REDEFINING STELAR THEORY AND DEFINING THREE NEW STELAR TYPES AND A NEW STELAR SUBTYPE

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ABSTRACT

The species of the genus *Aconitum* are collectively and commonly known as Aconites. The tuberous roots of majority of the Aconites are deadly poisonous. Since ancient times, the roots of Aconites are being used in folk, tribal and traditional systems of medicine after detoxification using customary methods. The anatomy of the tuberous roots of Aconites shows some unusual anomalous structural features, which may be used to identify or authenticate them when they are traded in crude form. The present research paper highlights some of the interesting stelar structures observed in the tuberous root anatomy of Aconites. In the light of the above, a century old extant stelar theory is modified and redefined. In addition, four new stelar terminologies are coined and proposed, viz., Stellostele, Pseudostele, Anomalostele and Sparsophloic confractostele.

KEYWORDS: *Aconitum*, Aconites, Plant anatomy, Stelar theory, Stelar terminology.

INTRODUCTION

The genus *Aconitum* L. belongs to a dicotyledonous plant family Ranunculaceae, which comprises *ca*. 400 species globally (Zhengyi *et al*., 2001). In India, it is represented by 27 species, distributed in the alpine and subalpine regions of Himalayas (Rau, 1993). The *Aconitum* species are commonly known as Aconites. The tuberous roots of Aconites are deadly poisonous. Therefore, the crude root paste of Aconites has been used as an arrow poison worldwide since ancient times. Further, after detoxification using the traditional methods, the roots of Aconites are being used as medicine due to their narcotic and sedative properties. In addition to tribal and folk medicines, the Aconites have been used in various traditional systems of medicine such as Siddha, Ayurveda, Unani, Chinese, Japanish, Nepalese, Burmese and Tibetan. The Aconites have become endangered in the wild due to...
overexploitation of their tuberous roots, which possess poisonous and medicinal properties. Therefore, in 1998, the Government of India has placed the genus *Aconitum* (Aconites) under “Negative List of Exports” to regulate its legal trade and also to check its illegal trade (Selvam, 2016a, b).

The tuberous roots of Aconites are known for anomalous anatomical structural features. Unlike other flowering plants, the Aconites show two types of tuberous roots, viz., the mother and daughter roots. The anatomical structures of the mother and daughter tuberous roots of most of the species of *Aconitum* exhibit both similarities as well as dissimilarities in their anatomical structures. The mother tuberous roots of Aconites exhibit four types of procambial/vascular cylinders, viz., continuous, discontinuous, successive and radial, which may be used in the identification and authentication of Indian Aconites in their crude form (Stapf, 1905; Selvam, 2016a).

**MATERIALS AND METHODS**

The plant materials (tuberous roots of Aconites) required for the present study were collected from Eastern and Western Himalayas by undertaking field tours. The collected plant specimens were identified by consulting national, regional, state and district floras and also by comparing with the authentic voucher specimens deposited in different recognised Indian herbaria, viz., Central National Herbarium, Howrah (CAL); Botanical Survey of India, Dehra Dun (BSD); Botanical Survey of India, Gangtok (BSHC); National Botanical Research Institute, Lucknow (LWG) and University of Kashmir, Srinagar (KASH). The voucher specimens (herbarium and crude aconite roots) are deposited in the Pharmacognosy Section, Botanical Survey of India, Howrah.

To study the anatomical characters of Indian Aconites, the customary Microtechnique procedure was used (Johanson, 1940; Sass, 1940). Light microscope (Olympus CX41) was used to study anatomical features of the tuberous roots of Aconites. To study the lignified cells particularly the xylem elements, polarizer and analyzer filters were used.

**OBSERVATION AND DISCUSSION**

The term ‘stele’ is a Greek word, which means pillar or column. Van Tieghem & Douliot (1886) proposed the stelar theory and they defined stele as a central cylinder or core of vascular tissues, consisting of mainly the primary vascular tissues (xylem, phloem and procambium), along with pericycle and with or without pith. Further, they considered
endodermis as an inner boundary of the cortex. The stelar structures are found in the roots and stems of different groups of vascular plants such as Pteridophytes, Gymnosperms and Angiosperms (Sharma, 2012).

