Comparative Anatomy of Cotton and its Applications

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Abstract

Present study reveals that there is a large variation in anatomy of cotton genotypes, which will help in selecting genotypes for drought tolerance, sucking pest resistant, boll warm resistant, and lodging resistance. Genotypes having long and compactly arranged palisade tissue, high density of trichomes, thick cuticle, high density of vascular tissue offers drought resistance. High density of trichomes offers sucking pest resistance. Thick stem offers lodging resistance under flooding condition.

1. Introduction

Cotton (*Gossypium* spp.) is the world's most industrialized crop. The term cotton is used both for plant and fibers obtained from the lint of the seed, which is derived from the Arabic word 'Qutn'. Cotton has been in use for the last 5000 years. Cotton is indigenous to South-east Asia and America. Domestication of the cotton plant for commercial cultivation for clothing and for other forms of human utilization is considered to have begun from Harappa civilization in Indian sub-continent using diploid or Asiatic cottons (*Gossypium herbaceum* L. and *G. arboreum* L.). Cotton, called as 'white gold', is grown in more than 80 countries all over the world. China, India and USA are the leading cotton growers accounting for 60% of the world cotton production. Other major cotton growing countries are Pakistan, Brazil, Uzbekistan and Turkey. There are four cultivated species of cotton. Of these, *Gossypium arboreum* (Asiatic/Indian cotton) and *G. herbaceum* (African cotton) are diploids (2n=2x=26) and *G. hirsutum* (Mexican cotton) and *G. barbadense* (Egyptian/sea island/south American cotton) are tetraploids (2n=4x=52). The diploid species of cotton are considered to be domesticated in the ancient world. The Indus valley civilization of India and Pakistan cultivated *G. arboreum*, from which it spreads to Mediterranean region and Africa. Cotton seeds and fibers dating back to 6000 B.C. have been identified in Mehrgarh, an initial establishment of Indus valley civilization. A few centuries later, *G. herbaceum* was domesticated in northern Africa and near East. The new world cotton, *G. hirsutum* and *G. barbadense* are considered to be domesticated in Mexico and Peru during 3500 B.C. and 3480 B.C., respectively. Although information are available on general morphology and development of plant organs of cotton (Maiti and Vidyasagar, 2009), literature on cotton anatomy is rare. Sufficient literatures have been documented on general anatomy (Beck, 2010; Cutler, 2007; Evert et al., 2006) and anatomy of bast fiber crops. Cotton fibers are the raw materials for the textile industry. Cloth and yarn are manufactured from cotton. Gun cotton (nitrocellulose) is obtained by mixing cotton with concentrated nitric acid. Cotton seed is used as livestock feed because it contains fats, proteins and vitamins. Oil is extracted from seed. It is hydrogenated and used as *vanaspathi* and also in soap making. Nowadays it is also used as cooking oil. Seed cake is also used as cattle feed. Bark is used for manufacturing of low grade paper. Cotton gin by-products are utilized for the manufacturing of fuel pellets.

2. Materials and Methods

All observations were made on materials grown in the fields of Vibha Agrotech Ltd., Hyderabad, India, during 2010-11. Seeds for various cultivars were supplied by Vibha Seed's cotton research department. Materials were collected from the field and put in a polythene bag containing water. Thin sections were cut by sharp razor blade and were immersed in water to avoid formation of air bubbles. Sections were stained with fast green solution safranine and excess of stain was washed with water. Sections are mounted in glycerol and covered with cover slip and observed under microscope. We adopted general principles documented by various authors on anatomy (Beck, 2010; Cutler, 2007; Evert et al., 2006).

3. Results and Discussion

3.1. Root anatomy

3.1.1. Anatomical features

Transverse section of young root shows tetrach conditiion of xylem Plate 1. Numerous root hairs arised from epidermis helps in absorbing water and minerals. Transverse section of matured root showed thin layer of bark at outer side of the root which was is produced due to rupture of epidermis. Below this 2-5 layered cortex which was compressed. Xylem was exarch with continuously formed secondary xylem vessels. Pith was absent at the center. Endarch xylem vessels with prominent secondary xylem vessels were present at the center of the root.

