

A COMPARATIVE STUDY OF THE SPECIFIC SURFACE AREA OF SOME EGYPTIAN COTTON VARIETIES BEFORE AND AFTER CHEMICAL TREATMENTS UNDER DIFFERENT MATURITY LEVELS

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ABSTRACT

Purpose: The specific surface area (SSA) is an important structural feature that affects how cotton fibers interact with dyes, finishing agents, and moisture. Because SSA influences mass transfer, it is closely linked to textile processing efficiency. However, there is limited quantitative analysis of SSA across different cotton varieties, maturity levels, and treatment conditions. This study measures SSA differences among selected Egyptian cotton varieties, looks at how fiber maturity affects SSA, evaluates the impact of chemical treatments on fiber structure, and compares the reliability of two SSA measurement methods.

Design and methods: The study used three Egyptian cotton varieties: extra Giza 93 (extra-long, extra-fine staple), Super Giza 94 (long staple), and Giza 98 (long staple). All samples were homogenized and conditioned under standard conditions ($20 \pm 1^\circ\text{C}$, $65 \pm 2\%$ relative humidity). Maturity ratios were measured and grouped using an image analyzer, and samples were classified as Immature, Medium, or High maturity based on international standards. Fibers underwent scouring and mercerization, and some were dyed. SSA was measured using both the Worley method and methylene blue adsorption. Mechanical and physical properties were tested with standard textile methods. Statistical analysis determined the significance of the results.

Findings: SSA values obtained from the Worley method decreased with increasing maturity, ranging from approximately 0.85 to $1.45 \text{ m}^2/\text{g}$. In contrast, methylene blue adsorption yielded higher values (45 – $120 \text{ m}^2/\text{g}$), reflecting internal surface accessibility. Mercerization increased SSA by up to 35% in immature fibers. Mature fibers showed higher strength but lower accessibility. A statistically significant interaction ($p < 0.05$) was observed between fiber maturity and treatment. The results show that there exists a strong correlation between the structure of fibers, specific surface area, and their mechanical properties. A higher specific surface area, especially considering internal surfaces, helps in improving the uptake of dyeing agents and water molecules. But although high crystallinity is good for improving tensile strength, it is also responsible for reducing accessibility.

Originality/value: This study is the first comparative evaluation that integrates structural and surface characterization methods to provide a thorough understanding of SSA behavior in Egyptian cotton. It highlights the importance of selecting appropriate processing conditions based on fiber maturity to improve textile performance. These findings guide the selection of cotton varieties suitable for chemical finishing and dyeing.

KEYWORDS: Egyptian cotton; specific surface area; methylene blue absorption; mercerization; maturity ratio; extra Giza 93, super Giza 94, Giza 98.

NOMENCLATURE

SSA: Specific surface area ($\text{m}^2 \cdot \text{g}^{-1}$)	MB: Methylene blue adsorption method
MIC: Micronair	UNT: Untreated (Control)
SD: Scoured and Dyed	MER: Mercerized (NaOH)
MD: Mercerization and Dyed	MR: Maturity ratio
HW: fiber linear density (hair weight)	

1. INTRODUCTION

Egyptian cotton (*Gossypium barbadense* L.) is well known for its superior fiber quality, with reference to length, fineness, and strength in the world of textiles. As a result of these qualities, it is highly sought after in high-end textile applications. Fiber quality improvement and maintenance are key targets in cotton research, especially properties with high impact upon processing performance (PP) and end-use functionality (EUF). Specific surface area (SSA) plays a key role among these properties. These determine how fibers interact with outside eventualities like colors, finishing chemicals, and moisture. The SSA value differed based on fiber morphology, with amorphous fibers containing internal pores that crystalline fibers lacked. (Abdel-Aziz et al. 2021; Abdel-Aty et al. 2022; Lamlom et al. 2024).

The properties of cotton fibers, including SSA, are influenced by multiple factors such as genetic background, environmental conditions, and agronomic practices. Egyptian cotton varieties such as Giza 93, Giza 94, and Giza 98 differ in their structural and physical characteristics, which in turn affect their behavior during chemical processing. These inherent differences are reflected not only in fiber dimensions but also in their accessibility and reactivity (Kaewprasit et al., 1999).

Fiber maturity is another key variable that affects cotton performance, including SSA, though its relationship to internal surface accessibility across varieties remains poorly understood. It represents the extent of secondary cell wall development and cellulose deposition during fiber growth. Immature fibers possess thin cell walls and higher internal void content, whereas mature fibers are characterized by thicker walls and increased crystallinity. Differences influence mechanical properties, dye uptake, and surface accessibility (Abdel-Aziz et al., 2021; Al-Ashwat, 1974).

Chemical treatments such as scouring and mercerization are routinely applied to boost fiber properties. Scouring removes non-cellulosic impurities, improving absorbency, while mercerization leads to fiber swelling and structural rearrangement of cellulose chains (Abdel-Aziz et al., 2021; Al-Ashwat, 1974). These processes modify both external and internal surfaces, thereby altering the effective SSA of the fibers (Meredith et al., 2018; Mohamed et al., 2022).

Cotton quality control focuses on improving fiber measurements and understanding how structure affects performance, with SSA being pivotal to dyeing efficiency (Kaewprasit et al., 1999). Fiber maturity, shaped by growth phases and harvest timing, influences strength and micronaire values. Immature fibers are weak, while over-mature ones resist dyeing (El Messirya et al., 2013; Mohamed et al., 2022; and El-Hashash et al., 2021). The maturity ratio, affected by genetics and environment, helps assess fiber quality (Abou-Bakr et al., 2023; El-Hashash et al., 2021; and Mansour et al., 2021). Mature fibers respond differently to chemical treatments, impacting SSA (Abdel-Aty et al., 2022; Abdel-Aziz, 2021). Nitrogen fertilization also affects maturity, though its role in SSA changes isn't fully understood (Abdel-Aty et al., 2022; Abdel-Aziz, 2021). Scouring and bleaching alter fiber properties; optimized treatments improve absorbency and whiteness without compromising strength (Abdel-Aziz, 2021; Meredith et al., 2018; Moses et al., 2014; Abdel-Aziz, 2015). Mercerization enhances luster, strength, and micronaire uniformity, with varied effects across cotton types (Al-Ashwat, 1974; Wakelyn et al., 2016).

The novelty of this study lies in the integrated evaluation of the specific surface area (SSA) of three commercially important Egyptian cotton varieties across different maturity levels before and after chemical treatments using two complementary measurement techniques, directly linking SSA changes to fiber maturity, mechanical behavior, and processing response. Unlike previous studies, which generally focused on a single cotton type or one SSA determination method, this work systematically compares the Worley and methylene blue adsorption methods while relating SSA changes to fiber maturity, mechanical behavior, and chemical processing. This integrated approach provides practical guidance for selecting suitable cotton fibers and processing conditions to improve textile performance.

2. MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 COTTONS

Three Egyptian cotton varieties were selected for this investigation: extra Giza 93 (extra-long extra-fine staple), Super Giza 94 (long staple), and Giza 98 (long staple).

