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**Research Article**

# Assessment of the adaptability and spectroscopic characterization of cotton plants and their properties in the semi-arid region of El-Meita, Khenchela (Algeria)

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El Meita.

**Abstract:**

Cotton is an important crop for the economy and textile sector in arid and semi-arid areas. This study evaluates the physical and chemical quality of cotton fibers grown in the El Meita region of Khenchela, Algeria, focusing on fiber fineness, length, and strength, as well as chemical analysis of the soil and fibers using Fourier transform infrared spectroscopy (FTIR). Samples taken from several experimental plants showed notable variability in fiber quality, highlighting the impact of local soil and climate conditions. FTIR analysis detected essential organic and inorganic compounds, such as lignin, cellulose, calcium, and silica, revealing positive relationships between various soil elements and the mechanical properties of the fibers. These results provide crucial insights for the selection and improvement of local varieties, enabling increased fiber productivity and quality while promoting sustainable agriculture of cotton in the Khenchela region.

## 1. Introduction

The growing impacts of climate change pose serious challenges to agriculture in arid and semi-arid regions, compromising the stability, adaptability, and sustainability of economic and agri-food systems in these vulnerable areas [1]. Climate change—particularly through changes in water availability, soil degradation, and declining agricultural production—significantly affects the sustainability of cropping systems in such environments [2]. To address these constraints and optimize the use of limited resources, it is crucial to adopt resilient crops such as cotton and apply appropriate agronomic practices to ensure both economic and social security. Cotton (Gossypium hirsutum L.), persistent plant with unlimited growth, can grow continuously under ideal climatic conditions. However, this growth pattern can lead to delayed crop maturity [3,4]. As one of the world's principal fiber crops, cotton plays a vital role in the textile industry and is an important source of income for several developing countries. Approximately 99% of cotton producers worldwide are smallholders, with nearly 66% located in Asian countries such as India, China, Pakistan, Uzbekistan, Turkmenistan, and Tajikistan. The remaining 33% are found in regions such as South America—particularly Brazil—as well as Egypt and West Africa [5,6,7]. In Egypt, cotton is of great national economic importance as a strategic crop supporting the country's textile industry [8,9]. Globally, cotton is grown on approximately 30 million hectares, representing about 2.5% of the world's arable land—mainly as part of crop rotation systems [10]. Nearly 20 million farmers practice cotton monoculture, while approximately 30 million integrate it into crop rotation systems [11]. However, since cotton is primarily a summer crop, agricultural soils are often left fallow during the winter months, raising environmental concerns. In addition, cotton generates relatively little post-harvest residue compared to other crops, limiting soil cover and organic matter return [12]. Cotton varieties differ significantly in terms of fiber characteristics such as length, strength, fineness, and maturity, which determine their suitability for the textile industry and influence the quality of finished products [13]. These fiber properties are highly sensitive to environmental conditions—including temperature, soil quality, and water availability—which play a crucial role in their development and overall quality [14]. In addition, cotton yield and productivity are influenced by various climatic and agronomic factors, including planting density, sowing date, irrigation practices, and fertilization methods. Among these, the sowing date is particularly decisive, as it directly affects plant development, final yield, and fiber quality. However, determining the optimal sowing period remains difficult due to seasonal variations in soil and air temperature, as well as fluctuations in solar radiation during the growing season [15,16]. In this context, the present study aims to assess the adaptability and agronomic potential of cotton to the semi-arid to arid climatic and soil conditions of the region located south of the wilaya of Khenchela (Algeria). The cotton variety used—Giza 95, originally from Egypt—is known for its high yield potential and tolerance to heat and water stress, making it particularly suitable for cultivation trials in arid environments.The specific objectives of this first experiment conducted in El-Meita on cotton cultivation are as follows: (i) to evaluate the success of cotton cultivation by estimating its yield, (ii) to examine the quality of the fibers produced under these environmental conditions through their physicochemical, FTIR spectroscopic, and morpho-anatomical characteristics; (iii) study the influence of soil properties and climatic conditions on cotton growth, and identify key factors that can improve its productivity.This research is based on a set of in-depth analyses, including the physicochemical characterization of soils and irrigation water, as well as the application of Fourier transform infrared spectroscopy (FTIR) to the soil and cotton plants. The study also includes an analysis of the physicochemical and morpho-anatomical properties of harvested cotton fibers.

## 2. Materials and Methods

### Site description and geographical context

The study area is located on the El-Meita plateau, in the southeastern part of the wilaya of Khenchela (Algeria), and is classified as a semi-arid region. This plateau extends between latitudes 34°30′ and 35°00′ North, and longitudes 6°78′ and 7°30′ East, covering an area of approximately 2,350 km². The altitude varies between 1,212 and 1,248 meters above sea level, indicating a relatively flat topography with gentle undulations [17]. The region stands out for its strategic geographical location and unique environmental characteristics, making it particularly well suited to agricultural and environmental research in arid and semi-arid areas (Fig. 1). The climate is characterized by hot, dry summers from May to October, while winter temperatures can drop to around 5°C. Annual rainfall varies from around 200 mm in the semi-arid areas of the north to just 60 mm in the desert areas of the south. Despite these harsh climatic conditions, agricultural activities continue—mainly wheat and barley cultivation—supported by underground irrigation systems. Wells in the region reach depths of between 30 and 200 meters, enabling agricultural production even under conditions of water stress [17,18].

### Experimental design

The field trial was conducted during the 2024 growing season in the semi-arid climate of the El-Meita region, located in the southern part of the Khenchela province in Algeria. In order to improve soil aeration and physical structure, the soil was plowed to a depth of approximately 30 cm, while ensuring that adequate moisture levels were maintained. To facilitate planting, improve soil drainage, and ensure even distribution of irrigation water, the land was leveled and arranged in rows. The Egyptian cotton variety Giza 95 was chosen as the plant material for this study. The experimental field consists of five rows, each 10 meters long, with 80 cm spacing between rows and 30 cm spacing between plants within each row. Sowing took place on March 15, and harvesting was carried out manually using traditional methods, with a first harvest in September and a second in October. A single nitrogen fertilizer application was made in the form of ammonium nitrate ($NH_4NO_3$, 46% N) at a rate of 2 kg/40 m², or approximately 0.70 kg of pure nitrogen. The application was made once, 45 days after sowing.