3.1.2. Significance of variations in root anatomy

Cultivar differences are expressed in a number of root characteristics: 1) presence or absence of sclerenchymatous exodermis in the cortex, 2) thickness of endodermal cell walls, and 3) variation in density and size of the xylem vessels. High density of vascular tissue (xylem) is essential under drought condition for efficient translocation of water to the plant parts. Large size xylem vessels help in efficient conduction of water and mineral to shoot system (Plate 2).

1.2. Stem anatomy

3.2.1. Anatomical features

Stem anatomy of cotton is typical of that of the dicots. Mature stem shows secondary growth. Primary stem shows 3 regions namely epidermis, cortex and stele (Plate 3).

3.2.1.1. Epidermis

Epidermis is the outermost region surrounding the stem. It is uniseriate having a single layer of compactly arranged barrel-shaped living cells (Plate 4). The outer walls of the epidermal cells are cutinized. Moreover, the epidermis is covered by a separate layer of cutin called cuticle on its outer surface. Cuticle reduces transpiration. Stomata are present in the epidermis for exchange of gases and transpiration. Unicellular hairs are present on epidermis.

3.2.1.2. Cortex

Cortex is the middle region present between the epidermis and stele. It comprises of three sections— hypodermis, middle cortex and endodermis. Hypodermis is the outermost region of the cortex. It is multilayered (2-6) and collenchymatic. Collenchyma may be in the form of complete cylinder or in the form of discrete strands. Hypodermis gives considerable

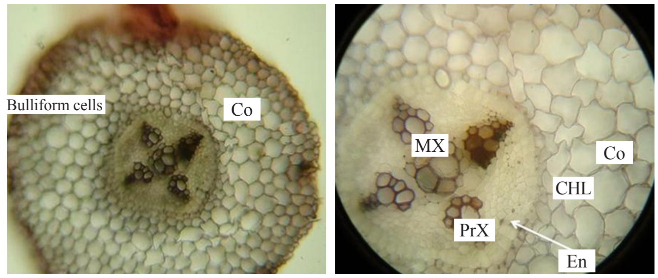


Plate 1: Transverse section of young root showing exarch, tetrarch, closed radial vascular bundles; Enodermis (En), cortex (Co), protoxylem (PrX), and metaxylem (MX) are clearly visible

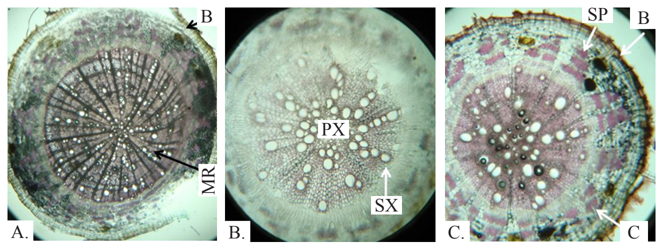
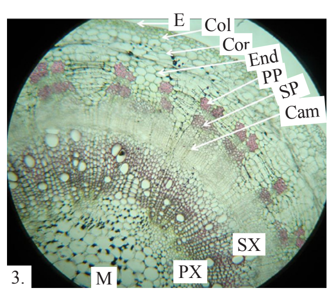


Plate 2: Transverse section of mature root (ground plan) showing secondary growth and variation in size of the secondary xylem vessels (SX), Medullary rays (MR), bark (B), primary xylem (PX), secondary phloem (SP), and cambium (C) are shown in Plate A. Low density of small size xylem vessels, B. High density of xylem vessels, C. Medium density of xylem vessels