2.1.2 SAMPLE PREPARATION AND CONDITIONING

Lint samples were collected from yield trials associated with breeding and genetic purity programs conducted at the Cotton Research Institute, Agricultural Research Center, Giza, Egypt, during the 2023 growing season. Before testing, all samples were carefully homogenized and conditioned under standard atmospheric conditions ($20 \pm 1^\circ\text{C}$ and $65 \pm 2\%$ relative humidity). This step ensured consistency and minimized variability in subsequent measurements (ASTM, 2005, D1776-05).

2.1.3 FIBER CHARACTERIZATION

2.1.3.1 MICRONAIRE AND MATURITY ASSESSMENT

Micronaire values were measured using an HVI system to represent fiber fineness and maturity. The maturity ratio was further determined using sodium hydroxide swelling combined with image analysis techniques. (BS 3085:1968). Based on these values, samples were categorized into three maturity levels: Immature, medium, and high maturity level Figure1, in accordance with the universal classification of cotton maturity (Uster manual 2001), which is: (ASTM, 2005. D1776-05).

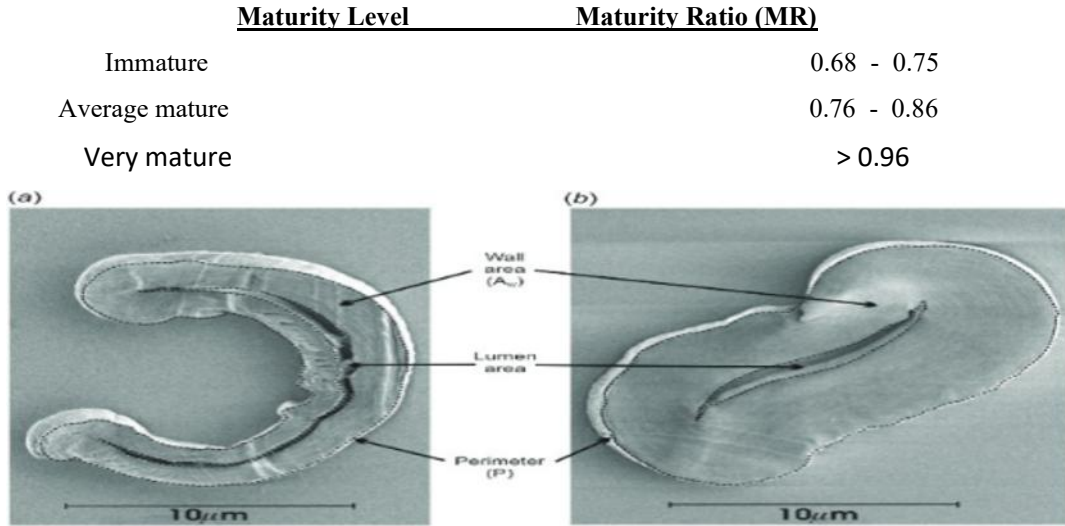


Figure 1: Cross-sectional views of (a) immature and (b) mature cotton fibers illustrating the measurements necessary for determining the extent of cell wall thickening.

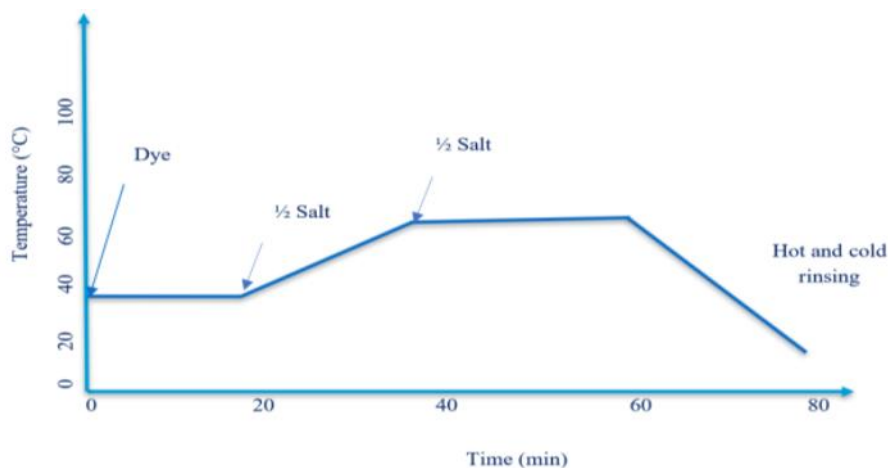
2.1.3.2 MECHANICAL PROPERTIES

The Stelometer instrument was used to measure flat bundle strength and elongation percentage, following (ASTM: D1445-1982) standards. The effect of fiber number in the Stelometer bundle test on breaking force, fiber strength, and elongation was examined across different maturity levels. A total of 10 – 15 tests were conducted for each maturity level of three cotton varieties, ensuring specimen weights were consistent at 270 ± 5 mg. The breaking force for each test was recorded in kilogram-force (kgf), and bundle strength (tenacity) was calculated using the formula $T=f/m15$, where f is the breaking force, m is the mass in milligrams, T is the tenacity in gf/tex, and 15.00 is the specimen length in millimeters. The linear density measured for each sample was used to determine the number of fibers in each bundle, calculated using the equation $N=m/HW 15.00$.

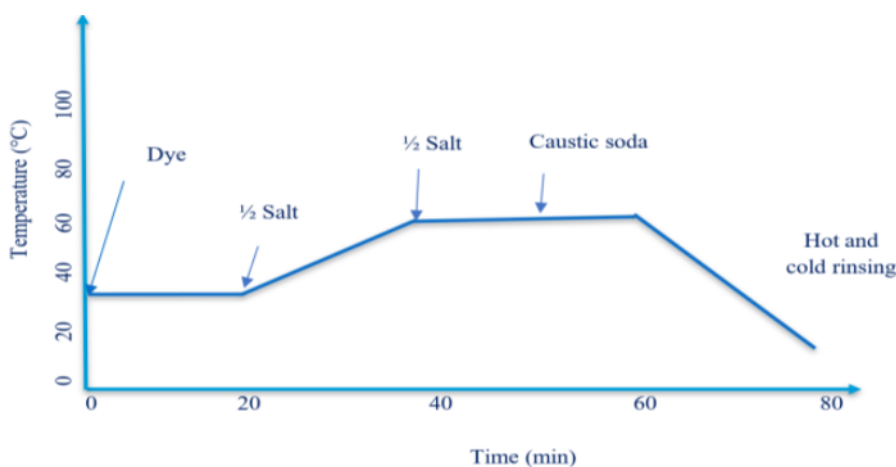
2.1.4 CHEMICAL TREATMENTS

1. **Scouring:** Fibers were treated in a sodium hydroxide solution at an elevated temperature to remove natural impurities, followed by thorough rinsing and neutralization with 0.25 g/L wetting agent; 3 % sodium hydroxide; L.R: 1:20; temperature: 90°C; time: 60 min. (Abdel-Aziz, 2015).
2. **Mercerization:** During this process, the fiber samples were immersed in a 20% sodium hydroxide solution at room temperature for 2 minutes. Afterward, the samples were rinsed with distilled water. Any residual alkali in the fibers was removed by soaking them in a 1% aqueous hydrochloric acid (HCl) solution for 5 minutes. Ultimately, the samples were dried in an oven at 100°C for 60 minutes. The mercerization process was executed in line with the methodology specified in (Abdel-Aziz, 2021).
3. **Dyeing:** A reactive dye was utilized to achieve a red color (C.I. Reactive Red 120- RR195) - Commercial name Remazol Red H6BN (DyStar) for scoured samples, and blue (C.I. Reactive Blue 19 - RB222) - Commercial name Sunfix Navy Blue SB (Oh Young) for mercerized samples. In the reactive dyeing bath, cotton fibers of various types at different stages of maturity were dyed, scoured, and mercerized using a 3% solution of (reactive red for scouring fibers) and (reactive blue for mercerized fibers), maintaining a liquor ratio of 1:30, as per the standard method illustrated in Figures (2, 3). Subsequently, the dyed fibers were rinsed with hot water, then with cold water, and finally air-dried. According to (Bahlool, 2019).

