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Morphological and anatomical adaptations of plants to cope up with environmental stress

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Abstract
Plant shows various modifications/adaptations to survive in extreme conditions. These adaptations may be morphological, anatomical or physiological. Present study is based on distinct observations which are morphological as well as anatomical. Microscopic evaluation clearly revealed that various diagnostic features like multicellular trichomes, anomocytic stomata were observed. These features are of taxonomic significance too besides being important for survival in stress condition.

Keywords: adaptations, evolution, environmental conditions and taxonomy

Introduction
Plants in natural world exhibit various types of morphological, anatomical and physiological adaptations. The special characteristic features of plants that enable them to survive successfully under prevailing set of environmental conditions are called adaptations. These special features have evolved over a long period of time through the process of natural selection.

Adaptation and succession both are quite different terminology and processes as previous one is the result of evolution [9] i.e., changes in the same species over very long period of time resulted in development of some new and changed modifications while later one is associated with continuous replacement of various species of plants inhabiting in a given area after a period of time completely as a result of exclusively changed environmental/ habitat conditions.

Historical background of Taxonomy (Plant classification)
The science that deals with classification and characterisation of plant is taxonomy [1]. Taxonomic classification, if typically based on morphological characters, then it is known as alpha taxonomy or descriptive taxonomy [11]. Usually, plants either monocot or dicot have a definite arrangement and appearance of stem, leaves, flower and fruit, but some plants may be dicot or monocot in different ecological conditions show unusual aerial modifications of leaf, petiole and stem. Thus, for their growth and development these adaptations can be correlated to different climatic conditions. These are not abnormalities but modifications to survive in either different ecological conditions or climates.

This study is compilation of plants with unusual but morphologically visible adaptations of leaf, petiole and stem in dicot and monocot plants that grow in hydrophytic (water loving), mesophytic or xerophytic conditions.

Plant parts (stem, petiole and leaves) used in studies
Morphological changes that help in survival in different ecological condition is called as eco-morphological changes.

- *Eichhornia* (water hyacinth), is a free-floating water weed that abundantly grows in ponds, lakes etc. Stem with nodes and internodes is modified to spongy offsets. Rosettes of aerial leaves with spongy petiole which store air and help in buoyancy is characteristic feature. Free floating leaves with spongy stem is also seen in *Jussiaea* (Ludwigia), *Salvia* (water cabbage) and *Pistia*.
- *Trapa bispinosa* (water chestnut), is a free floating hydrophytic plant. Its floating character is due to inflated, spongy petiole that store air. Leaves are of two types i.e., dimorphic (free floating and submerged). The floating leaves arise in clusters while submerged leaves are highly dissected and arise in pairs from each node of stem.
- In *Asparagus*, Liliaceae, stem branches are suppressed while leaves are single internode long arranged in a ring or circular manner at each node. Small, flat, narrow single internode long leaf is known as cladode. Here, leaves are modified into spines as defence mechanism.

- *Citrus* leaf petiole modified into wing like structure while having dotted glands with aroma too.
- In *Eucalyptus* leaf oil glands are present on both the surfaces which make plant aromatic and medicinal.
- Bamboo is considered longest grass with nodes and internodes that flowers once in the lifetime.
- *Opuntia* / cactus, stem is modified into jointed, branched, flat, fleshy and succulent leaf like structure called phylloclade, as green in colour modified for photosynthesis while leaves modified to spines to reduce transpiration rate. Phylloclade modification is also seen in plants like Ruscus (Liliaceae) and Muehlenbeckia (Polygonaceae).
- *Acacia auraeculaeform* is phyllode in which petiole is modified to leaf like structure as seen in *Acacia aculiformis*, Mimosaceae and *Parkinsonia*, Caesalpiniaceae (elongated leaf like with parallel venation). In Acacia, compound leaves are devoid of lamina that drops of later while in Parkinsonia, leaf bear stipulate, rachis is green and perform photosynthesis and leaf is bipinnately compound.
- *Cuscutta reflexa* (dodder), is total stem parasite as usually stem is green in colour, but in this plant, it is non-chlorophyllous and pale yellow in colour and normal leaves are modified to small scale leaves, Convolvulaceae.
- *Napenthese* (pitcher plant), Napanthaceae, has epiphytic adaptation having leaf apex bear long petiole like structure, with further modification of lamina into long pitcher with covered lid.
- *Utricularia* (Bladder wort), Utriculariaceae, commonly seen in Dal Lake of Kashmir, here plant body is free floating with dissected leaves, but some leaves are also modified into sensitive little pear-shaped sac like traps called bladder with small opening guarded by valve,
- *Drosera* (sundew), Droseraceae, leaves are spoon shaped with and possess large number of glandular hairs called tentacles on upper surface. These tentacles are mucilage secreting that resembles to dew drop in sunshine,
- *Dionoea* (Venus fly trap), Droseraceae, bear rosette of leaves. Leaves are large with winged petiole. The lamina of leaf is modified into two toothed jaws to trap the insects.