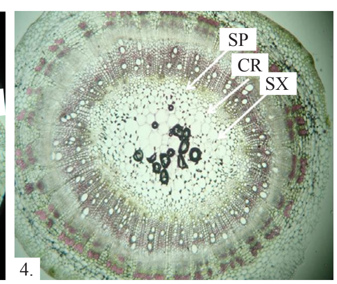


Plate 3: Transverse section of stem (sector enlarged) showing secondary growth in vascular tissue Primary structures are also clearly distinguishable. Epidermis (E), collenchyma (Col), cortex (Cor), endodermis (End), primary phloem (PP), secondary phloem (SP), cambium (Cam), Ssecondary xylem (SX), primary xylem (PX), medulla (M) are visible

Plate 4: Transverse section of stem (ground plan) showing initiation of secondary growth in vascular tissue. Cambium ring (CR) forming outer secondary phloem (SP) and inner secondary xylem (SX)

strength, flexibility and elasticity to young stem.

Middle cortex is multilayered and parenchymatic. The cells may be round or oval with prominent intercellular spaces. This region also stores food materials temporarily. Endodermis is the innermost layer of the cortex. In young stem, the innermost layer of the cortex contains abundant starch. Hence this layer is called starch sheath.

3.2.1.3. Stele

Stele is the central region of stem. It consists of pericycle, vascular bundles and medullary rays. Pericycle is the non-vascular region of the stele. It is multiseriate and sclerenchymatic. Vascular bundles are arranged in one or two rows. Each vascular bundle is wedge shaped. Vascular bundle is described as conjoint, collateral and open type. Xylem is endarch with protoxylem present towards the center. Xylem consists of many vessels. Medullary rays are the extensions of parechymatous pith between vascular bundles called primary medullary rays which help in lateral conduction and may give rise to secondary meristem (Plate 5).

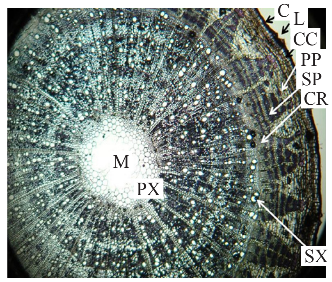


Plate 5: Transverse section of stem showing complete secondary growth; Cork tissue (C), lenticel (L), cork cambium (CC), primary phloem (PP), secondary phloem (SP), cambium ring (CR), secondary xylem (SX), primary xylem (PX) and medulla (M) are visible

3.2.2. Significance of variations in stem anatomy

Cotton genotypes exhibit good variation in cuticle thickness, number and types of trichomes, shape and size of hypodermis layer, distribution of collenchyma cells and lignification, numbers of pericycle layers, shape of sclerenchyma cells, number of secondary xylem vessels and number and size of vascular bundles (Plate 6). High amount of sclerenchyma gives mechanical support and avoids the loss of water from internal parenchyma tissue by evapo-transpiration. It is expected that medium to large size and high number of xylem vessels are required for efficient translocation of water under drought condition (Plate 7 and 8). Presence of large vessels associated with dense lignified sclerenchyma offer strength to the stem, as well as drought resistance facilitating efficient translocation of water and photosynthates through phloem to the growing bolls.

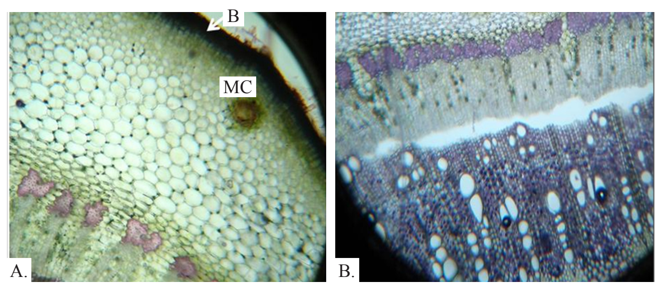


Plate 6: Transverse section of stem showing variability in thickness of bark (B) and density of mucilage cavities (MC) in the cortex; A. Highly thick bark and less density, B. Thin bark and high density of mucilage cavities