All treated samples were dried under controlled conditions (20°C, 65% relative humidity) before testing.

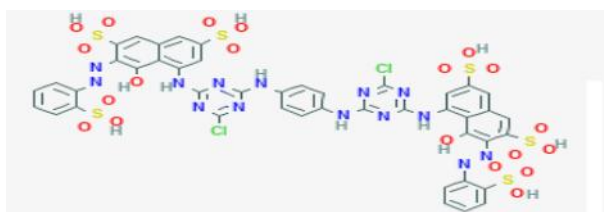


(a) Scoured and Dyed (SD)

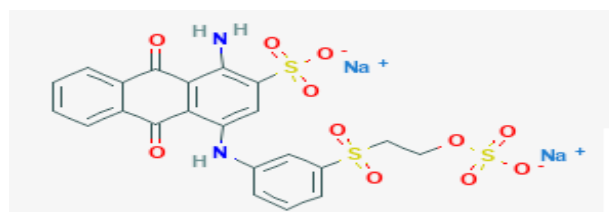


(b) Mercerization and Dyed (MD)

Figure 2: (a) Scouring followed by (C.I. Reactive Red 12) reactive dyeing cycle of cotton fibers, (b) mercerization followed by (C.I. Reactive Blue 19) reactive dyeing cycle of cotton fibers.



C.I. Reactive Red 12



C.I. Reactive Blue 19

Figure 3: Molecular structure of dyes

2.1.5 SPECIFIC SURFACE AREA MEASUREMENT

a) Specific surface area measured by the Worley method (*Worley et al., 1975*)

This approach was implemented by utilizing the Worley formula. The formulas are derived from the micronaire values. The specific surface area determined by the method of Worley et al. ($\text{mm}^2 \text{mm}^{-3}$) was converted to ($10^{-3} \text{ km}^2 \text{kg}^{-1}$) using the sample room volume of the micronaire instrument (ASTM D1448) to enable a direct comparison between the Worley equation (volume-based, mm^2/mm^3) and the mass basis using the Micronaire chamber volume mm^3 and the sample weight. The converted values were then expressed in the same units as the Methylene Blue method ($10^{-3} \text{ km}^2 \text{kg}^{-1}$), allowing both methods to be directly compared. The conversion was performed by dividing the SSA values obtained from the Worley equation by the volume of the Micromat measuring chamber (24.5 cm^3), which was calculated from the chamber dimensions using the cylinder volume equation ($V=\pi r^2 h$). This conversion follows the standard geometry of the Micromat chamber used for Micronaire measurements.

b) Absorption of Methylene Blue

SSA was also determined using the adsorption of methylene blue, assuming monolayer coverage on the fiber surface. The amount of dye absorbed was measured with a spectrophotometer, allowing calculation of accessible surface area.

Two standard cotton samples, one UNT and one MER, were evaluated for specific surface area for each variety and maturity level used using the methylene blue adsorption method at 25°C, as described by (Abdel-Aziz, 2015). The concentration of the methylene blue solution used ranged from 0.004 to 0.18 g/L. The absorption of methylene blue at equilibrium (pH 7, 25 °C, with an initial concentration of 200 mg•L⁻¹ and a liquor ratio of 1:100) was translated into an apparent specific surface area (SSA) predicated on a mono-layer coverage assumption of 1.30 nm² for each MB molecule. The absorption isotherms were conducted as follows: 2 g of cotton fibers were placed in 250 mL of a methylene blue solution with a known concentration. Accordingly, the mixture was stirred with a rod until the cotton fibers were completely immersed in the dye solution. The solution was maintained at 25°C and continuously agitated at 180 rpm for 24 hours. The quantity of methylene blue absorbed by the cotton was then determined by calculating the difference in methylene blue concentration before and after absorption. The concentrations of the methylene blue solutions were obtained by measuring their absorbance at 660 nm using spectrophotometer (UV WINLAB). (Kaewprasit et al., 1998).

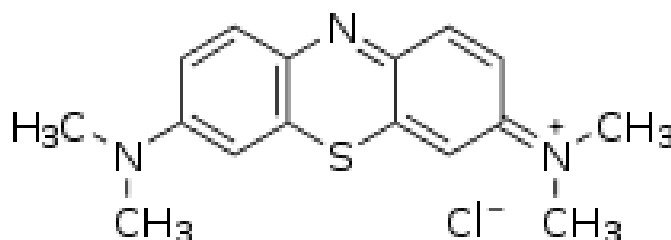


Figure 4: Chemical structure of Methylene blue

Although scoured-dyed (SD) and mercerized-dyed (MD) samples were prepared for evaluating mechanical and physical properties, SSA measurements were intentionally limited to untreated (UNT) and mercerized (MER) fibers because the objective was to evaluate the direct effect of mercerization on fiber surface accessibility. Dyeing introduces adsorbed colorants that may interfere with accurate SSA determination, particularly in the methylene blue adsorption method.

2.1.6 STATISTICAL ANALYSIS

All experiments were conducted using a randomized complete design with four replicates by Software SPSS v.26.0. Statistical significance was evaluated using analysis of variance (ANOVA), and mean comparisons were performed using the least significant difference (LSD) test at a 5% probability level. (Snedecore et al., 1986).

3. RESULTS AND DISCUSSION

3.1 DETERMINATION OF SPECIFIC SURFACE AREA (SSA)

The data presented in Table 1 showed significant differences in the mean values of specific surface area (SSA) due to maturity levels (M), chemical treatments (T), and their interactions (M × T), as indicated by the LSD values at the 0.05 probability level. To avoid repetition and table crowding, the LSD values for Tables 2 to 4 are shown in Table 1.

3.1.1 SSA ESTIMATED BY THE WORLEY METHOD (WORLEY ET AL., 1975)

The specific surface area derived from micronaire values using the Worley equation showed a clear and consistent decline as fiber maturity increased across all examined cotton varieties in Table 2. This trend can be explained by the progressive development of the secondary cell wall, which reduces the relative surface area per unit mass as fibers become thicker and denser (Kaewprasit et al., 1998).

$$SSA = 1904.8 + 169.32 (\text{mic}) - 1047.4 (\text{mic})^{0.5}$$

Where:

- (SSA): Stands for Specific Surface Area in mm² mm⁻³
- (Mic.): Represents The Micronaire Reading.