Materials and Methods

The present study was carried out to observe the various morphological parameters visually. For anatomical studies and visualisation of special features inside the cell, sections were cut by moving the blade back & forth and placing them in watch glass containing water. For further step in process, cut sections were passed through varying concentrations of alcohol 10%, 30%, 50%, 70%, 90%, absolute alcohol for dehydration followed by staining in saffranine and fast green and finally passing it in xylene series in sequential manner as 10%, 30%, 50%, 70%, 90%, 100%. After permanent staining and mounting of section in Canada balsam sections were visualised under different magnifying power of microscope i.e., 4X, 10X, 40X and 100X and snaps were taken. For surface/ peel microscopy study a leaf piece of $1mm^2$ was placed in chloral hydrate solution for 5-10 minutes and cleared by scratching with blade for further study. Powder microscopy studies was done by soaking the sieved powder of leaf/stem part in chloral hydrate for few minutes and mounting it in glycerine for further study. Clearing and staining for anatomical and powder microscopy studies were done by methods described by Evans & Trease [2] and Kokate [7].

Result and Discussion

Description of anatomical observations, powder microscopy and peel/ surface microscopy study

Special features observed under microscope in different magnification power (4X, 10X, 40X, 100X) which are adaptive to survive in different stress/ environmental conditions are described below:

- **Photo 1:** Single layered epidermis with thick one layered cuticle. Epidermis with clear, distinct dark brown coloured tannin deposition followed by hypodermis with tannin deposition and very prominent two layered resin canal which is a special feature to store resin [10]. It is an adaptation of stress survival by release of specific compound (Image- 40X view).
- **Photo 2:** Bark, epidermis and hypodermis with tannin deposition and two layered thick resin canal [10], (Image- 40X view).
- **Photo 3:** Single layered epidermis with thick one layered cuticle. It is followed by 2-3 layered parenchymatous hypodermis and 3-4 layered aerenchymatous zone for storing trapped air that provide buoyancy to plant, an adaptation of hydrophytic condition [10], (Image- 40X view).
- **Photo 4:** Sclerenchymatous endodermis is seen followed by prominently distinct sclerenchymatous patch of pericycle above sclerenchymatous phloem, large distinct xylem vessel towards centre [10], (Image- 100X view).
- **Photo 5:** Clear view of anatomy of leaf trace attached to stem part, well-developed xylem vessels arranged in a ring as well as in scattered manner, differential staining showing distinct xylem and phloem, scattered vascular bundle an adaptation of monocot plants (Image- 10X view).
- **Photo 6:** T.S. of stem circular with sclerenchymatous xylem, centrally directed phloem and parenchymatous pith and cortex region. (Image- 10X view)
- **Photo 7:** T.S. of petiole, Vascular bundles in two rings as well as scattered which is an anomalous feature (Image- 4X view).
- **Photo 8:** T.S. of stem with quadrangular arrangement of vascular bundles and few scattered, traces of periderm is also seen (Image- 4X view).
- **Photo 9:** T.S. of stem with haphazardly arranged indistinct vascular bundles showing somewhat early developmental stage (Image- 4X view).
- **Photo 10:** Scattered vascular bundles throughout the pith region and with secondary growth (Image- 10X view).
- **Photo 11:** Densely packed stomata cells are scattered throughout the epidermal surface of leaf. Leaf peel study (Image- 4X view).
- **Photo 12:** Leaf peel study showed enlarged stomata surrounded by subsidiary cell throughout epidermal surface of leaf, an opening meant for gaseous exchange (Image- 40X view).
- **Photo 13:** Very distinct starch grains are seen scattered throughout cortex as well as centrally located pith region showing storage of reserve food for future use (Image- 100X view).
- **Photo 14:** Distinct orange-yellow oil globules deposited in parenchymatous cell of cortex showing storage of reserve food for future use (Image- 100X view).