Most of the researchers including Eames & MacDaniels (1947), Esau (1953), Foster & Gifford (1959) recognize two major types of stelar structures, viz., Protostele and Siphonostele. Protostele means a stele consists of a solid core of xylem surrounded by phloem, pericycle and endodermis, but lacking pith. Protostele has simplest organisation of vascular tissues. Therefore, phyllogenetically as well as ontogenetically, protostele is considered to be the most primitive type of stele. It is further divided into three major stelar subtypes, viz., Haplostele, Actinostele and Plectostele (Sharma, 2012).

Siphonostele is known as medullated protostele, as it is possessing pith. Further, siphonostele is considered as an advanced stelar structure. Siphonostele is divided into two main subtypes on the basis of the position of the phloem, viz., ectophloic siphonostele (phloem is restricted only on the external side of the xylem) and amphiphloic siphonostele (phloem is present on both sides of the xylem). Ectophloic siphonostele is further divided into two major stelar subtypes, viz., Eustele (common in dicots) and Atactostele (common in monocots); Amphiphloic siphonostele is further divided into two major stelar subtypes, viz., Solenostele and Dictyostele (Sharma, 2012).

Foster & Gifford (1959) said that the most debated and controversial aspect of the stelar theory is the nature of the anatomical boundaries, which separate the cortex from the stele. In the stems of many of the seed plants, the characteristic endodermal layer is absent. Some of the researchers suggest that, in such cases, the pericycle may be considered as a stelar boundary and also a separating layer between the stele and cortex. Since pericycle has already been considered as a part of stele by majority of the researchers, it cannot be again considered as either the stelar boundary or the separating layer. Therefore, the concept of stelar theory becomes again debatable and controversial (Sharma, 2012).

REDEFINING (MODIFYING) EXTANT STELAR THEORY AND DEFINING (PROPOSING) THREE NEW STELAR TYPES AND A NEW STELAR SUBTYPE
Stelar structure is applied to primary vascular tissues found in plants, which includes pith, and primary vascular tissues (xylem, phloem and procambium). Sometimes pericycle is also included. This is the conventional definition for the stele.
The stelar concept was established to highlight the presence of a variety of primary vascular structures and all the cells/tissues that support them irrespective of their location in the plants/plant parts, mainly in the roots and stems. Since the primary vascular tissues mainly the additional phloem elements that are distributed mostly in the cortical region and rarely in the pith region of the tuberous roots of some of the Aconites are not fitting into the existing stelar theory and the stelar types/subtypes, to accommodate these unique structural features in the stelar concept, the extant stelar theory is redefined/modified. As a result, the cortical region becomes a part of the stelar theory/definition. Hence, according to the new stelar definition (redefinition), “Stele includes all the cells and tissues that are surrounding and supporting the primary vascular tissues, found both in the core as well as in the peripheral regions of the plants, especially in the roots and stems and their modifications, excluding the dermal tissues”.

In precise, as per the new definition, the stele includes pith, primary vascular tissues (xylem, phloem and procambium), pericycle, endodermis and cortex. In other words, the stele consists of ground tissues (pith and cortex), primary vascular tissues (xylem, phloem and procambium), including pericycle and endodermis and excluding the dermal tissues (epidermis or periderm).

Further, while studying the tuberous roots of Indian Aconites, the author has come across different types of anomalous stelar structures that are common in Aconites, viz., a star-shaped structure, a pseudo-stelar structure and an anomalous-stelar structure. Based on these structures, the author has proposed three new stelar types (Stellostele, Pseudostele and Anomalostele) and a new stelar subtype (Sparsophloic confractostele), which are explained hereunder in detail.

1. Stellostele
In some of the tuberous roots of Indian Aconites studied, particularly the tuberous daughter root of *A. laciniatum*, the cambial (procambial) cylinder along with the primary vascular tissues (xylem and phloem) show a star-shaped outline. To highlight this unique structure, a new stelar term/type, Stellostele (star-shaped stele) is coined and proposed (Plate 1, figures A & B). This new stelar type may be defined as “Stelar structure showing star-shaped outline with well-developed parenchymatous pith”.

This stelar structure is completely different from Actinostele (one of the subtypes of protostele), in which, there is a star-shaped solid xylem surrounded by the phloem, but without pith, whereas in the case of the proposed Stellostele, there are no solid xylem and phloem structures, but there are scattered xylem and phloem structures along with a well-developed pith.

