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Comparative rhizome anatomy of four species of *Curcuma*

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Abstract

The anatomy of rhizomes of four economically important species of *Curcuma* namely, *C. longa* (turmeric), *C. aromatica* (*kasthuri* turmeric), *C. amada* (mango-ginger) and *C. zedoaria* (yellow zedoary) were studied. Though all the species basically had similar anatomical characters, variations were nocticed in the number and arrangement of primary and secondary vascular bundles, orientation of endodermoid layer, number and shape of starch grains and curcumin cells. Maximum number and size of curcumin cells were found in *C. longa*. The endodermoid layer formed a continuous ring along with the pericycle in *C. longa* and was more or less circular in *C. amada*. But in *C. aromatica* and *C. zedoaria*, this layer was discontinuous and wavy in nature. In *C. longa*, the meristematic layer was associated with true cambium with ray and fusiform initials. Apart from this, the number of companion cells was directly proportional to metabolic translocation and deposition of reserve substances which can be considered as identifying characters among the species.

Key words: anatomy, *Curcuma* spp., rhizome.

Introduction

In spite of the economic importance of the genus *Curcuma*, our knowledge on the anatomical aspects of this genus is very limited. The earlier studies were concentrated mainly on general anatomy and morphological aspects such as systematic anatomy of Zingiberaceae (Tomlinson 1956; 1969), root apical organization (Pillai *et al.* 1961), vascular pattern of rhizome of ginger (Bell 1980) and occurrence and role of fugacious cambium in rhizome growth of turmeric (Chakraverti 1939). This paper describes the comparative rhizome anatomy of four economically important species of the genus *Curcuma*, namely *C. longa* L. (turmeric), *C. aromatica* Salisb. (*kasthuri* turmeric), *C. amada* Roxb. (mango-ginger) and *C. zedoaria* Rosc. (yellow zedoary) for a better understanding of the interrelationships among these species.

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Materials and methods

Rhizomes of the four species received from the National Conservatory for Turmeric of Indian Institute of Spices Research, Calicut were planted in pots and samples were collected at 30 day intervals and fixed in FAA. The materials were processed and embedded in paraffin wax for microtomy as per standard procedures (Johanson 1940). Serial microtome sections were cut at 10 μm thickness and stained with safranin - fast green for histological studies and Periodic Acid Schiff's Reagent (PAS) for starch localization. Fresh materials were sectioned using an electric sledge microtome at 8 μm thickness and mounted in saturated boric acid to locate curcumin cells (Mayer 1943).

Results and discussion

The basic anatomical features of the rhizomes is similar in all the four species of *Curcuma* studied. Transections of rhizomes are round in shape and bounded by the epidermis composed of almost rectangular cells. Epidermal hairs are present all over the rhizome, that are either unicellular or branched. Cortex consists of outer and inner zones with vascular bundles scattered in both zones. Meristematic cells having 2-3 layers were also noticed in between the two zones. These meristematic layers produce vascular tissues towards the inner side and parenchyma tissues on both the sides.

The common features of rhizome development are described below, and the comparative anatomical profile is provided in Table 1. Initial rhizome enlargement in all the species takes place by the activity of meristematic tissues present below the leaf primordia of developing rhizome. These meristematic tissues develop into the primary thickening meristem (Fig.1 A), which on further growth, produces primary vascular bundles and parenchyma cells. Finally, the collateral vascular bundles with a parechymatous bundle sheath are found scattered in the ground tissue, which are responsible for the initial thickning in width of the developing cortex. Soon after the completion of development of primary vascular cylinder, some cells of the pericyclic region become meristematic and produce secondary thickening meristem, which in turn produces secondary vascular bundles and parenchyma cells (Fig.1 B). After completing the secondary thickening, the meristematic layers get converted into a single endodermoid layer. In addition to this, increase in size of the cortical and central parenchymatous regions in the rhizome is primarily the result of the activity of the ground meristem that divides at many loci followed by cell enlargement.

Secondary vascular bundles are amphicribral in nature and arranged in distinct zones or wavy patches (Fig. 1 C). Each vascular bundle consists of xylem and phloem. Xylem is composed of tracheids, xylem fibres and xylem parenchyma. The tracheids have spiral and scalariform thickening (Fig. 1 D). The phloem consists of sieve tubes, companion cells and phloem parenchyma. Two to three companion cells are present in association with each sieve tube. At maturity (6 months after planting) starch grains show variation in number, size and shape (Fig. 2 A). Curcumin cells and lysigenous oil cavities vary among species.