- **Photo 15:** Scalariform type of xylem vessels, a conducting tissue (Image- 100X view).
- **Photo 16:** Clearly distinct oil globules and scattered starch granules in parenchymatous pith region showing storage of reserve food for future use (Image- 100X view).
- **Photo 17:** Tannin deposition in parenchymatous cells, a magnified view (Image- 100X view).
- **Photo 18:** Scattered starch granules in pith region as well as surrounding xylem vessel (Image- 100X view).
- **Photo 19:** T.S. of leaf with centrally located vascular bundles surrounded by sclerenchymatous tissues showing xerophytic adaptation (Image- 40X view).
- **Photo 20:** Scattered crystals, a magnified view (Image- 100X view).

Anatomical Adaptation and Significance

In hydrophytic plants epidermis is single layered, thin walled without cuticle, cortex is aerenchymatous consisting of air chamber, mechanical tissue less developed, vascular bundles are scattered with xylem, phloem less developed and pith is absent. E.g., water chestnut, water hyacinth, *Jussiaea* (Ludwigia), *Salvia* (water cabbage) and *Pistia*.

Mesophytic plants show characters somewhat in between hydrophytes and xerophytes. Physiological adaptations like presence of sclereids and trico-sclereids stellate sclereids is seen in some plants like *Nymphaea*. *Nelumbo* etc.

In xerophytic plants, cell wall of epidermis is thick with heavily cutinized, epidermis sometimes coated with wax and silica. Epidermal cell also shows presence of hygroscopic hair in furrow region. Stomata are less in number and sunken. Hypodermis and bundle sheath are sclerenchymatous. Mechanical tissue and water conducting elements are well developed. Conjoint, collateral and closed vascular bundles are well developed. The desert grass possesses bulliform or motor cells which help in folding and rolling of leaves. Some plants show presence of oil gland too. E.g., *Cynodon dactylon* (Doob grass) and *Casuarina*, *Asparagus*, *Nerium indicum*, *Eucalyptus*, *Citrus*, *Muehlenbeckia* and *Ruscus*.

There are some special plants that grow in stress conditions like nitrogen deficient soil, namely *Cuscutta reflexa* (dodder), *Napenthese* (pitcher plant), *Utricularia* (Bladder wort), *Drosera* (sundew), *Dionoea* (Venus fly trap), such plants have developed special features to survive in such stress conditions. Here, usually leaf is modified into different shaped structures to trap insects and fulfil their nitrogen need by preying upon them.

Ecological Significance

Ecological groups of plants are indeed much broader group without any air-tight boundaries between them. Warming (1909), classified plant communities on the basis of plants dependence upon and relation to water, as done earlier by Grabner [3] in 1898, 1901 and 1908. Water as an ecological factor occupied the foremost position in distribution of vegetation and its structure. On the basis of their water requirement, Warming, primarily recognised three major group of plant viz. aquatic or hydrophyte, land or terrestrial plant categorised as xerophytes and mesophytes [12], last but not the least helophytes or marshy plants.

Physiological Adaptation / Stress Physiology / Metabolites Synthesised

Earlier it was assumed that only structural adaptations are result of ecological changes but now after advancement in physiological studies it has been observed that plants have developed and finally stored many biochemical compounds as a result of physiological adaptation. For example, many xerophytic plants show accumulation of proline amino acid in the cell to maintain osmotic potential and water potential in their leaves. The heat shock protein i.e., chaperonins provide physiological adaptations to plants at high temperatures [4, 13]. These proteins help other proteins to maintain their structures and avoid denaturation at high temperature. Mangrove plants of marshy condition can excrete salt through salt glands on the leaves. For coping with condition of high salt concentration and osmotic potential, many mangrove plants have high level of solute, such as proline and sorbitol [5]. Many xerophytic plants show storage of starch grains, raphides and calcium oxalate crystals, tannin and oil globules, rosette crystals, stellate crystals etc.