### Physicochemical characterization of soil

A granulometric analysis was carried out to determine the distribution of soil particles—clay, silt, and sand—revealing useful information about soil texture and its compatibility with cotton cultivation. At the same time, a physicochemical analysis was used to assess the fundamental properties of the soil, including pH, salinity (measured by electrical conductivity), total and active calcium content, organic matter, and concentrations of essential nutrients such as available phosphorus, potassium ($K_2O$), and nitrogen in the form of nitrate ($NO_3^-$). These analyses were carried out at the laboratory of the National Technical Institute for Soils, Irrigation and Drainage (INSID), under the supervision of the Algerian Ministry

**Characterization of the physicochemical quality of water**

The water used in the El-Meita region in the form of groundwater, extracted through boreholes, was analyzed to assess its quality and suitability for agricultural irrigation. The analysis focused on several key parameters such as pH, electrical conductivity (EC), bicarbonate ($HCO_3^-$) and chloride ($Cl^-$) concentrations, and sedimentation rate, with the aim of anticipating potential impacts on crop growth. These investigations were conducted at the National Technical Institute for Soils, Irrigation and Drainage (INSID), under the auspices of the Ministry of Agriculture.

**Evaluation of climate parameters**

The climatic characteristics of the study area were assessed using data obtained via the WorldClim platform [19], which compiles key meteorological parameters. This analysis took into account variables such as temperature, precipitation, humidity, and wind speed, providing a comprehensive and up-to-date overview of climate trends and local environmental conditions from March to October 2024.

**Fourier Transform Infrared Spectroscopy (FTIR)**

Fourier transform infrared spectroscopy (FTIR) is an analytical method used to identify functional groups present in the samples studied. FTIR spectra were obtained using a Perkin-Elmer spectrometer with a resolution of 8 $cm^{-1}$, in transmission mode, in the spectral range from 4000 to 400 $cm^{-1}$. Approximately 100 µg of sample was mixed with 23 ± 2 mg of potassium bromide (KBr) and then cold-pressed using an isostatic press at 150 MP to form a pellet 200–250 µm thick. Each infrared spectrum represents the absorbance ($A = -\log (I/I_0)$) as a function of the incident wave number. This method was applied to soil, plant leaf, and cotton fiber samples to highlight the main chemical and structural variations. Furthermore, the use of the second derivative allows the minima corresponding to the precise frequencies of the main absorption peaks to be exploited. This method improves spectral resolution for better peak detection and chemical component identification, particularly in complex mixtures.

**Physical analysis of cotton fibers and estimation of yield**

The physical properties of cotton fibers—length, strength, uniformity, maturity, and micronaire—were evaluated using a High-Volume Instrument (HVI) model 1000. These properties are used to calculate the Spinning Consistency Index (SCI) and Fiber Quality Index (FQI) in order to predict the quality of cotton fibers and their suitability for spinning. Also estimate the ginning yield and seed weight. Prior to analysis, fiber samples were conditioned for at least 24 hours under controlled conditions (temperature of 24 ± 1°C and relative humidity of 64 ± 2%). The evaluation was carried out at the National Agricultural Research Center (ARC) in Giza, Cairo, Egypt.

## 3. Results and discussion.

**Soil particle size distribution and physicochemical profile**

Representative soil samples were collected prior to sowing at the experimental site, then prepared and analyzed according to standardized protocols. The results of this analysis are presented in Table 1.

The results of the physical and chemical analyses of the soil reveal a pH of 8, indicating slight alkalinity. Although this value remains tolerable for cotton cultivation, it can reduce the availability of certain essential trace elements such as iron, zinc, and manganese [20]. On the other hand, high electrical conductivity (3.42 dS/m) is a major constraint. Although cotton is known for its relative tolerance to salinity [21], several studies show that high salinity levels can negatively affect germination, growth, and, above all, the technological characteristics of the fibers. The Giza 95 variety, although adapted to semi-arid environments, could see its length and fineness compromised under these conditions [22].Total and active limestone content is within the normal range, ensuring sufficient calcium intake, which is essential for cell wall development and fiber strength [23]. However, the low organic matter content (1.26%) reflects limited fertility, reducing the soil's ability to provide nutrients and retain moisture. In addition, the levels of available phosphorus (157 ppm), potassium (51.5 ppm), and nitrate nitrogen (2.4 ppm) are below the thresholds required for optimal growth. These nutrients play a central role in vegetative growth, photosynthesis, fruiting, and, above all, fiber quality, influencing fineness, strength, and elasticity [24]. These results suggest that, for the Giza 95 variety, sustainable fertilization and monitoring of soil salinity are necessary to preserve productivity and maintain the technological quality of the fibers.

**Physicochemical quality of water**

According to the results of the analysis carried out (Table 2), the water quality is considered suitable for cotton irrigation in the El-Meita region. Indeed, the pH, electrical conductivity, and bicarbonate and chloride concentrations are all within the recommended ranges. However, the salt content (1362 ppm), although moderately higher than the ideal range of 500 to 1000 ppm, could slightly reduce yields if appropriate irrigation management techniques are not implemented.

**Climate data conditions in the region of El-Meita**

Climate data (Fig.3) for the El-Meita region indicate a semi-arid environment characterized by high temperatures in summer and a marked water deficit, which directly influences the management of crops such as cotton and other sensitive plants. Maximum temperatures reaching 35°C in July, combined with moderate minimum temperatures of around 10°C in February and March, provide a favorable period for seed germination, as mild temperatures promote the enzymatic activation necessary for this process [25]. However, the significant temperature contrast between seasons can cause stress on plants during their active growth phase, making it necessary to carefully control irrigation to compensate for the water deficit and avoid heat stress [26]. Low summer humidity leads to high evaporation rates, increasing water demand and highlighting the importance of efficient irrigation techniques. On the other hand, higher humidity in fall can increase the risk of plant diseases [27].Finally, atmospheric stability, often associated with dry and constant conditions, shows that agricultural planning must be adapted to these climatic constraints. Rigorous planning, from sowing in March to harvesting in October, is essential to optimize growth and yield, reduce losses due to abiotic stress, and ensure final product quality [28]. These results confirm the importance of integrated water and input management in semi-arid agricultural systems, in line with previous climate recommendations [29].

**Fourier Transform Infrared Spectroscopy (FTIR)**

FTIR spectra were analyzed separately for soil, fibers, and cotton leaves in order to highlight the main chemical and structural variations specific to each type of sample.