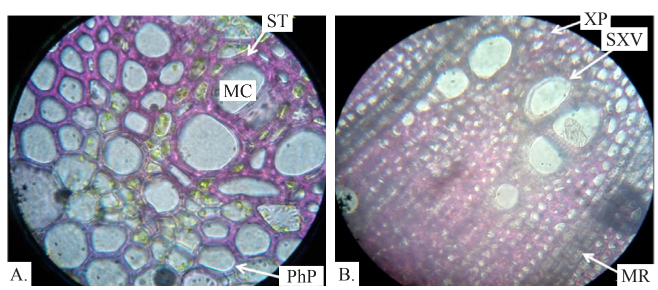


Plate 7: A. Transverse section of stem showing secondary phloem and phloem parenchyma (PhP) and sieve tubes (ST) are observed in the picture; B. Xylem parenchyma (XP), secondary xylem vessels (SXV) and medullary rays (MR) are visible

3.3. Leaf anatomy

3.3.1. Anatomical features of leaf

Leaf shows dorsi-ventral nature, i.e. the leaf blade consists of distinct dorsal and ventral surfaces. Epidermis is single layered having compactly arranged barrel shaped (tabular) cells (Plate 9). The cell walls are cutinized and also covered by a thin cuticle. The cutinized outer walls and cuticle reduce the loss of water due to transpiration. Anisocytic type of stomata are present on both the epidermal layers. But the stomata are usually more in lower epidermis. Stomatal density varies among cotton cultivars. Stomatal index of upper epidermis on an average is 25 and lower epidermis is 33. Stomata facilitate the exchange of gases between the leaf and environment. Epidermis contains two types of trichomes—small unicellular spine like and hooks like trichomes. The mesophyll is chlorenchymatic and differentiated into an upper palisade tissue and lower spongy tissue. The palisade tissue is thick and compact in drought resistant genotypes, while in susceptible ones these are loose leading to greater loss of water by transpiration. Cells of the spongy tissue are thin-walled, irregular in shape, arranged loosely with large continuous intercellular spaces. Stomata open into large intercellular spaces called sub-stomatal chambers. The cells of spongy parenchyma contain less number of chloroplasts. Hence the lower surface of the leaf is light green in color. Vascular bundles (veins) occur in between the palisade and spongy tissue (median in position). They are collateral and closed. The vascular bundle is surrounded by parenchymatous bundle sheath.

3.3.2. Significant variation in leaf anatomy

Ample genotypic variability is observed for the leaf ana-

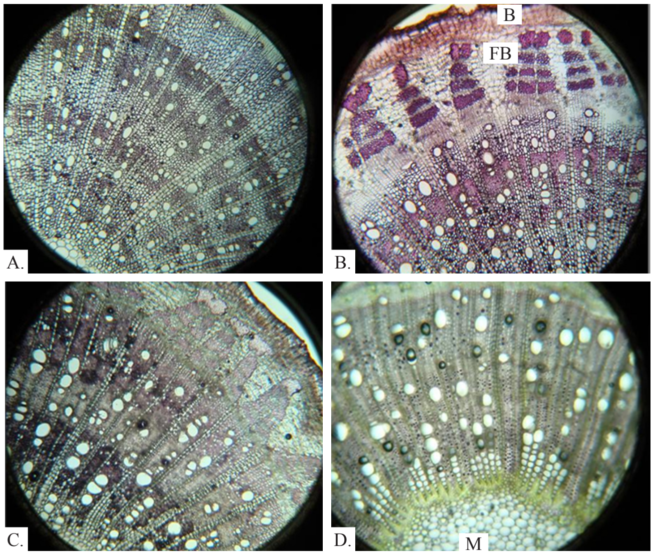


Plate 8: Transverse section of stem showing variability in size of the xylem vessels; A. Small size xylem vessels, B. Medium size xylem vessels, C. & D. Large size xylem vessels