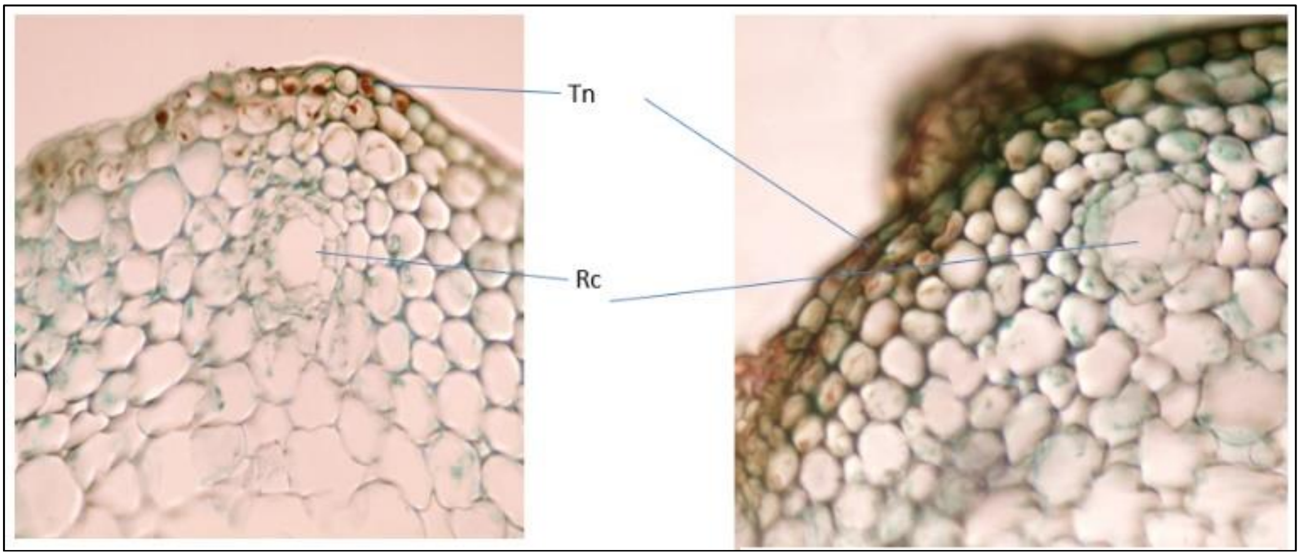

Photo 1: T.S. of stem with two layered resin canal and tannin deposition, 40X
Photo 2: T.S. of stem with tannin deposition on and outer surface of epidermal cell, 40X