**FTIR spectrum of the soil**

FTIR analysis of soil samples reveals a particularly diverse mineralogical and organic composition, reflecting the combined influence of pedogenic processes and agricultural practices. The bands between 3700–3000 $cm^{-1}$, attributed to ν(O–H) vibrations, confirm the abundance of structural hydroxyls in clays such as illite, kaolinite, and montmorillonite, but also reveal the presence of humic and phenolic organic compounds [30]. This duality reflects a strong interaction between the mineral fraction and organic matter, which is essential for soil aggregate stabilization and water retention. The signature between 3000 and 2800 $cm^{-1}$, associated with aliphatic ν(C–H), highlights the role of organic inputs (lipids, plant waxes, microbial residues) in soil carbon dynamics [31]. These signals indicate not only persistent biological activity but also continuous recycling of organic matter.The 1800–1500 $cm^{-1}$ range, dominated by ν(C=O) and δ(O–H) bands, illustrates the contribution of organic acids and humic substances [32], key elements in nutrient complexation and metal mobility. The band at 1635 $cm^{-1}$ could also reflect the presence of carbonates and structured water, suggesting a water and chemical balance specific to this type of soil.In the 1450–1350 $cm^{-1}$ range, the presence of δ(C–H) and nitrate signals probably reflects the use of nitrogen fertilizers [33]. This indicates a direct anthropogenic impact linked to historical agricultural practices on the plot. The remarkable intensity of the bands between 1200 and 900 $cm^{-1}$, dominated by ν(Si–O) vibrations from silicates and ν(P–O) vibrations from phosphates, highlights the mineralogical richness in quartz and clays, but also reveals a clear trace of past use of phosphate fertilizers [34]. This observation highlights the persistence of agricultural traces in the soil, despite changes in crops, particularly the shift from wheat to other production systems.Then the bands below 900 $cm^{-1}$, particularly those associated with Fe–O bonds, confirm the presence of iron oxides such as hematite and goethite [35], known to play a central role in sorption processes and soil color. The possible presence of gypsum identified between 1100–600 $cm^{-1}$ [36] reflects local salinity conditions or exogenous deposits, reinforcing the hypothesis of a combined influence of environmental factors and agricultural practices. Thus, all of these results show that the spectroscopic composition of the soil reflects a complex interaction between natural mineralogy and anthropogenic inputs. The simultaneous presence of clays, organic matter, carbonates, sulfates, and traces of fertilizer indicates active soil dynamics, influenced by both environmental conditions and the history of agricultural use.

**FTIR spectra of cotton shrub leaves**

FTIR analysis of the cotton leaf (Figure 5a) shows a set of specific absorption bands, demonstrating the diversity of functional groups present in the leaf structures. In the 3700–3000 $cm^{-1}$ region, a broad band structured around 3432 $cm^{-1}$ is assigned to the ν(O–H) stretching vibrations of bound water molecules, hydrophilic polysaccharides, and phenolic and alcoholic groups involved in leaf defense and hydration mechanisms [49]. The bands between 2956, 2924, and 2854 cm⁻¹ correspond to the aliphatic ν(C–H) vibrations of the lipid chains, indicating the presence of cuticular waxes and membrane lipids that play a protective role against water loss and environmental stress [50]. The region 1800–1400 $cm^{-1}$ shows clear bands at 1662, 1549, 1515, and 1453 $cm^{-1}$, associated respectively with ν(C=O) vibrations of carbonyl groups and δ(C–H) vibrations, typical of phenolic compounds, flavonoids, and lignin, key molecules in antioxidant defense processes and wall stiffening [51]. The 1384–1238 $cm^{-1}$ range reveals bands characteristic of C–O–C and C–OH bonds, a signature of cellulose, polyholosides, and hemicellulose, essential constituents of leaf tissue [52]. Between 1200 and 900 $cm^{-1}$, strong absorption bands at 1157, 1078, 1020, and 1000 $cm^{-1}$ are attributed to ν(C–O) vibrations of complex carbohydrates and polysaccharides, confirming the leaf's richness in cellulose and parietal components. Below 900 $cm^{-1}$, particularly at 837, 764, 672, 602, and 535 $cm^{-1}$, the bands observed indicate δ(C–H) deformation vibrations of aromatic cycles, as well as ν(M–O) vibrations (M = Si, Fe, P), which are due to the presence of mineral traces such as silicates, phosphates, or metal oxides [53] [54]. Thus, the FTIR spectrum reveals the complex biochemical composition of cotton leaves, dominated by cellulose, lignin, flavonoids, waxes, and phenolic compounds. The strong O–H band indicates a high state of hydration, while the lipid and aromatic signals highlight physiological functions of protection and adaptation.The FTIR spectrum therefore confirms the composition of the cotton leaf, including cellulose, lignin, flavonoids, and lipids. The broad water absorption band at 3432 $cm^{-1}$ indicates a high level of hydration. Lipids and waxes protect the leaf from excessive evaporation. The presence of signals linked to polyphenols also indicates natural antioxidant properties.

**FTIR spectrum of cotton fibers (Kh01)**

FTIR analysis of cotton fibers highlights the richness and purity of cellulose as the major component, which is consistent with previously reported results [53,54]. The presence of a broad band between 3500–3200 $cm^{-1}$, attributed to O–H stretching vibrations, confirms the formation of hydrogen bonds and highlights the hygroscopic state of the fibers, characteristic of hydrophilic polysaccharides [55]. This hygroscopic property is essential for textile and industrial applications, as it directly influences the water absorption and chemical reactivity of the fibers. Thus, the bands observed between 2962 and 2853 $cm^{-1}$, corresponding to aliphatic C–H vibrations of CH, $CH_2$, and $CH_3$ groups, highlight the carbohydrate nature of the cell walls [56], confirming the typical structural composition of cellulose and hemicellulose. Similarly, the bands at 1637 and 1454 $cm^{-1}$ reflect the C=O vibrations of the carbonyl groups and the C–H deformations, respectively, highlighting the hydrophilic nature and low lignin content of the fibers [57]. The almost total absence of lignin clearly distinguishes cotton fibers from those derived from wood, which explains their softness, flexibility, and suitability for certain chemical and mechanical transformations. Vibrations in the 1450–1200 $cm^{-1}$ region associated with $CH_2/CH_3$ and C–OH groups confirm the presence of cellulose and hemicellulose, while intense peaks between 1200 and 1000 $cm^{-1}$ indicate β-1,4 glycosidic bonds characteristic of the crystalline structure of cellulose [58,54]. This high crystallinity correlates with improved mechanical strength and increased thermal stability, two properties that are essential for industrial fiber applications. Finally, the bands below 900 $cm^{-1}$, corresponding to the vibrations of carbohydrate cycles and pyranose rings, confirm the structural nature of polysaccharides [59]. All of these observations indicate high cellulose purity, high crystallinity, and significant water absorption capacity, supporting previous conclusions [60].

**FTIR analysis of cotton seeds**

FTIR spectroscopic analysis of cotton seeds (Fig 8) reveals characteristic bands similar to those observed in fibers, particularly in the regions between 3500–3200 $cm^{-1}$ (stretching vibrations of O–H hydroxyl groups linked to hydrogen bonds), 2962–2853 $cm^{-1}$ (stretching vibrations of C–H bonds in CH, $CH_2$, and $CH_3$ groups), 1200–1000 $cm^{-1}$ (β-(1→4) glycosidic bonds typical of cellulose), and below 900 $cm^{-1}$ (vibrations associated with carbohydrate cycles and pyranose rings), confirming that cellulose is the main component [61]. Furthermore, unlike fibers, which consist mainly of almost pure cellulose, seeds have a more complex and heterogeneous biochemical matrix, comprising not only cellulose and hemicellulose, but also proteins, lipids (oils), traces of lignin, and phenolic compounds [62]. This molecular diversity is reflected in additional bands: the signal at 1637 $cm^{-1}$ and the region 1740–1700 $cm^{-1}$ are attributed to C=O vibrations of esters, lipids, and proteins [63]. In addition, the characteristic bands of amides I and II, located at 1650 and 1540 $cm^{-1}$ respectively, confirm the presence of proteins [64,65], while additional bands in the 2850–2920 $cm^{-1}$ range are linked to long aliphatic chains, signatures of triglycerides present in seed oils [66]. The crystallinity of cellulose in seeds generally appears to be lower than that of fibers, as evidenced by the broader and less intense signals recorded in the 1200–1000 $cm^{-1}$ region, which directly influences the physicochemical properties of seeds [67].