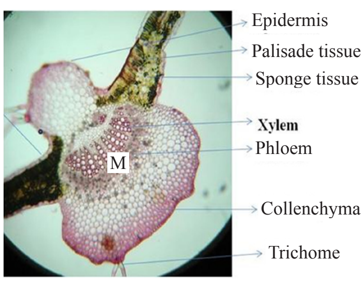


Plate 9: Transverse section of leaf showing various parts

tomical structures under different adaptive environments. Variations in arrangement of palisade tissues (Plate 10 and 11), density of gossypol glands (Plate 12), leaf trichome density (Plate 13 and 14) and types, number of stomata (Plate 15), type and arrangement of vascular bundles both in the lamina and midrib and size and shape of bundle sheath chloroplasts are found in different genotypes. A number of mechanisms providing resistance to dehydration are observed in genotypes adapted to water limited environments. Sclerenchyma gives mechanical support and avoids the loss of water from internal parenchyma tissue by evapo-transpiration. Presence of thick cuticle on epidermis of leaf reduces traspirational loss of water. Besides, thick compactly arranged palisade tissue and reduced stomatal density minimize water loss. Some additional mechanisms like high trichome density reduce the direct sunlight effect and minimize leaf temperature, thus finally reducing transpirational loss. High density of trichomes also offers resistance to sucking insect pests. Insect pest resistance is also enhanced by presence of higher number of glands producing gossypol.

No information is available on the role of leaf structure and palisade tissue in relation to drought in cotton observed in the present study but in tomato leaves of resistant type had longer palisade mesophyll cells with compact arrangement, thin spongy mesophyll layer leading to higher tissue ratio

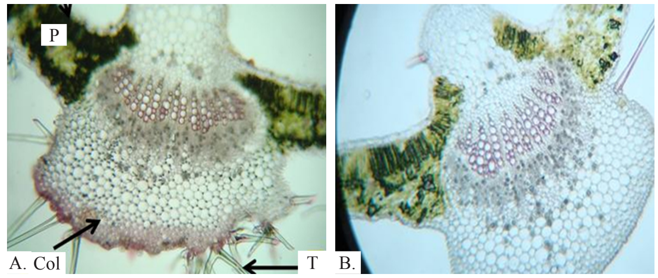
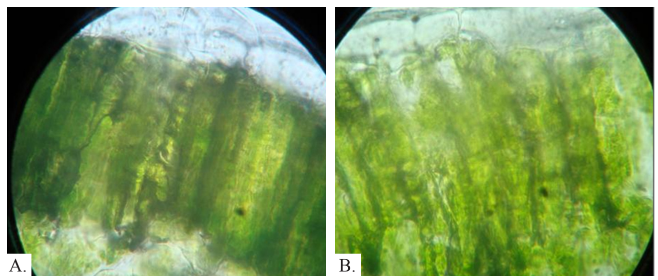


Plate 10: A. Transverse section of leaf showing high density of trichomes (T) on both the epidermis, thick compactly arranged palisade (P) tissue, thick cuticle, 3-4 layers collenchyma (Col) tissue above the lower epidermis; B. Low density of trichomes on both the epidermis, thin loosely arranged palisade tissue, thin cuticle, 2-3 layers of collenchyma tissue above the lower epidermis



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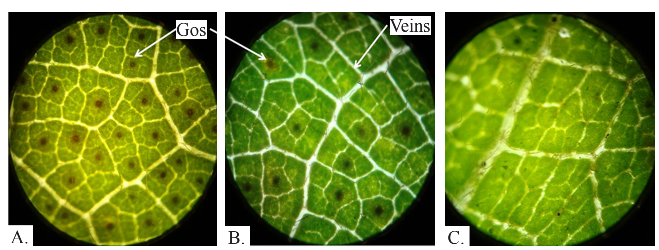

Plate 12: Lower epidermis of the leaf (10X) showing variability in gossypol gland (Gos) density; A. High density, B. Medium density, C. Low density

(palisade mesophyll: spongy mesophyll). Thickness of leaves was invariably more in drought resistant genotypes (500-550 μm) as compared to susceptible ones (Kulkarni and Deshpande, 2006).