Among the tested varieties, Giza 93 consistently exhibited higher SSA values compared to Giza 94 and Giza 98. This observation reflects differences in fiber fineness and morphology, as finer fibers provide a larger surface-to-mass ratio (Abdel-Aziz, 2021).

Chemical treatments also influenced the measured SSA values. Untreated fibers exhibited higher SSA than mercerized samples when evaluated by the Worley method. This apparent decrease is primarily related to the limitations of the method itself, which mainly captures external surface characteristics under dry conditions. During mercerization, fiber swelling and internal structural changes occur, increasing internal porosity while reducing the measurable external surface. As a result, the method underestimates the total accessible surface area after treatment (Schenek, 2019).

The effect of maturity further supports this interpretation. Fibers with higher maturity exhibited lower SSA values due to increased crystallinity and reduced pore accessibility. In contrast, immature fibers, which possess thinner walls and a more open internal structure, displayed relatively higher surface accessibility when measured using external-based techniques (Sief et al., 1995).

SSA decreased with increasing maturity across all varieties. This trend is attributed to progressive thickening of the secondary cell wall, which reduces surface area per unit mass. Untreated fibers exhibited higher SSA values than mercerized fibers when assessed by this method, reflecting its limitation in capturing internal structural changes induced by chemical treatment.

3.1.2 SSA DETERMINED BY METHYLENE BLUE ADSORPTION

In contrast to the Worley method, the methylene blue adsorption technique produced significantly higher SSA values across all samples in Table 3. This difference arises from the ability of dye molecules to penetrate both external and internal surfaces in a denser aqueous environment (Kaewprasit et al., 1998). The data in Table 3 show differences in the means of specific surface area to maturity levels (M), chemical treatments (T), and their interactions, the significance of means are indicated in Table 1 by the mentioned values of LSD at 0.05.

The specific surface area was determined using the equation provided by (Gregg et al., 1982).

$$S_{MB} = N_g x a_{MB} x 10^{-20}$$

M

Where:

- (**S_{MB}**): Represents the specific surface area in **10⁻³ km² kg⁻¹**
- (**N_g**): Denotes the number of methylene blue molecules adsorbed at the monolayer of fibers in **kg kg⁻¹ (or N_g = N_m*M)**
- (**a_{MB}**): Indicates the occupied surface area of a single methylene blue molecule, which is **=197.2 Å²** by (Graham, 1955).
- (**N**): Signifies Avogadro's number, **6.02 x 10²³ mol⁻¹**
- (**M**): Refers to the molecular weight of methylene blue, which is **373.9 g mol⁻¹**

Following chemical treatment, particularly mercerization, SSA values increased noticeably for all cotton varieties and maturity levels. This increase can be attributed to fiber swelling under alkaline conditions, which disrupts hydrogen bonding and reduces crystallinity. As a result, previously inaccessible regions within the fiber become available for adsorption.

The effect was especially pronounced in immature fibers. Their less compact structure allows greater expansion during treatment, leading to a larger increase in accessible surface area. However, mature fibers maintained comparable or, in some cases, slightly higher absolute SSA values due to their more developed and stable structure.

Less mature fibers generally exhibited greater relative increases in surface accessibility after mercerization, whereas medium- and fully mature fibers often maintained higher absolute SSA values depending on cotton variety.

SSA values obtained using methylene blue adsorption were substantially higher than those from the Worley method due to the ability of dye molecules to access internal pores. Mercerization increased SSA through fiber swelling and partial disruption of hydrogen bonding, thereby enhancing internal accessibility. The magnitude of increase was more pronounced in immature fibers, consistent with their less compact structure. (Abdel-Aziz, 2021; Clark, 2011; Moses et al., 2014; Wakelyn et al., 2016).

These findings suggest that methylene blue adsorption provides a more realistic representation of functional surface area, particularly when evaluating chemically treated fibers.

Impact of UNT and MER of cotton fibers on the specific surface area as determined by the Absorption of methylene blue

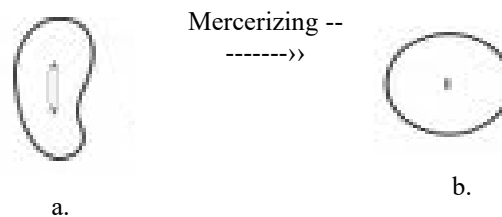


Figure 5: Representation of the cotton fibers cross-section before mercerization (a.) and after mercerization (b.)

3.1.3 COMPARATIVE EVALUATION OF SSA MEASUREMENT METHODS

A direct comparison between the two methods highlights substantial differences in measured SSA values. The Worley method consistently produced lower values, whereas methylene blue adsorption reflected significantly higher surface areas (Table 4).

This discrepancy arises from the fundamental difference in measurement principles. The Worley method is based on air permeability and primarily represents the external fiber surface under dry conditions. In contrast, methylene blue adsorption occurs in a liquid environment where water molecules disrupt intermolecular hydrogen bonds, allowing dye molecules to access internal pores (Kaewprasit *et al.*, 1998; Gregg *et al.*, 1982).

This specific difference is fundamentally linked to the measurement environment. The Worley method operates under dry conditions and primarily reflects external surface characteristics. In contrast, methylene blue adsorption occurs in a liquid medium, where water molecules help the opening of internal pores by weakening intermolecular hydrogen bonds. This allows dye molecules to access regions that remain inaccessible in dry conditions (Graham, 1955; Kaewprasit, 2004).

As a result, the methylene blue method is more suitable for evaluating treated fibers, where internal structural changes play a major role. On the other hand, the Worley method remains useful for rapid assessment of untreated cotton under standardized conditions.

Accordingly, method selection should align with the intended application: rapid external assessment (Worley) versus functional accessibility assessment (methylene blue).

The maturity of fiber had a significant impact on the response of cotton to chemical treatments ($p < 0.05$). Notably, less mature fibers exhibited larger relative increases in specific surface area (SSA) following chemical treatments, especially during mercerization and post-mercerization dyeing. Nevertheless, in absolute terms, mature fibers retained higher final SSA values after treatments, attributable to their superior initial values and enhanced structural integrity throughout the treatment process. The interaction between fiber maturity and the effectiveness of treatments was particularly pronounced in mercerization; this conclusion is in agreement with (Elhawary, 2021).

The methylene blue method measures both external and internally accessible surfaces, whereas the Worley equation estimates only the external surface derived from micronaire values. Therefore, the superiority of the methylene blue method in evaluating chemically modified fibers is related to its greater sensitivity to internal structural changes rather than higher numerical values alone.

3.2 INFLUENCE OF FIBER MATURITY AND CHEMICAL TREATMENTS

The data in Table (5 a) and Table (5 b) revealed significant differences in the means of MIC, MR, HW, breaking load, bundle strength, elongation percentage, number of fibers, and specific surface area attributable to maturity levels (M), chemical treatments (T), and their interactions, except for the effect of chemical treatment on MR, which was not significant for G.93.