**FTIR analysis of the cotton capsule**

The results of the FTIR analysis of the cotton capsule reveal a structure dominated by cellulose and hemicellulose, with characteristic bands around 3400 $cm^{-1}$ (O–H), 2920 $cm^{-1}$ (C–H), 1635 $cm^{-1}$ (C=O), and 1050–1000 $cm^{-1}$ (glycosidic bonds). Compared to the fibers, which are almost entirely composed of crystalline cellulose, the capsule has a more heterogeneous composition including pectins, phenolics, and traces of lignin, giving it rigidity and mechanical strength. In contrast to seeds, it retains a similar polysaccharide base but with a higher proportion of secondary compounds, reflecting its role in protecting fibers and seeds. These chemical differences explain its mechanical properties and essential biological function [68, 69].

**FTIR analysis of scraped cotton bark**

FTIR analysis shows that the capsule and bark of cotton share a common lignocellulosic base, characterized by a broad O–H band (3500–3200 $cm^{-1}$), aliphatic C–H vibrations (2920–2850 $cm^{-1}$), and peaks associated with crystalline cellulose (1200–1000 $cm^{-1}$), confirming the presence of cellulose and hemicellulose. However, the bark exhibits more intense bands in the 1700–1600 $cm^{-1}$ region, related to C=O vibrations, indicating a higher content of lignin and phenolic compounds compared to the capsule. These results indicate that the bark plays a more pronounced protective role, with lignin and phenols contributing to mechanical rigidity and resistance to microbial degradation, which are essential for protecting the plant's internal tissues. These differences can be discussed in the context of the biological functions of each part of the plant, with the chemical composition reflecting variations in protection, thermal stability, and water absorption, which explains the specific use of each part in various industrial applications [70,71].

**Physical properties of cotton fibers**

The cotton fibers were tested in a specialized fiber analysis laboratory in Egypt, at the Cotton Research Institute, Agricultural Research Center (ARC), in Giza, Egypt. This part focused on seed cotton in order to evaluate the quality characteristics of Kh 01 cotton fibers. Table 1 shows several indicators that were used to measure this quality in order to predict the performance of cotton fibers, including fineness (Micronaire), maturity index, Upper Half Mean Length (mm) (UHML), uniformity index (UI%), fiber strength (STR), elongation (Elg), and degree of reflection and luster (Rd). These indicators are essential for determining their performance in the textile industry. These properties vary greatly depending on genotype, environmental conditions (climate, soil, agricultural management), and cultivation practices [63], which explains the notable differences observed between varieties such as Kh 01 and Giza 95. The quality characteristics of cotton fibers, such as length, strength, fineness, and uniformity, are particularly influenced by the interaction between genetics and the environment, and certain regions or innovative agricultural practices can significantly improve these parameters [72].The results obtained (Table 4) show that the Kh 01 variety has a significantly greater fiber length, with a difference of approximately 2 mm compared to other varieties, which is a notable advantage for textile applications. According to the Cotton Incorporated classification [73], the Giza 95 variety is considered a long-fiber cotton, confirming that Kh 01 falls into the same or a similar category, offering attractive properties for the production of high-quality yarns.The high uniformity index and superior tensile strength of Kh 01 are essential characteristics for ensuring yarn stability during spinning, a key criterion for the textile industry [74]. These mechanical properties reinforce the potential of Kh 01 for the production of durable and resistant textiles. In terms of agronomic aspects, the higher average boll weight (+2.6 g) and higher reflectance give Kh 01 a significant advantage in terms of yield and visual quality of the fibers, which is essential for commercialization and adaptation to semi-arid conditions [75]. However, the lower fiber fineness and elongation rate compared to Giza 95 suggest that Kh 01 fibers are rougher and less elastic, which may influence certain applications requiring high elasticity or a very soft feel [76].Furthermore, although Giza 95 has a higher +b yellowness rating, it also has a higher shredding rate, indicating greater material loss during industrial processing stages [77]. This result highlights the advantage of Kh 01 for industrial processing, limiting material losses and improving the efficiency of the spinning process.

**Fiber Quality Index (FQI)**

One of the first attempts to establish an aggregate criterion for assessing cotton fiber quality was the introduction of the Fiber Quality Index (FQI), formulated according to the relationship (1) proposed by the South India Textile Research Association (SITRA) [78]. This index combines several essential physical characteristics such as strength, length, and fineness of the fibers, with the aim of providing a comprehensive and synthetic measure of cotton fiber quality. Based on the results obtained by the high-throughput analyzer (HVI), the fiber quality index (FQI) is determined according to formula (2) [79].FQI = (fiber strength*length*uniformity*maturity coefficient)/fineness

$$FQI = (Str * UHML * UI * MR)/Mic \quad \textbf{(1)}$$

$$FQI = (UHML * UI * Str)/Mic \quad \textbf{(2)}$$

Although the Kh 01 variety has a Fiber Quality Index (FQI) of 154.75, which is lower than that of Giza 95 (172.4) [80], the Algerian variety (Kh 01) has a higher fiber length and retains interesting technological qualities. This difference reflects a slight superiority of Giza 95 in terms of overall fiber performance, particularly in terms of fineness and elongation.

**Consistency index (SCI)**

The consistency index (SCI) is a measure that can be predicted from the properties of the cotton sample using a regression model [81]. The SCI relationship is given by equation (3) :

$$SCI = -414.67 + 2.9*STR + 49.1*UHML + 4.74*UI - 9.32*MIC + 0.95*Rd + 0.36*b \quad \textbf{(3)}$$

The results show that the SCI values reported for the Giza 95 variety generally range between 147 and 159, which ranks it among the best long varieties for spinning according to international standards [22]. In comparison, the local variety Kh 01 also achieved a very satisfactory value (142.92), falling within the acceptable range for industrial use. This result is particularly important in semi-arid environments, where climatic and edaphic constraints strongly influence fiber quality [82].The consistency of the values obtained for Kh 01 demonstrates its good adaptation to arid conditions and its potential as a credible alternative to imported varieties. Its promising technological characteristics open up interesting prospects for its integration into local agricultural development strategies, thereby helping to reduce dependence on foreign seeds and strengthen agricultural security. Although Giza 95 remains an international benchmark for fiber quality and spinning suitability, Kh 01 demonstrates that selecting and promoting local varieties and improving the resilience of agricultural systems in semi-arid areas [83].