An unusual feature of chickpea plants is the secretion of a highly acidic fluid from glandular trichomes. This exudates was shown inhibiting germination at higher concentrations (0.3 and 1.5 mg ml^{-1}) (Armstrong-Cho and Gossen, 2005).

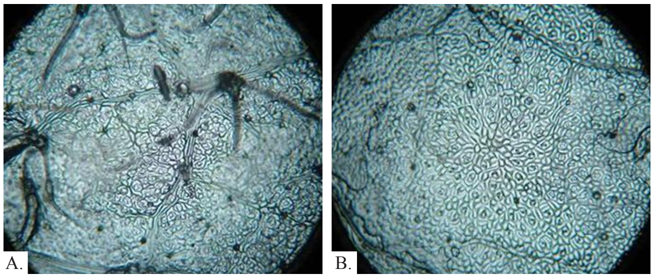

Plate 13: Variability in trichome density on leaf upper epidermis (4X); A. High density, B. Low density

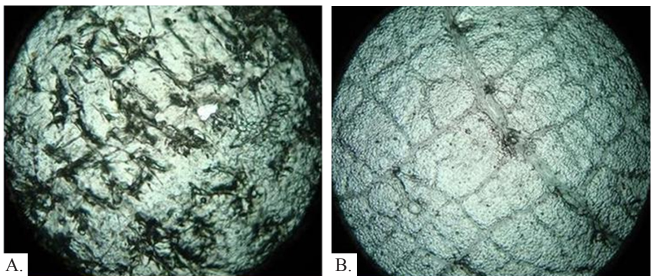

Plate 14: Variability in trichome density on leaf lower epidermis; A. High density, B. Low density

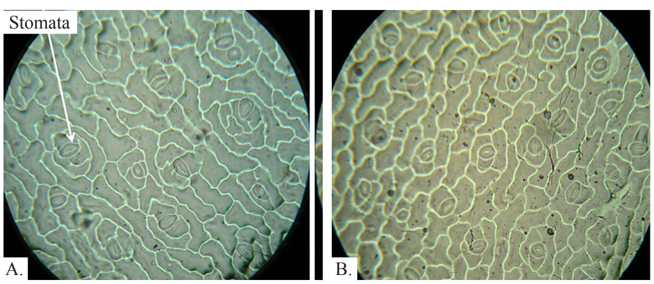

Plate 15: Showing variation in stomatal distribution; A. High frequency, B. Low frequency

3.4. Petiole anatomy

3.4.1. Anatomical features of petiole

There is a close similarity between petiole and stem with regard to the structure of epidermis. The ground parenchyma of petiole is like the stem cortex in arrangement of cells and in number of chloroplast. The supporting tissue is collenchyma in relation to the arrangement of vascular tissues in the stem (Plate 16). The vascular bundles of the petiole are collateral. Epidermis contains unicellular trichomes. Multilayered (2-6 layers) hypodermis of collenchyma cells is found immediately beneath the epidermis and having chloroplasts it may carry on photosynthesis. Just beneath the hypodermis ground tissue is found. It consists of thin walled parenchymatous cells having well defined intercellular spaces among them. Vascular bundles are arranged in half ring and scattered in ground tissue. The vascular bundles are of various sizes in the same petiole. Each vascular bundle is wedge-shaped. In petiole, the xylem is always found towards upper side whereas phloem towards lower side.