The mean values of MIC, MR, and HW across the three maturity levels are presented in Table (5a). The means for MIC values were 3.03 (immature), 3.30 (average mature), and 3.85 (very mature). The MR means were 0.75, 0.88, and 0.98 for these maturity levels, while the HW means were 97.66, 110.09, and 129.42 m/tex.

Table (5b) presented the Stelometer test results, illustrating the influence of specimen weight on breaking force, fiber strength, and elongation percentage. The number of fibers for a constant bundle weight of 270 ± 5 varied significantly, recorded as 191.28 for immature, 166.84 for average mature, and 139.87 for very mature levels. This conclusion is in harmony with (ASTM, 2005; D1776-05; El-Marakby *et al.*, 2011; Sief *et al.*, 2022).

The study showed that the number of fibers in each bundle decreased as maturity increased. This decline indicates a relationship between fiber maturity and the number of fibers needed for a constant bundle weight, due to thicker secondary walls and more substantial individual fibers. The average bundle strength and elongation percentage from the stelometer test varied at different maturity stages: immature (34.46 g/tex, 6.57%), average mature (36.24 g/tex, 6.55%), and very mature (37.04 g/tex, 6.15%) for the fiber strength and fiber elongation, respectively. Environmental factors affect fiber strength and cellulose deposition, contributing to variations in mechanical properties.

The SSA values recorded were 599.94, 560.86, and 503.56 for immature, average mature, and very mature levels, respectively. This may be due to the reduction in specific surface area (SSA) that occurs during maturation is associated with the thickening of the secondary wall and an increase in crystallinity, which restricts pore accessibility.

Chemical treatments impacted various traits, with values recorded for untreated (UNT), Mercerized (MER), securing and dyeing (SD), and mercerized and dyeing (MD) at immature, average mature, and very mature stages. Hair weight (HW) increased with maturity across treatments. Micronaire (MR) showed no significant differences, but mercerization combined with dyeing improved micronaire due to fiber swelling and increased dye penetration. Fiber count decreased with chemical treatments, with mercerized fibers having higher micronaire but lower counts. The SD treatment yielded the best results for breaking force, bundle strength, and fiber characteristics, with mercerization creating more accessible but weaker fibers due to reduced crystallinity.

Data shown in Tables (6a, 6b) and (7a, 7b) illustrate the effects of fiber maturity levels and chemical treatments on micronaire value, hair weight, breaking load, bundle strength, elongation, fiber number per bundle for G.94 and G.98. micronaire values increased from immature to very mature levels, rising from 4.25 to 5.18 in Giza 94 and from 4.25 to 5.33 in Giza 98, similarly hair weight increased from 132.24 to 164.19 m/tex in Giza 94 and from 144.17 to 188.04 m/tex in Giza 98. Chemical treatments induced significant variations in all properties, with consistent trends observed for varieties.

Micronaire measurements showed a notable increase after mercerization treatment compared to other chemical treatments, likely due to fiber swelling, which reduces the number of fibers per weight. However, the maturity ratio (MR %) didn't exhibit significant differences among treatments, MR is primarily determined by cellulose deposition during fiber development. Fiber fineness followed the same trend as micronaire values, since both parameters are affected by fiber porosity.

In stelometer tests assessing bundle strength and elongation, specimen weight significantly influenced breaking force and strength. The number of fibers in the test specimens varied with maturity, with immature fibers averaging 130.91 and 137.58 in G. 94 and G. 98, respectively, while mature and very mature fibers showed lower counts, declining to 79.28 and 100.15 in both varieties.

For G. 94, the fiber number across four treatments at the immature level ranged from 142.12 to 122.41, while G. 98 showed values from 176.38 to 98.84. At the very mature level, the fiber number averaged 105.44 to 90.74 in G.94 and from 116.33 to 68.04 in G.98. The reduction in fiber count after mercerization is attributed to structural changes induced by fiber swelling.

Bundle strength in G. 94 generally increased with maturity, with values rising from 31.45 g/tex (immature) to 32.62 g/tex (very mature). In contrast, bundle elongation decreased with maturity. The SD treatment provided the highest strength values recorded: 34.06, 34.42 and 35.44 g/tex at the three maturity levels, respectively, while MER resulted in the lowest values. G.98 had the same trend as G.94. A negative correlation was observed between bundle strength and elongation percentage. (Bange, *et al.*, 2009, Thibodeaux, *et al.*, 1999, Somashekhar, *et al.*, 1977 and Bugao, *et al.*, 2009) have reported that cotton fiber maturity is a key determinant of fiber mechanical properties.

The interaction between level and treatment significantly influenced specific surface area, confirming that fiber response to treatments depends on maturity. In immature fibers, SSA decreased from 506.46 (UNT) to 409.34 m²/g (MD) in G.94, while from 572.98 to 396.82 m²/g in G.98, whereas in very mature fibers, it declined from 415.95 to 374.39 m²/g. In G.94 and from 444.87 to 359.66 m²/g in G.98. This indicates that immature fibers have thicker walls and compact crystalline structures. Therefore, maturity level should be considered when selecting appropriate treatments. Practically, this highlights the need to optimize treatment conditions based on maturity to balance property enhancement with preservation of porous structure; these results are consistent with (Abdel-Aziz, 2021; Abdel-Aziz & Abdel-Twab, 2021).

3.2.1 EFFECT OF FIBER MATURITY

Fiber maturity had a significant impact on both structural and mechanical properties as maturity increased:

- Micronaire values increased
- Fiber linear density increased.
- The number of fibers per bundle decreased.

These changes reflect the continued deposition of cellulose and progressive thickening of the secondary cell wall. As fibers become more mature, their individual mass increases, resulting in fewer fibers within a bundle of constant weight.

From a mechanical perspective, bundle strength improved with increasing maturity, while elongation tended to decrease. This behavior is consistent with the transition from flexible, thin-walled fibers to more rigid and compact structures.

In terms of surface characteristics, increased maturity led to reduced surface accessibility. This is primarily attributed to higher crystallinity and reduced pore size, which limit the availability of active sites for chemical interaction.

3.2.2 EFFECT OF CHEMICAL TREATMENTS

Chemical treatments induced noticeable changes in fiber structure and performance, with each treatment exhibiting distinct effects:

3.2.2.1 DYEING AFTER SCOURING (SD)

This treatment improved fiber cleanliness and surface activation, resulting in moderate increases in SSA and enhanced mechanical properties.

3.2.2.2 MERCERIZATION (MER)

Mercerization caused significant fiber swelling and structural rearrangement. While this increased internal surface area and accessibility, it also reduced crystallinity, which contributed to a slight decrease in mechanical strength .

3.2.2.3 DYEING AFTER MERCERIZATION (MD)

This treatment combined the effects of both processes, leading to increased apparent density and modified airflow characteristics, as reflected in higher microneaire values .

Among the treatments, mercerization had the strongest influence on SSA, particularly when evaluated using the methylene blue method. The transformation of cellulose structure and the formation of amorphous regions significantly enhanced accessibility.