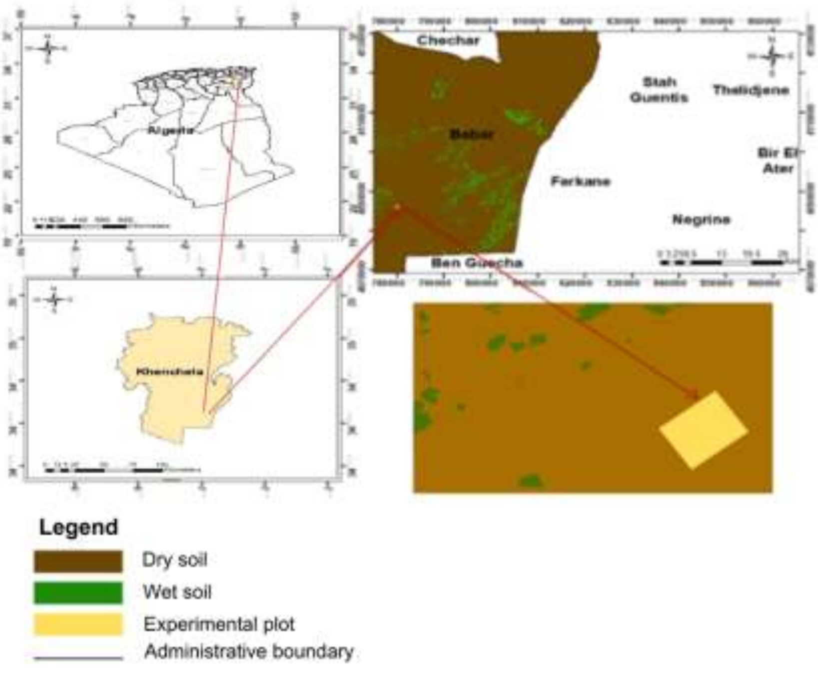


***Figure 1**: Geographical location of the study area*

***Table 1**. Physical and chemical properties of soil*

| Parameter | Value | Required level | Rating |
|---|---|---|---|
| PH<br>(1:2.5 soil-to-water ratio at 25 °C) | 8 | 6,5-7,5 | Slightly basic |

| | | | |
|---|---|---|---|
| Electrical Conductivity (EC, dS/m) 1:5 soil-to-water ratio at 25°C) | 3.42 | <0,6 | Very high |
| Total Limestone (%) | 15.81 | 5%-25% | Normal |
| Active Limestone (%) | 5.57 | < 8 | Normal |
| Organic Matter (%) | 1.26 | 1,5%- 2,5% | Low |
| Assimilable Phosphorus ($P_2O_5$, ppm) | 157.10 | De 180 à 220 ppm | Normal |
| $K_2O$ FAO SOP (Standard Operating Procedure) | 51.5 | 150-250 ppm | Very low |
| Nitrate Nitrogen ($N–NO_3^-$) Determined by Nitrate Check Method | 2.4 | 15-30 ppm | Very low |

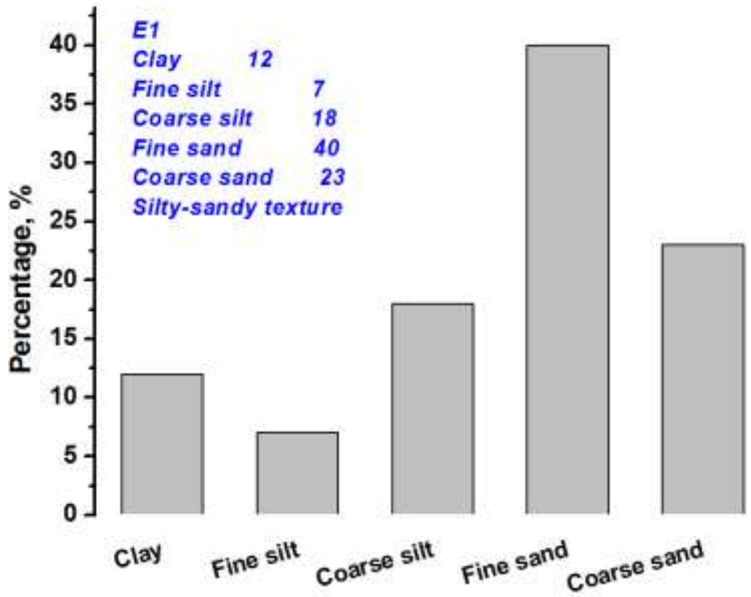


***Figure 2:*** *Diagram of soil texture analysis in the region of El-Meita Khenchela , Algeria*

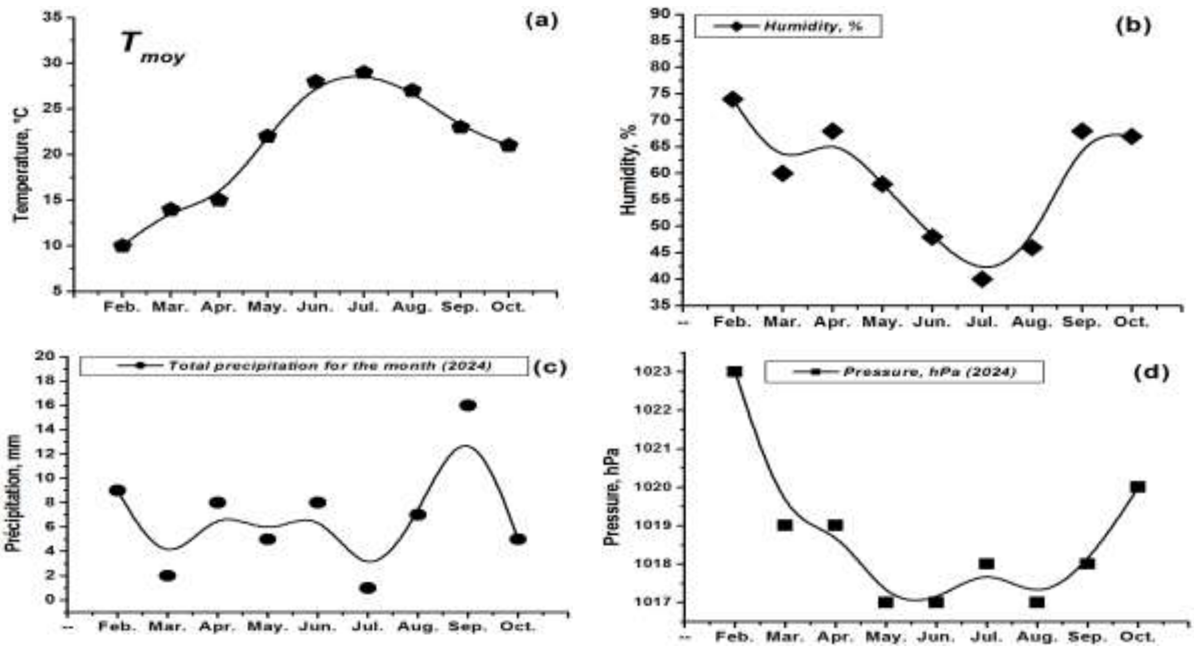


***Figure 3:*** *Climatic factors in the region of El-Meita (Khenchela, Algeria),* ***(a)*** *Temperature;* ***(b)*** *Humidity;* ***(c)*** *Precipitation;* ***(d)*** *Pressure.*