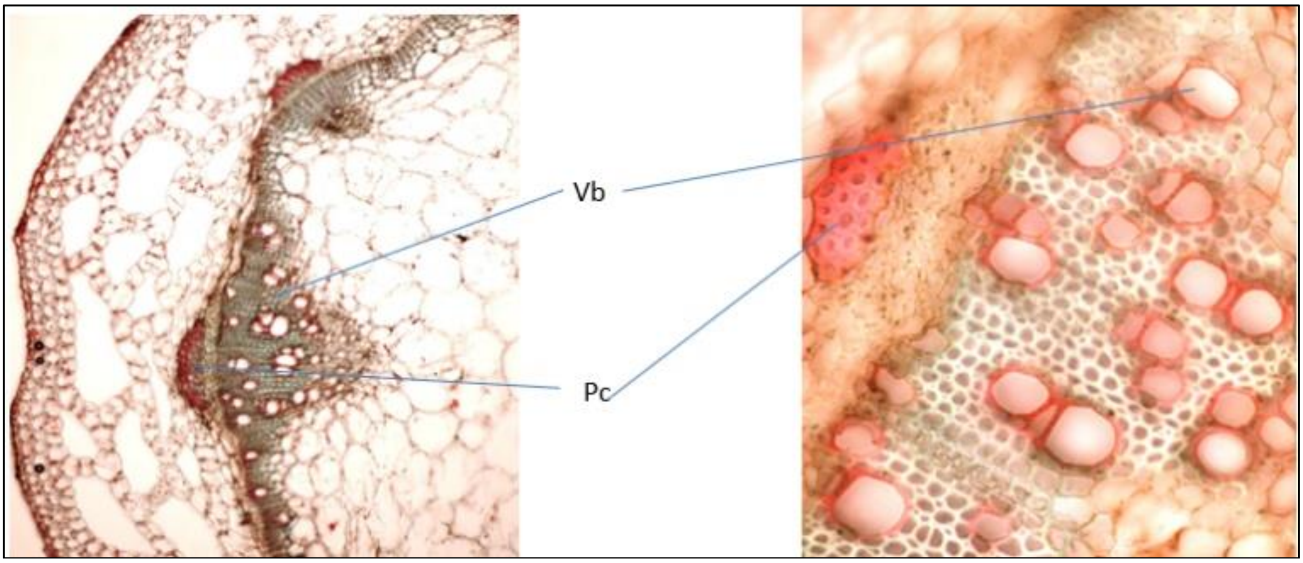

Photo 3: T.S. of stem with aerenchyma below epidermis and well-developed vascular bundle, 40X
Photo 4: T. S. of stem (40 X), Well-developed phloem with scattered xylem and sclerenchymatous endodermis, 100X

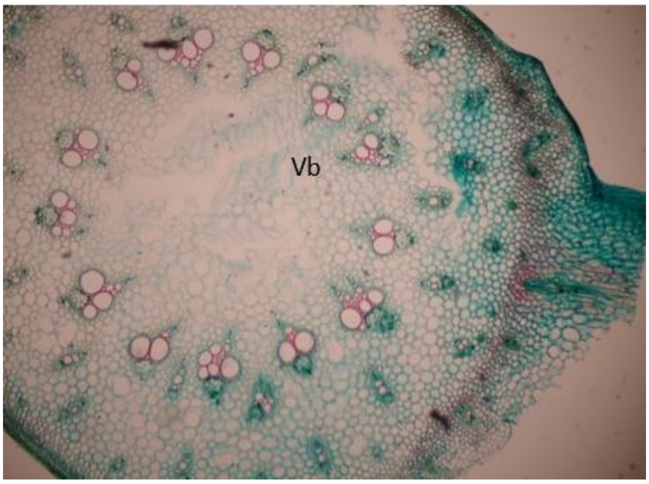

Photo 5: T.S. of stem with leaf trace, Well-developed xylem vessels arranged in a ring as well as scattered, 10X

Photo 7: T.S. of petiole, Vascular bundles in two rings and scattered, 4X.

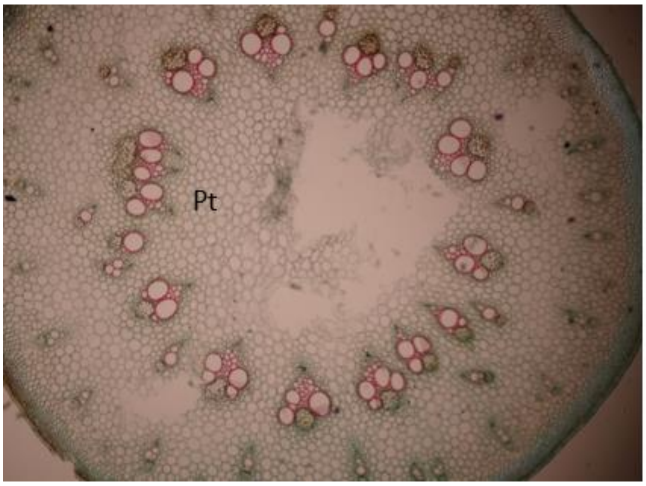

Photo 6: T.S. of stem circular with sclerenchymatous xylem, centrally directed phloem and parenchymatous pith and cortex region, 10X

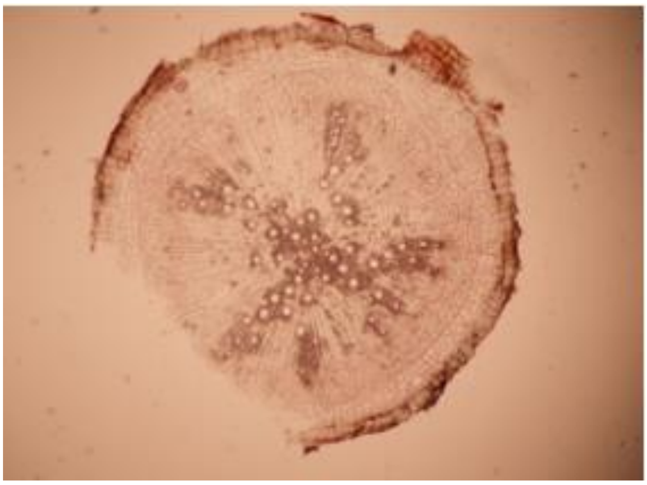

Photo 8: T.S. of stem with quadrangular arrangement of vascular bundles and few scattered, 4X