3.4.2. Significant variation in petiole anatomy

Plant water deficits induce both leaf and boll abscission from cotton under field conditions. Petiole being near the abscission zone plays important role in hormonal regulation of leaf abscission. Cotton petioles with higher number of vascular bundles will thus help increasing longevity of leaves, thus increasing photosynthesis and biomass. Drought resistant cotton cultivars possess variation in trichome density (Plate 17), types of trichomes (Plate 18), thick cuticle (Plate 19),

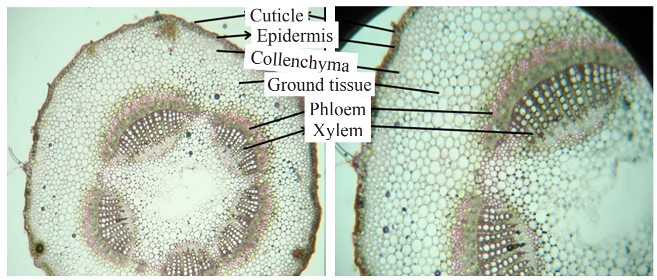

Plate 16: Transverse section of petiole showing different parts

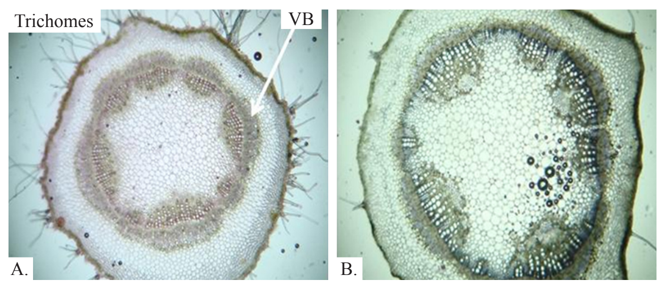

Plate 17: Transverse section of petiole showing variation in trichome density; A. High density, B. Low density

Plate 18: Transverse section of petiole (portion of epidermis) showing stellate (St), bifurcated (Bif), unicellular long type (simple-sim) trichomes

collenchyma layers (Plate 20), thereby giving flexibility and strength to the petiole, besides having long and stout petiole in drought resistant cultivars. Petiole is also commonly used for nitrogen status analysis in cotton, as the nitrate taken up

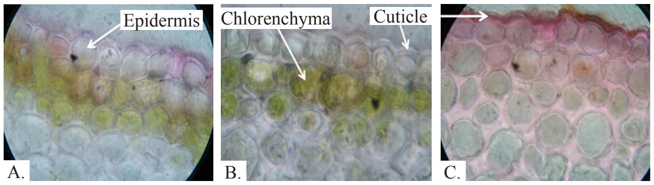

Plate 19: Variation in cuticle thickness- less, medium and high

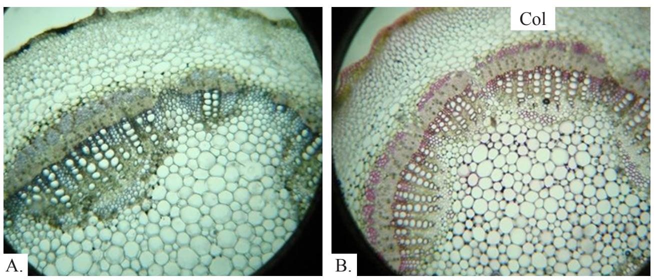

Plate 20: A. Transverse section of petiole (sector enlarged) showing 5-6 layers of collenchyma tissue, B. 6-7 layers of collenchyma tissue

by root moves to leaves through petiole. Hence, higher number of vascular bundles and presence of thick collenchyma for stiffness and flexibility of the petiole will be helpful for efficient translocation of photosynthates, particularly under water stress conditions.

4. Conclusion

Large variation in anatomy of cotton genotype was noted, which helps in selecting genotypes for drought tolerance, sucking pest resistant, boll warm resistant and lodging resistance. Root genotypes with high density of vascular system can survive under drought condition. Genotypes having long and compactly arranged palisade tissue, high density of trichomes, thick cuticle, and high density of vascular tissue offers drought resistance. High density of trichomes offers sucking pest resistance. Thick stem offers lodging resistance under flooding condition.

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