***Table 2**: Analysis of water samples collected in the region El-Meita*

| Parameter | Value | Required level | Rating |
|---|---|---|---|
| PH (2325$^0$C) | 7.09 | 6.5-8.4 | Conforming value |
| Ce (ds/m25°C) | 2.63 | 0.7-3 | Conforming value |
| $HCO^-_3$ (méq/l) | 2.3 | 1.5-8.5 | Conforming value |
| $CL^-$ (méq/l) | 6 | 3-10 | Conforming value |
| Salt concentration (ppm) | 1362 | 500-1000 | Slightly elevated value |

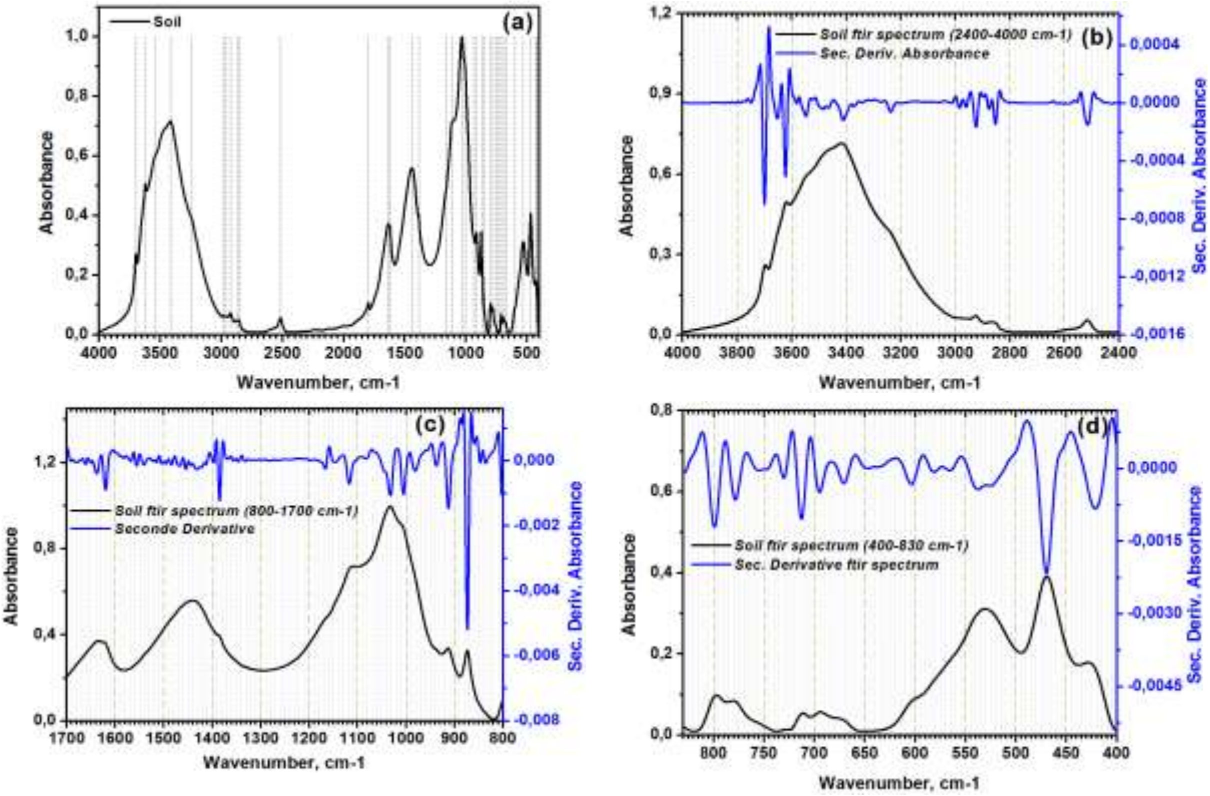


***Figure 4:** FTIR spectra of soil of the El-Meita region (Khenchela, Algeria). **(a)** Full spectrum (4000 to 400 cm⁻¹); **(b)** Region (4000 to 2400 cm⁻¹), **(c)** Fingerprint region (1700 to 800 cm⁻¹) and **(d)** Region (800 to 400 cm⁻¹).*

***Table 3:** Identification of FTIR bands specific to mineral and organic components of soil*

| Wavenumber (cm⁻¹) | Assignments | Explanation | Ref |
|---|---|---|---|
| 3700 - 3000 | Stretching vibrations O-H | Water adsorbed in the soil ($H_2O$ on the surface of minerals),Clay minerals such as kaolinite, montmorillonite, and illite, which contain structural hydroxyl groups, Humic and fulvic acids, the main constituents of soil organic matter | [37] |
| 3000 - 2800 | C-H stretching vibrations of organic materials | Lipids, waxes, and humic compounds,<br>Soil organic matter, which comes from the decomposition of plant and microbial residues. | [38] |
| 1800 - 1500 | C=O vibrations and O-H deformations | This band is typical of C-H bonds in organic compounds. | [39] |
| 1700 - 1600 | Stretching vibrations C=O | Carboxylic acids and organic carbonates. | [40, 41] |
| 1600 - 1500 | Deformations of O-H bonds | Typical of humic and fulvic acids. | [42] |
| 1450 - 1350 | C-H deformation and presence of nitrates | C-H stretching vibrations of organic compounds, aliphatics, CO–$CH_3$.<br>Nitrates ($NO_3^-$), often introduced by fertilizers such as ammonium nitrate or potassium nitrate. | [43, 44] |

| | | | |
|---|---|---|---|
| 1200 - 900 | Clays, quartz, Phosphates ($PO_4^{3-}$) from phosphate fertilizers | Silicates and phosphates | [45, 46, 47] |
| 1050 - 950 | Inorganic phosphates | Phosphate fertilizer | [48] |