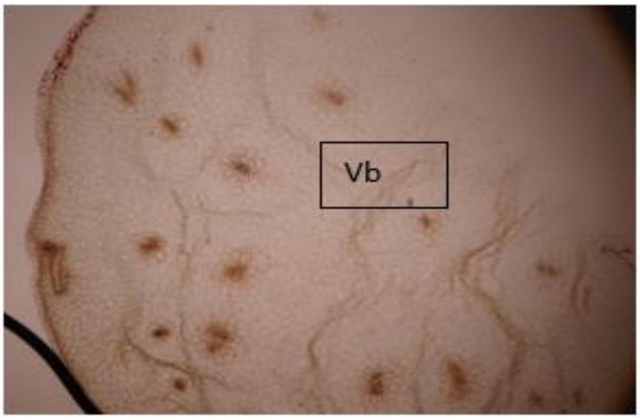

Photo 9: T.S. of stem with haphazardly arranged vascular bundles, 4X

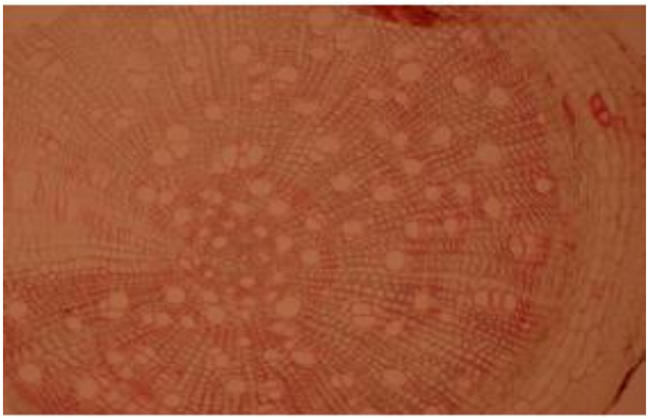

Photo 10: Scattered vascular bundles throughout the pith region and with secondary growth, 10X

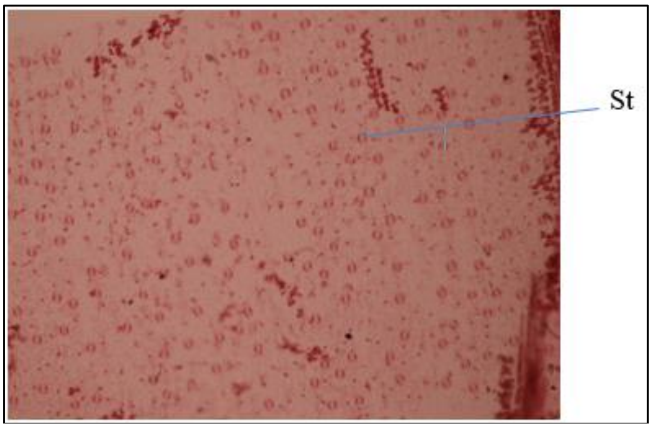

Photo 11: Stomata cells are scattered throughout the epidermal surface of leaf (4X)

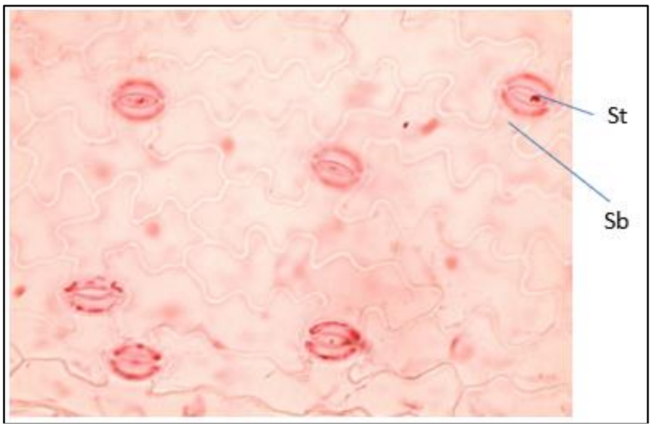

Photo 12: Enlarged stomata through epidermal surface of leaf (40X)