3.2.3 INTERACTION BETWEEN MATURITY AND TREATMENT

The interaction between fiber maturity and chemical treatment was statistically significant. Immature fibers showed greater relative changes in SSA following treatment, particularly during mercerization and subsequent dyeing. Their less developed structure allows for greater expansion and modification.

In contrast, mature fibers exhibited more stable behavior, with smaller relative changes but higher overall structural integrity. This suggests that treatment conditions should be carefully adjusted depending on fiber maturity to achieve optimal performance without compromising strength.

3.2.4 RELATIONSHIP BETWEEN STRUCTURAL AND MECHANICAL PROPERTIES

The results highlight a strong connection between fiber structure, specific surface area, and mechanical behavior. Higher SSA, especially when internal surfaces are considered, enhances dye uptake and moisture absorption. But increased crystallinity, while beneficial for strength, reduces accessibility. Similarly, fiber swelling improves chemical reactivity but may lead to reduced mechanical stability.

An inverse relationship was observed between fiber count in a bundle and maturity level. As fibers become thicker, fewer are present in a bundle of constant weight, which influences strength measurements.

These observations confirm that SSA should not be considered in isolation. A thorough evaluation of fiber quality requires simultaneous consideration of structural, surface, and mechanical properties.

4. CONCLUSION

This study demonstrated that fiber maturity and chemical treatments significantly influence the specific surface area (SSA) of Egyptian cotton fibers, with the magnitude of these effects depending on both cotton variety and the measurement technique employed. Mercerization altered fiber structure and accessibility, leading to measurable changes in SSA compared with untreated fibers. Although the Worley and methylene blue methods exhibited similar overall trends, the methylene blue adsorption method provided a more comprehensive assessment of fiber surface accessibility because it reflects both external and internally accessible surfaces.

A major contribution of this work is the integrated comparison of two SSA determination methods across three Egyptian cotton varieties representing different maturity levels. This approach provides a better understanding of how fiber

morphology and chemical modification influence surface characteristics and demonstrates that the selection of an appropriate SSA measurement technique is essential for accurate fiber characterization.

The findings of this study provide valuable information for optimizing cotton processing, particularly in dyeing, finishing, and other chemical treatments where fiber surface accessibility plays a critical role. The proposed comparative methodology may also support future studies aimed at improving the utilization and quality of Egyptian cotton for high-value textile applications.

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REFERENCES

- [1] Abdel-Aty, M. S., Youssef, S. A., Yehia, W. M. B., et al. (2022). Genetic analysis of yield traits in Egyptian cotton crosses (*Gossypium barbadense* L.) under normal conditions. *BMC Plant Biology*, 22, Article 462. <https://doi.org/10.1186/s12870-022-03839-8>
- [2] Abdel-Aziz, H. M. (2015). Biochemical studies on some textiles of Egyptian cotton varieties [Unpublished doctoral dissertation]. Cairo University.
- [3] Abdel-Aziz, H. M. (2021). Chemical modification treatments on extra-long Egyptian cotton fiber. *International Journal of Advanced Science and Engineering*, 8(1), 2090–2098.
- [4] Abdel-Aziz, H. M., & Abdel-Twab, R. M. (2021). Study of chemical and technological properties of some Egyptian cotton varieties fertilized with different nitrogen sources and chemically treated. *Egyptian Journal of Agricultural Sciences*, 72, 1–11. <https://doi.org/10.21608/EJARC.2021.210202>
- [5] Abou-Bakr, H. A., El-Sayed, H. A., & El-Sayed, S. A. M. (2023). Genetic analysis for yield, its components, and fiber quality traits in Egyptian cotton crosses. *Journal of Natural Fibers*, 20(2), Article 2272844.
- [6] Al-Ashwat, A. A. (1974). Effect of sodium hydroxide and hydrogen peroxide on structural and mechanical properties of Egyptian cotton fiber and yarn [Unpublished doctoral dissertation]. Cairo University.
- [7] American Society for Testing and Materials. (2005). Standard practice for conditioning and testing textiles (ASTM D1776-05). ASTM International.
- [8] Bahloul, S. O. (2019). Dyeing of cotton fabric with reactive dye using infrared heating technique. *Egyptian Journal of Agricultural Research*, 97(1).
- [9] Bange, M. P., Constable, G. A., Gordon, S. G., Long, R. L., Naylor, G. R. S., & Vander Sluijs, M. H. J. (2009). A guide to improving Australian cotton fiber quality (2nd ed.). Cotton Catchment Communities CRC.
- [10] British Standards Institution. (1974). Cotton fiber maturity test (BS 3085). BSI.
- [11] El-Hashash, E. F., El-Attar, A. B., & Agwa, A. M. (2021). Estimation of genetic parameters of yield and fiber traits in Egyptian cotton crosses. *Journal of Cotton Research and Development*, 35(2), 123–135.
- [12] El-Hashash, E. F., El-Attar, A. B., Agwa, A. M., & El-Maksoud, M. M. A. (2021). Pedigree selection for yield and fiber traits in Egyptian cotton. *Asian Journal of Research in Crop Science*, 6(4), 1–17.
- [13] Elhawary, I. A. (2021). Effect of mercerization on surface area and dyeability of Egyptian cotton. *Journal of Textile Science & Engineering*, 11(3), 112–125.
- [14] El-Marakby, A. M., Seif, M. G., Mohamed, A. Z. A., & Younis, S. A. (2011). Fiber fineness and maturity in Egyptian cotton genotypes. *Egyptian Journal of Plant Breeding*, 15(3), 13–32.
- [15] El-Messiry, M., & Abd-Ellatif, S. A. M. (2013). Characterization of Egyptian cotton fibers. *Indian Journal of Fibre & Textile Research*, 38, 109–113.
- [16] Graham, D. (1955). Characterization of physical adsorption systems. *Journal of Physical Chemistry*, 59, 896–900.
- [17] Gregg, S. J., & Sing, K. S. W. (1982). Adsorption, surface area, and porosity (2nd ed.). Academic Press.
- [18] Kaewprasit, C. (2004). Relationship between cotton fiber surface area and properties. *Textile Research Journal*, 73, 730–734.
- [19] Kaewprasit, C., Hequet, E., Abidi, N., & Gourlot, J. P. (1998). Methylene blue adsorption method for surface area measurement. *Journal of Cotton Science*, 2, 164–173.
- [20] Kaewprasit, C., Hequet, E., Abidi, N., & Gourlot, J. P. (1999). Specific surface area of cotton fiber. In *Proceedings of the Beltwide Cotton Conference* (pp. 718–720).
- [21] Lamloom, S. F., Yehia, W. M. B., Kotb, H. M. K., et al. (2024). Genetic improvement of Egyptian cotton for yield and fiber quality. *Scientific Reports*, 14, Article 7723. <https://doi.org/10.1038/s41598-024-57676-w>
- [22] Mansour, H., & Farag, S. (2021). Impact of location on Egyptian cotton quality. *Bulletin of the National Research Centre*, 45(1), 1–9.
- [23] Meredith, W. R., & Bradow, J. M. (Eds.). (2018). *Cotton fiber chemistry and technology*. CRC Press.
- [24] Mohamed, A. A., El-Hadidy, A. E., & El-Sayed, H. A. (2022). Technological evaluation of Egyptian cotton varieties. *Alexandria Science Exchange Journal*, 43(3), 451–462.
- [25] Moses, J. J., & Venkataraman, V. K. (2014). Mechanical and surface properties of chemically treated cotton fabric. *International Journal of Engineering Research & Technology*, 3(5), 2395–2411.