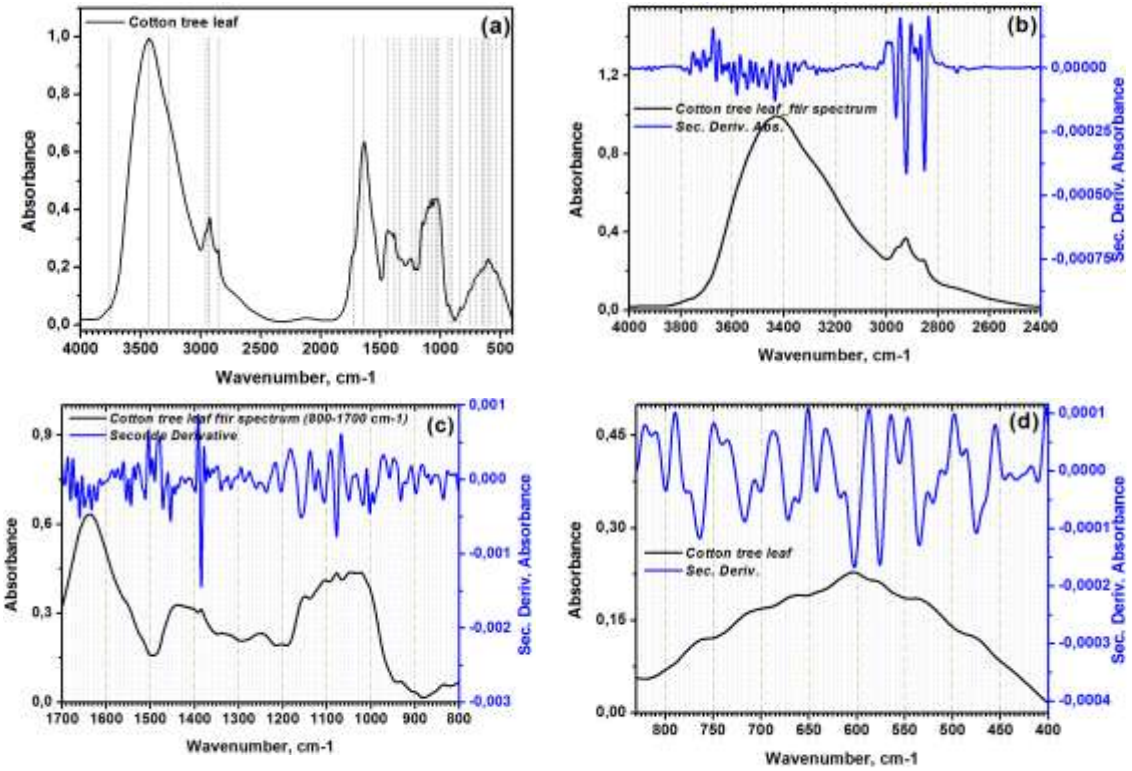


***Figure 5**: FTIR spectra and second derivative of cotton tree leaf of the El-Meita region (Khenchela, Algeria). **(a)** Full FTIR spectrum (4000–500 cm⁻¹); **(b)** Region (4000–2400 cm⁻¹); **(c)** Fingerprint region (1700–800 cm⁻¹) and **(d)** Region 800 to 400 cm⁻¹.*

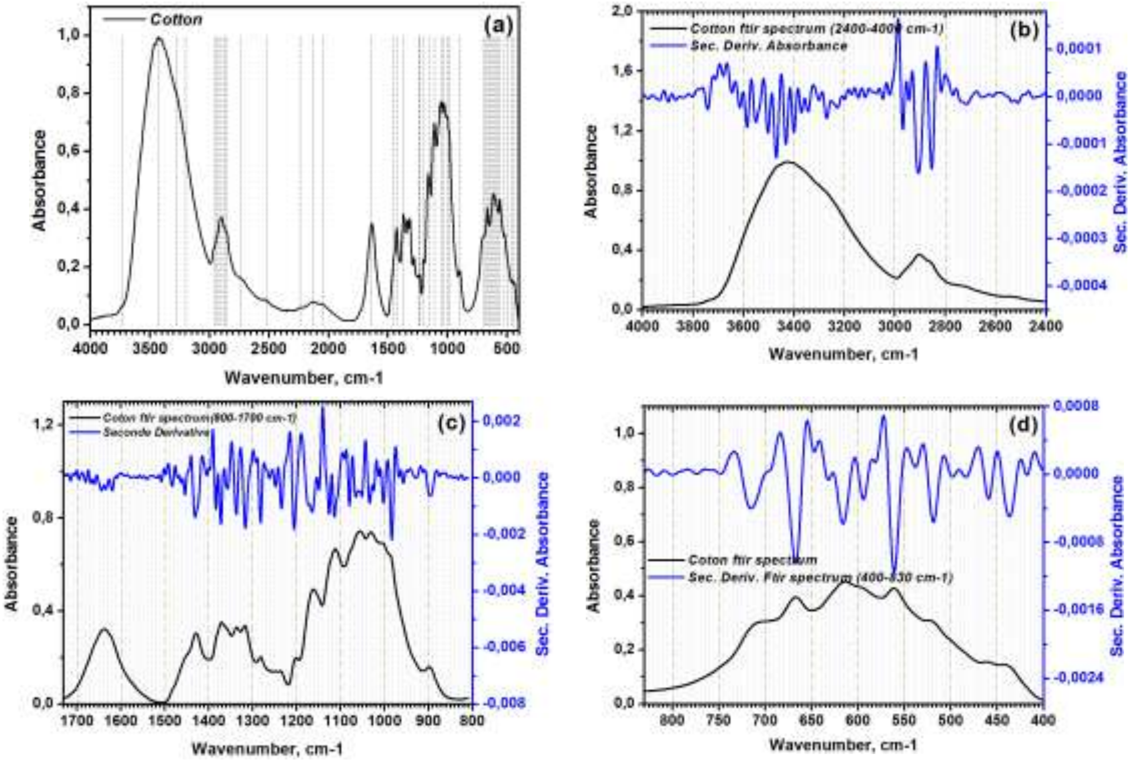


***Figure 6:** FTIR spectra of cotton fibers (Kh 01) of the El-Meita region (Khenchela, Algeria). **(a)** Full FTIR spectrum (4000 to 400 cm⁻¹); **(b)** From 4000 to 2400 cm⁻¹; **(c)** Fingerprint region (1700 to 800 cm⁻¹) and **(d)** Region (800 to 400 cm⁻¹).*


***Figure 7****: Cotton seeds.* ***(a)*** *Macroscopic view;* ***(b)*** *Side view of the seed under a stereomicroscope;* ***(c)*** *Longitudinal section revealing the inner kernel, surrounded by the wall and tegument, with the fibrous coat remaining at the periphery (outer surface), observed under a stereomicroscope.*

