

Table (3) : the relative importance of fibre microscopic properties, fibre length and elongation to fibre strength:-

No. of X included	R^2	r	Equation
X_5	0.53	0.73	$Y= 30.07 +0.29 X_5$
X_1, X_5	0.74	0.86	$Y= 53.82 -0.478 X_1 +0.28 X_5$
X_1,X_3, X_5	0.97	0.98	$Y= 51.10 - 0.612 X_1 + 12.06X_3 +0.26 X_5$
X_1, X_3,X_4, X_5	0.98	0.99	$Y= 63.97 - 0.698 X_1 + 8.91 X_3 - 0.535X_4 +0.357X_5$

X_1: Perimeter X_4: Number of reversals
X_2: matyrity ratio X_5: number of convolutions
X_3: degree of thickening Y: Fiber strength

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