- [26] Raes, A. T. J., & Verschraege, L. (1981). Cotton fiber maturity analysis. *Journal of the Textile Institute*, 72, 191–200.
- [27] Sief, M. G., El-Hariry, H. M., & Ghorab, M. A. (1995). Fiber strength relations in cotton. In *Proceedings of the Beltwide Cotton Conference* (pp. 1168–1170).
- [28] Sief, M. G., Shahat, S. A., & Arafa, H. M. (2022). Impact of fiber maturity on cotton properties. *IOSR Journal of Polymer and Textile Engineering*, 9(4), 13–23.
- [29] Snedecor, G. W., & Cochran, W. G. (1986). *Statistical methods* (7th ed.). Iowa State University Press.
- [30] Somashekhar, T. H., Narasimham, T., Kulshreshtha, A. K., & Dweltz, N. E. (1977). Analysis of cotton fiber maturity. *Journal of Applied Polymer Science*, 21, 1519–1529.
- [31] Thibodeaux, D. P., & Rajasekaran, K. (1999). Development of cotton fiber maturity standards. *Journal of Cotton Science*, 3, 188–193.
- [32] Wakelyn, P. J., Bertoniere, N. R., French, A. D., et al. (2016). *Cotton fiber chemistry and technology*. CRC Press.
- [33] Worley, S., Krowicki, R. S., & Cox, E. L. (1975). Conversion of micronaire readings to surface area values. *Textile Research Journal*, 45, 326–332.

Table 1: L.S.D. at 5% level of significance

L.S.D. at 5%	Giza 93		Giza 94		Giza 98	
	Converted SSA (Worley)	SSA (MB)	Converted SSA (Worley)	SSA (MB)	Converted SSA (Worley)	SSA (MB)
L.S.D Maturity level (m)	0.35	0.53	0.29	0.36	0.22	0.24
L.S.D. Treatment (t)	0.28	0.42	0.25	0.30	0.22	0.27
L.S.D. m $\times$ t	0.67	0.70	0.42	0.50	0.30	0.34

Table 2: SSA values (Worley method) for untreated and mercerized cotton at different maturity Levels

Variety	Maturity level	Micronire	Chemical preparation	SSA (mm ² mm ⁻³)	SSA conversion to (10 ⁻³ km ² kg ⁻¹)
Giza 93	Immature	2.40	UNT	688.54	27.99
		3.10	MER	585.55	23.80
	Medium Maturity	2.80	UNT	626.26	25.46
		3.30	MER	560.86	22.80
	High Maturity	3.30	UNT	560.86	22.80
		4.00	MER	487.28	19.81
Giza 94	Immature	3.40	UNT	506.46	20.59
		4.40	MER	452.76	18.40
	Medium Maturity	3.80	UNT	444.87	18.08
		5.10	MER	402.97	16.38
	High Maturity	4.60	UNT	415.95	16.91
		5.30	MER	390.9	15.89
Giza 98	Immature	3.50	UNT	572.98	23.29
		4.70	MER	429.89	17.48
	Medium Maturity	4.00	UNT	506.46	20.59
		5.00	MER	409.34	16.64
	High Maturity	4.80	UNT	444.87	18.08
		5.60	MER	374.39	15.22

LSD values for maturity level (M), treatment (T), and M $\times$ T interaction at $P \leq 0.05$ are presented in Table 1.

Table 3: The impact of chemical treatment of cotton fibers on the specific surface area values, as determined by the methylene blue absorption method, for UNT and MER cotton.

Variety	Maturity levels	Micronire	Chemical preparation	SMB (10 ⁻³ km ² kg ⁻¹)
Giza 93	Immature	2.40	UNT	80.33
		3.10	MER	83.47
	Medium Maturity	2.80	UNT	85.46
		3.30	MER	89.32
	High Maturity	3.30	UNT	83.45
		4.00	MER	86.88
Giza 94	Immature	3.40	UNT	68.77
		4.40	MER	73.41
	Medium Maturity	3.80	UNT	82.59
		5.10	MER	85.22
	High Maturity	4.60	UNT	74.36
		5.30	MER	81.85
Giza 98	Immature	3.50	UNT	62.34
		4.70	MER	65.72
	Medium Maturity	4.00	UNT	74.94
		5.00	MER	81.68
	High Maturity	4.80	UNT	64.18
		5.60	MER	68.74

LSD values for maturity level (M), treatment (T), and M × T interaction at P ≤ 0.05 are presented in Table 1.

Table 4: Comparing the specific surface areas determined by both the Worley method and the methylene blue absorption technique.

Variety	Maturity levels	Micronire	Chemical preparation	SSA Worley (10 ⁻³ km ² kg ⁻¹)	SMB (10 ⁻³ km ² kg ⁻¹)
Giza 93	Immature	2.40	UNT	27.99	80.33
		3.10	MER	23.80	83.47
	Medium Maturity	2.80	UNT	25.46	85.46
		3.30	MER	22.80	89.32
	High Maturity	3.30	UNT	22.80	83.45
		4.00	MER	19.81	86.88
Giza 94	Immature	3.40	UNT	20.59	68.77
		4.40	MER	18.40	73.41
	Medium Maturity	3.80	UNT	18.08	82.59
		5.10	MER	16.38	85.22
	High Maturity	4.60	UNT	16.91	74.36
		5.30	MER	15.89	81.85
Giza 98	Immature	3.50	UNT	23.29	62.34
		4.70	MER	17.48	65.72
	Medium Maturity	4.00	UNT	20.59	74.94
		5.00	MER	16.64	81.68
	High Maturity	4.80	UNT	18.08	64.18
		5.60	MER	15.22	68.74

LSD values for maturity level (M), treatment (T), and M × T interaction at $P \leq 0.05$ are presented in Table 1.

Table 5 a: Impact of maturity levels and chemical treatments on Micronaire reading and hair weight in Giza 93 ELS Egyptian cotton variety.

Maturity levels	Treatments	MIC	MR	HW	Worley SSA
Immature	UNT	2.40	0.75	71.84	688.54
	MER	3.10	0.74	104.23	585.55
	SD	3.00	0.74	95.47	598.61
	MD	3.60	0.75	119.10	527.05
	Mean	3.03	0.75	97.66	599.94
Average mature	UNT	2.80	0.88	87.59	626.26
	MER	3.30	0.88	118.50	560.86
	SD	3.30	0.87	107.28	560.86
	MD	3.80	0.88	126.97	506.46
	Mean	3.30	0.88	110.09	563.61
Very mature	UNT	3.30	0.95	107.28	560.86
	MER	4.00	0.98	136.76	487.28
	SD	3.90	0.98	130.91	496.70
	MD	4.20	0.99	142.73	469.41
	Mean	3.85	0.98	129.42	503.56
LSD 5%	Maturity levels(M)	0.11	0.03	3.42	49.72
	Treatments	0.09	NS	4.00	55.09
	M x T	0.12	NS	4.55	69.82

Table 5 b: Impact of maturity levels and chemical treatments on breaking load, bundle weight, number of fibers, bundle strength, and elongation % in Giza 93 ELS Egyptian cotton variety.