2. Pseudostele
In some of the tuberous roots of Aconites, the vascular structures look like a stele superficially, but on critical observation, the vascular structures do not fit into the existing stelar concept/theory. In precise, the stelar structure shows both primary and secondary vascular structures in close-up. However, in overall view, it looks like as if having only primary vascular structure. This type of stelar structure is designated as Pseudostele (false-stele). For instance, in the mother root of A. heterophyllloids var. leucanthum, the secondary vascular structure looks like the primary vascular structure superficially, but when study critically, one can observe primary as well as secondary vascular structures. The secondary vascular structure (secondary growth) has already begun in this plant.

Further, in the case of mother root of A. balfouri, it shows primary vascular structure, in addition, it shows periderm, which is an indication of formation of the secondary growth/structure. It is to be noted that the stelar concept applies only to the primary vascular structure and not to the secondary vascular structure or secondary growth in plants. Therefore, in a strict sense, it cannot be considered as a true stele, but as a pseudostele (Plate 1, figures C, D & E). This new stelar type may be defined as “Stelar structure looks like a true stele in overall appearance, but on critical observation, it shows a false stelar structure”.

3. Anomalostele
In most of the tuberous roots of Indian Aconites studied, the procambial/vascular cylinders exhibit anomalous structures (including successive vascular cylinders) in cross sectional view. To refer this unusual/anomalous primary vascular structure found in the tuberous roots of Indian Aconites in general and in the daughter tuberous root of A. balfouri in particular, a new stelar term Anomalostele (anomalous stele) is coined and proposed here (Plate 1, figure F). This new stelar type may be defined as “Stele showing anomalous primary vascular structure especially successive vascular cylinders”.

i. Sparsophloic confractostele

In some of the tuberous roots of Indian Aconites, a unique stelar structure is observed. To refer this unique stelar structure, a new sub-stelar term is coined and proposed, viz., sparsophloic confractostele (Latin, *sparso* means scattered, which is suffixed with *phloem*, to coin a new term *sparsophloic*, meaning scattered phloem; *confracto* means irregular, uneven or broken and this word is suffixed with *stele*, to coin a new term *confractostele*, meaning uneven/irregular stele). The new stelar subtype highlights, “Unevenly or irregularly scattered primary vascular structures (additional phloem elements/strands) found in the ground tissue (mostly in the cortex and rarely in the pith) of the tuberous roots of Aconites”.

Apart from this unusual primary vascular structure (particularly phloem), an usual primary vascular structure (including phloem) is found in the daughter tuberous root of *A. balfouri* (Plate 1, figures *G & H*). This unusual new stelar subtype is placed/categorized under the newly proposed stelar type Anomalostele. This new stelar subtype may be defined as “Presence of unevenly scattered primary vascular structures particularly additional phloem elements in the ground tissue of the plant parts”.

![Plate 1. Figures showing three new stelar types and a new stelar subtype found in Aconitum species.](image-url)

*A & B* - Daughter root of *Aconitum sp.*, *C & D* - Daughter root of *A. lancifolium*,
*C & D* - *A. heterophyllus* var. *leucanthum* mother root, *E* - *A. balfouri* mother root,
*F* - *A. balfouri* daughter root, *G & H* - *A. balfouri* daughter root showing usual vascular strand and additional phloem strand, respectively.
**Abbreviations:** IVc – Inner Vascular cylinder; OVc – Outer Vascular cylinder; Pi – Pith; Ps – Phloem strand; PVs – Primary Vascular structure; SVs – Secondary Vascular structure; Vc – Vascular cylinder; Vs – Vascular strand.

A schematic representation of the existing major stelar types and subtypes along with **three newly proposed stelar types and a new stelar subtype** (highlighted in yellow colour) are depicted hereunder for easy and quick understanding of the readers.

**CONCLUSION**

The stelar theory was first proposed by Van Tieghem & Douliot in 1886. Subsequently, in 1898, Jeffrey proposed basic stelar types and subtypes. Some of the prominent anatomists across the globe have proposed additional stelar types and subtypes from time to time. The stelar structures (primary vascular structures) observed in the tuberous roots of Indian Aconites are not fitting into either the extant stelar theory or the existing stelar types and subtypes. Therefore, to highlight these unique structural features, the extant stelar theory is redefined (modified) by the author by including the cortical region as a part of the stelar theory. The author believes that the redefinition of stelar theory would put an end to all the controversial opinions related to the existing stelar concept. Further, defining/proposing of three new stelar types (Stellostele, Pseudostele and Anomalostele) and a new stelar subtype (Sparsophloic conftractostele) by the author are additions to the stelar types and subtypes in particular and to the plant science in general.
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REFERENCES