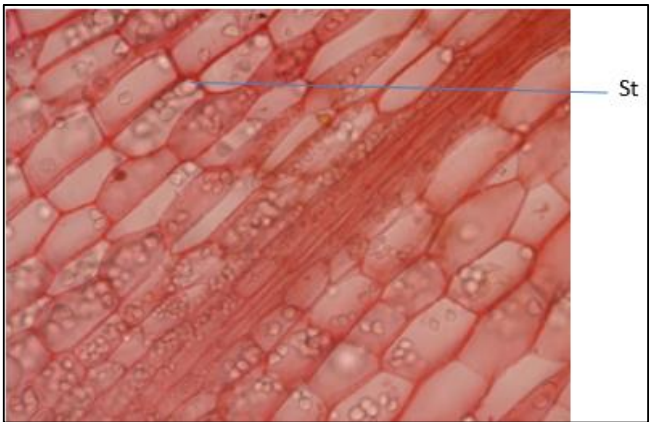

Photo 13: Starch grains scattered from cortex to centrally located pith region, 100X

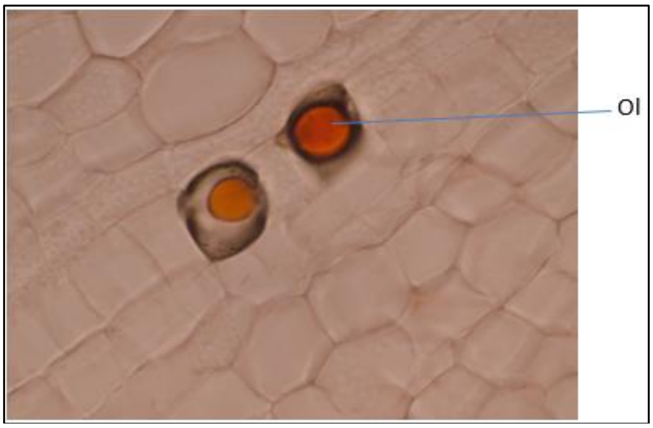

Photo 14: Distinct oil globules deposited in parenchymatous cell of cortex, 100X

Photo 15: Scalariform type of xylem vessels, 100X

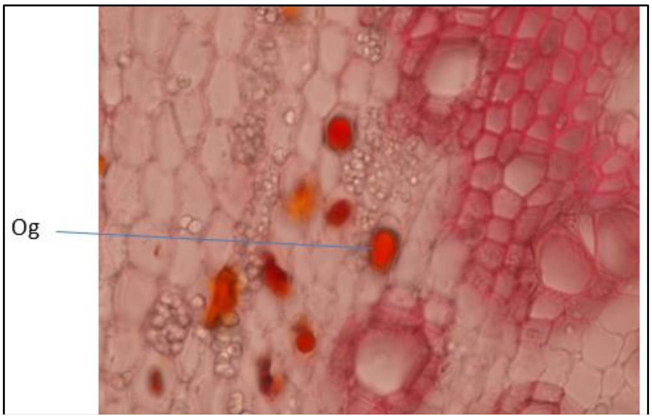

Photo 16: Clearly distinct oil globules and scattered starch granules in parenchymatous pith region, 100X