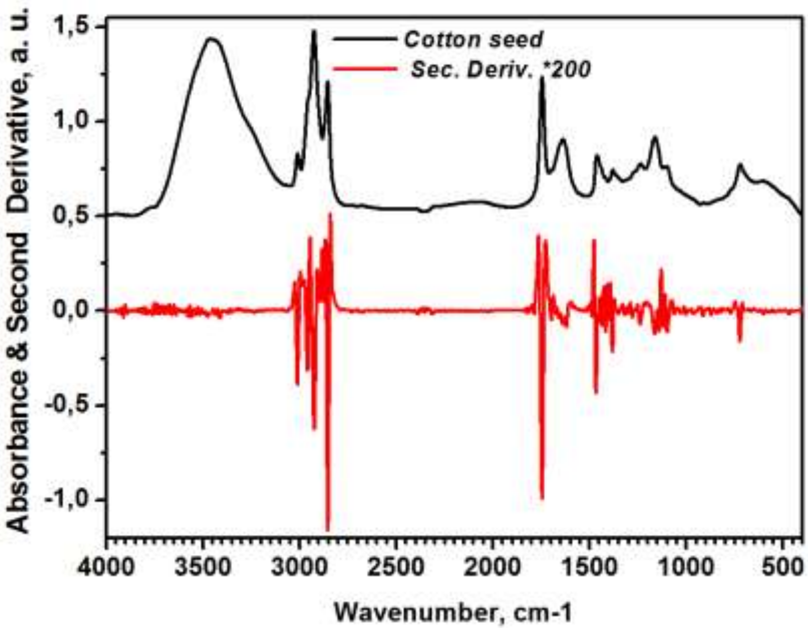


***Figure 8:*** *FTIR spectrum of cotton seed and its second derivative spectrum (x200).*

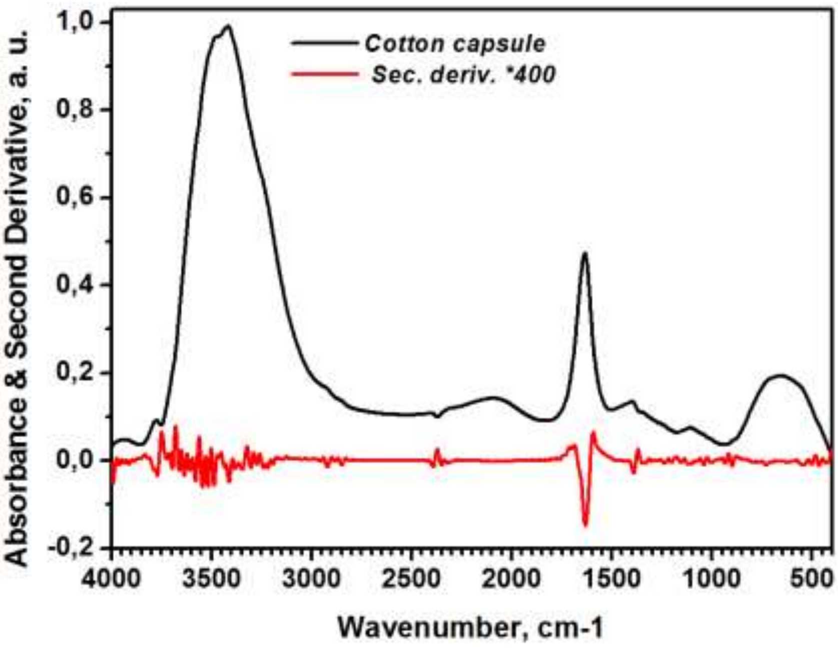


***Figure 9 :*** *Spectre FTIR et sa dérivée seconde* capsule coton *(x400)*

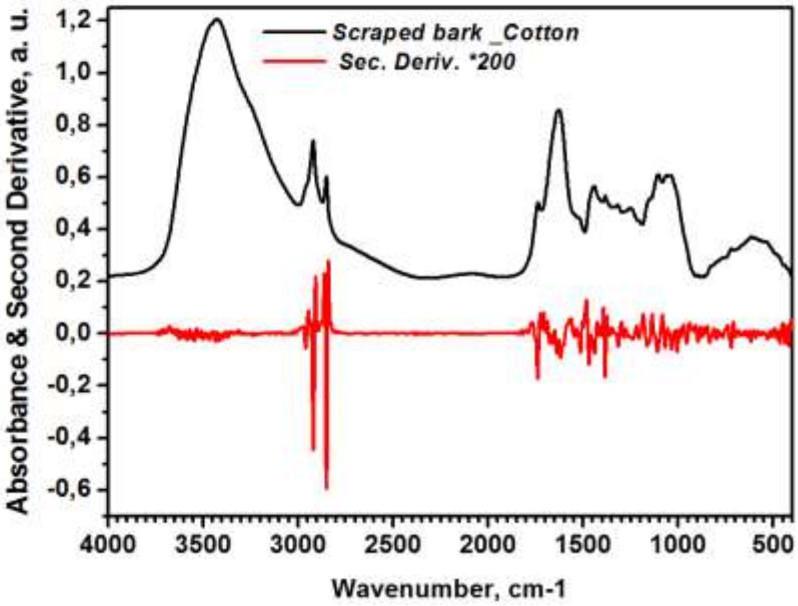


***Figure 10****: FTIR spectrum of scraped cotton plant bark and its second derivative (×200)*

***Table 4.*** *Comparison of fiber properties between cotton varieties.*

| **Fiber properties** | **Variétés** | |
|---|---|---|
| | **Giza 95** | **Kh 01** |
| **U.H.M.L (mm)** | 20.5 | 22.33 |
| **UI%** | 83.71 | 86.86 |
| **Mic** | 4.11 | 5.13 |
| **MR** | 90 | 88.66 |
| **Str g/tex** | 36.93 | 40.93 |
| **Elg** | 9.01 | 6.2 |
| **Rd** | 61.89 | 71.7 |
| **+b** | 11.76 | 10.46 |
| **BW** | 2.1 | 2.6 |
| **GR** | 41 | 23.4 |

**Abbreviations: U.H.M.L**: Upper Half Mean Length (mm), **UI:** Uniformity Index (%), **Str**: Strength (g/tex), **Elg**: Elongation (%), **Mic**: Micronaire value, **MR**: Maturity Ratio, **BW**: Average Boll Weight (g), **GR**: Ginning Rate, **Rd**: Reflectance degree, **+b**: yellowness degree.

## 4. Conclusions

The study showed that the Giza 95 cotton variety is highly adaptable to the arid and semi-arid conditions of the El Meita–Khenchela region, with high fiber and seed yields. Physicochemical analyses of the fibers, supplemented by FT-IR spectroscopic studies of different parts of the plant, revealed remarkable mechanical, agricultural, and functional properties. The significant differences observed from Giza 95 and Kh 01 in terms of fiber length and strength, color, boll weight, and spinning percentage confirm the comparative superiority of Giza 95 under the local conditions studied. Furthermore, the quality and chemical composition of the fibers appear to be strongly correlated with soil characteristics and climatic conditions, highlighting this variety's ability to grow effectively in its environment. FT-IR analyses revealed high levels of cellulose, hemicellulose, and protein in the fibers and leaves, reinforcing its industrial potential and functional performance.

## Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could

have appeared to influence the work reported in this paper


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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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