Maturity levels	Treatments	Breaking Load (kg)	Bundle Weight (mg)	Number of fibers HW by Micromat	Bundle Strength (g/tex)	Elongation
Immature	UNT	5.30	272.00	252.41	35.93	6.47
	MER	4.78	270.00	172.70	31.28	7.44
	SD	5.33	269.67	188.31	38.85	5.49
	MD	4.80	271.00	151.69	31.78	6.87
	Mean	5.05	270.67	191.28	34.46	6.57
Average mature	UNT	5.45	270.00	205.50	36.93	6.40
	MER	5.19	270.00	151.90	33.82	7.44
	SD	5.40	271.00	168.41	39.30	5.36
	MD	4.93	269.56	141.53	34.90	7.00
	Mean	5.24	270.14	166.84	36.24	6.55
Very mature	UNT	5.13	270.00	163.74	39.14	5.40
	MER	4.65	270.00	131.62	34.48	7.98
	SD	5.52	270.67	137.84	40.00	4.20
	MD	4.73	270.33	126.27	34.54	7.01
	Mean	5.01	270.25	139.87	37.04	6.15
LSD 5%	Maturity levels(M)	0.16	NS	3.69	0.58	0.19
	Treatments	0.14	NS	2.53	0.49	0.13
	M x T	0.3	NS	4.2	0.78	0.29

Table 6 a: Impact of maturity levels and chemical treatments on Micronaire reading and hair weight in Giza 94 ELS Egyptian cotton variety.

Maturity levels	Treatments	MIC	MR	HW	Worley SSA
Immature	UNT	3.40	0.72	103.35	506.46
	MER	4.40	0.72	140.65	452.76
	SD	4.20	0.73	137.73	469.41
	MD	5.00	0.72	147.23	409.34
	Mean	4.25	0.72	132.24	459.49
Average mature	UNT	3.80	0.87	126.97	444.87
	MER	5.10	0.88	172.00	402.97
	SD	5.00	0.87	138.79	409.34
	MD	5.30	0.87	156.04	390.90
	Mean	4.80	0.87	148.45	412.02
Very mature	UNT	4.60	0.87	154.54	415.95
	MER	5.30	0.98	170.10	390.90
	SD	5.20	0.97	164.23	396.82
	MD	5.60	0.98	167.87	374.39
	Mean	5.18	0.97	164.19	394.52
LSD 5%	Maturity levels(M)	0.12	0.03	3.60	49.00
	Treatments (T)	0.11	NS	4.10	57.09
	M x T	0.14	NS	4.70	66.82

Table 6 b: Impact of maturity levels and chemical treatments on breaking load, bundle weight, number of fibers, bundle strength, and elongation % in Giza 94 ELS Egyptian cotton variety.

Maturity levels	Treatments	Breaking Load (kg)	Bundle Weight (mg)	Number of fibers HW by Micromat	Bundle Strength (g/tex)	Elongation
Immature	UNT	3.23	270.67	142.12	32.6	5.89
	MER	3.68	270.00	127.98	28.24	8.01
	SD	4.85	270.89	131.12	34.06	4.74
	MD	3.73	270.33	122.41	30.89	5.85
	Mean	3.87	270.47	130.91	31.45	6.12
Average mature	UNT	3.72	270.29	116.60	32.4	5.45
	MER	3.75	271.00	100.70	30.47	7.56
	SD	4.10	271.83	104.01	34.42	4.89
	MD	3.64	271.67	97.35	31.5	5.31
	Mean	3.80	271.20	104.67	32.20	5.8
Very mature	UNT	3.60	269.33	105.44	33.47	5.21
	MER	3.90	269.00	94.34	29.26	6.86
	SD	3.66	269.33	98.60	35.44	4.31
	MD	3.92	269.33	90.74	32.3	5.84
	Mean	3.77	269.25	97.28	32.62	5.56
LSD 5%	Maturity levels(M)	0.15	NS	2.81	0.52	0.21
	Treatments (T)	0.12	NS	2	0.41	0.14
	M x T	0.25	NS	3.37	0.72	0.31

Table 7 a: Impact of maturity levels on Micronaire reading and hair weight in Giza 98 LS Egyptian cotton variety.

Maturity levels	Treatments	MIC	MR	HW	Worley SSA
Immature	UNT	3.50	0.72	126.97	572.98
	MER	4.70	0.73	149.87	429.89
	SD	3.60	0.73	137.73	527.05
	MD	5.20	0.74	162.11	396.82
	Mean	4.25	0.73	144.17	481.69
Average mature	UNT	4.00	0.88	154.54	506.46
	MER	5.00	0.87	179.41	409.34
	SD	4.10	0.88	174.23	478.19
	MD	5.40	0.87	189.98	385.19
	Mean	4.63	0.88	174.54	444.80
Very mature	UNT	4.80	0.98	170.29	444.87
	MER	5.60	0.99	190.10	374.39
	SD	5.00	0.99	182.11	409.34
	MD	5.90	0.99	209.67	359.66
	Mean	5.33	0.98	188.04	397.07
LSD 5%	Maturity levels(M)	0.13	0.02	3.50	55.56
	Treatments (T)	0.11	NS	4.23	60.56
	M x T	0.14	NS	4.75	69.89

Table 7 b: Impact of maturity levels on breaking load, bundle weight, number of fibers, bundle strength, and elongation % in Giza 98 LS Egyptian cotton variety.

Maturity levels	Treatments	Breaking Load (kg)	Bundle Weight (mg)	Number of fibers HW by Micromat	Bundle Strength (g/tex)	Elongation
Immature	UNT	4.17	273.43	176.38	28.99	7.70
	MER	3.34	273.00	121.44	26.69	8.63
	SD	3.75	274.50	153.65	30.80	6.37
	MD	3.40	270.00	98.84	27.23	8.49
	Mean	3.67	272.73	137.58	28.43	7.80
Average mature	UNT	4.96	270.67	142.12	28.90	9.00
	MER	4.42	268.91	104.23	27.04	8.56
	SD	4.93	269.74	129.57	30.97	7.81
	MD	4.55	268.00	94.04	27.95	8.50
	Mean	4.72	269.33	117.49	28.72	8.47
Very mature	UNT	4.03	269.67	116.33	31.80	7.10
	MER	4.20	270.00	94.74	28.07	7.98
	SD	4.27	270.50	103.50	33.20	5.57
	MD	4.23	270.60	86.04	28.85	8.10
	Mean	4.18	270.19	100.15	30.48	7.19
LSD 5%	Maturity levels(M)	0.12	NS	2.99	0.42	0.21
	Treatments (T)	0.1	NS	2.87	0.39	0.17
	M x T	0.19	NS	3.47	0.52	0.36