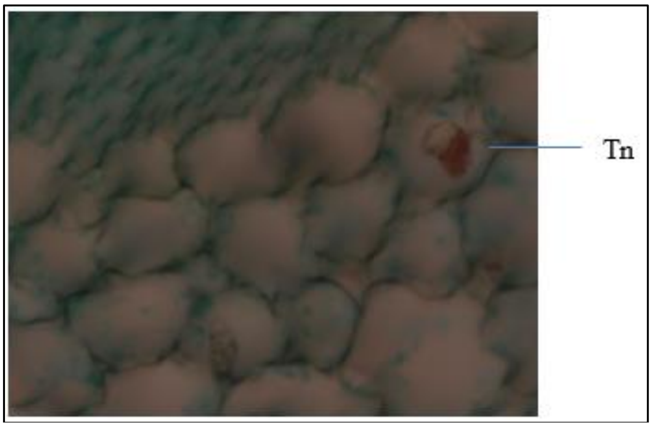

Photo 17: Tannin deposition in parenchymatous cells, 100X

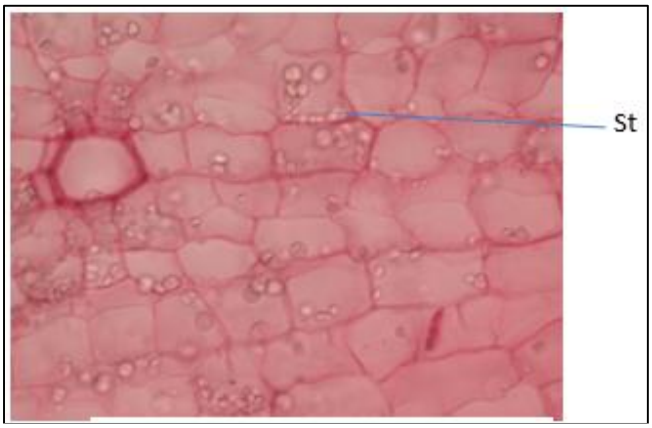

Photo 18: Scattered starch granules in pith region, 100X

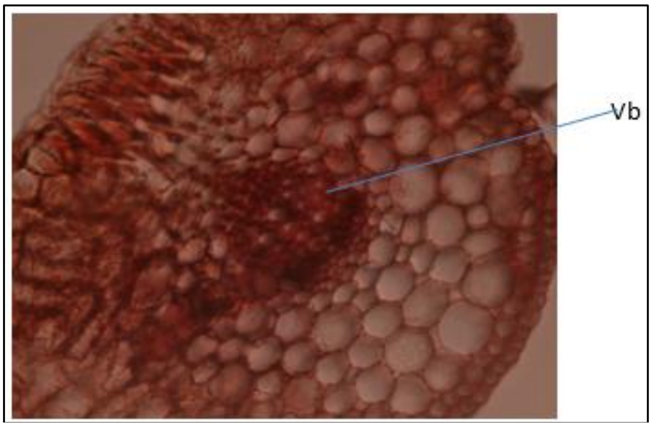

Photo 19: T.S. of leaf with centrally located vascular bundle surrounded by sclerenchymatous tissues, 40X

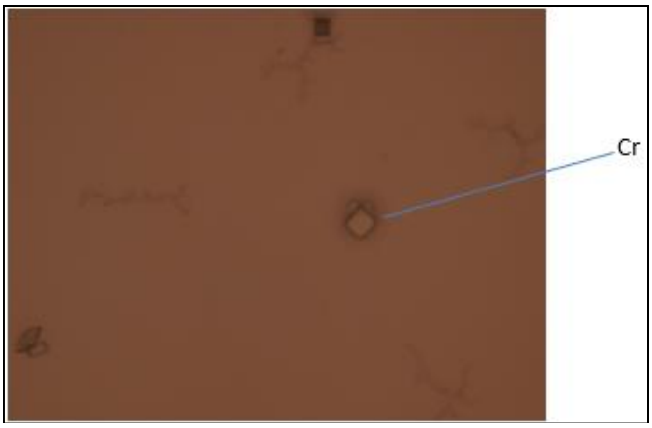

Photo 20: Scattered crystals, 40X

Abbreviations- Tn- tannin, Rd- resin canal, Ar- aerenchyma, Vb- vascular bundle, Xy- xylem, Ph- phloem, Ed- endodermis, Lt- leaf trace, Xv- xylem vessel, Pt- pith, Ct- cortex, St- stomata cell, Sb- subsidiary cell, St- starch grain, Og- oil globule, Sc xv- scalariform xylem vessel, Sc- sclerenchyma, Crystal.

Conclusion

This result corroborates the findings of as morpho-anatomical differences observed in medicinal plant *Geranium ocellatum* leaves [6] and *Casearia sylvestris* [7]. Studies clearly revealed that the plants are having the morphological adaptation due to anatomical and physiological changes as compared to usual ones. These facts are also evidence from the earlier studies done by several researchers on various plants with anatomical modifications like in hydrophytes, xerophytes and mesophytes. Similarly, there are many plants that have developed different pigments or biochemical molecules to survive in stress conditions.

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