Though all the species basically have similar anatomical characters, variations are noticed in the number and

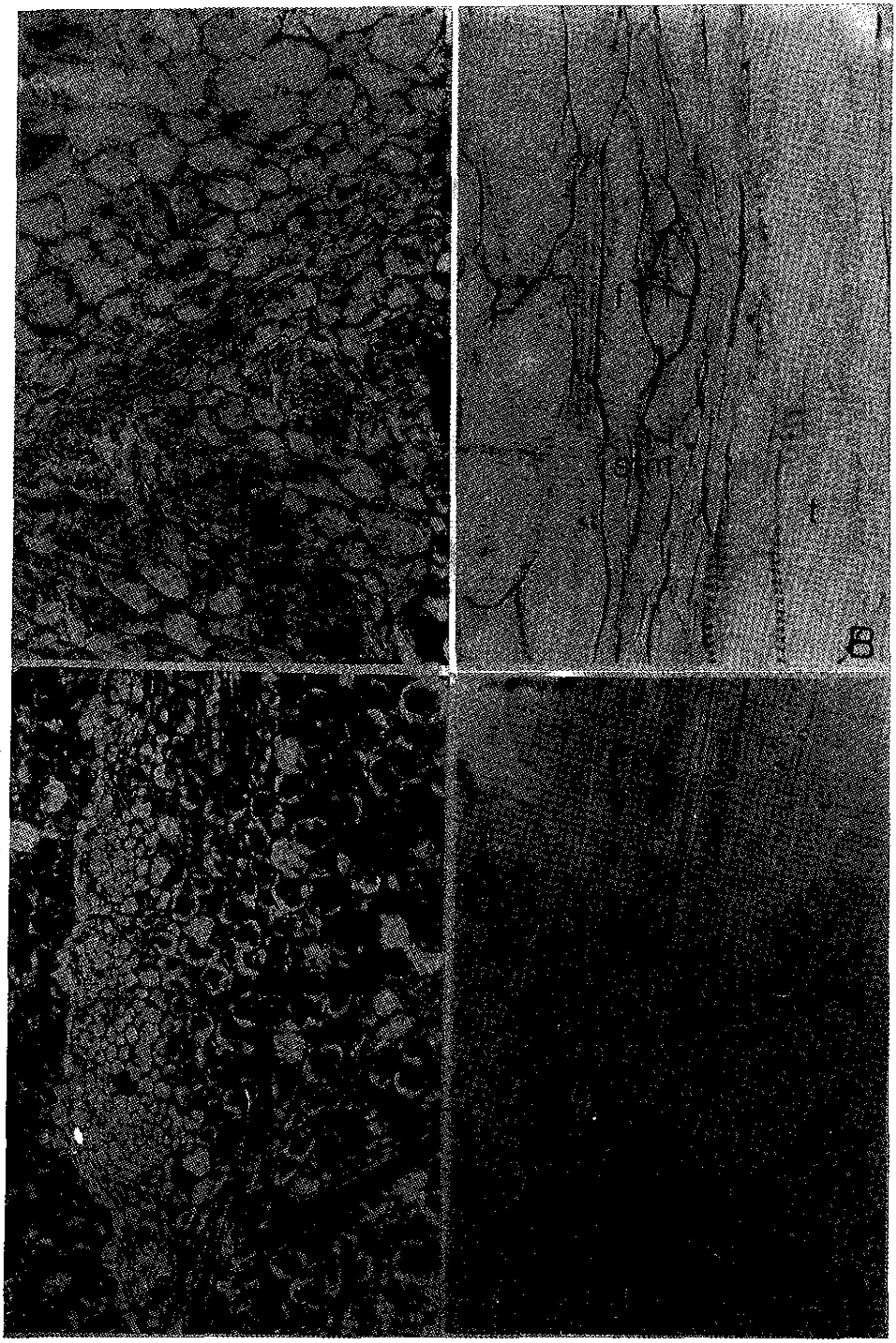

Fig. 1. C S of rhizomes of *Curcuma longa* and *C. aromatica*
A. Primary thickening meristem in *C.longa* (x 100) B. Secondary thickening meristem in *C. longa* (x 200) C. Wavy patches of secondary thickening in *C. aromatica* (x 100) D. Tracheids with spiral thickening in *C. longa* (x 200) (f-fusiform initial; ptm-primary thickening meristem; stm-secondary thickening meristem; r-ray initial; t-tracheids)

Table 1. Comparative morphological and anatomical profile of four species of *Curcuma*

Character	*Curcuma longa*	*Curcuma aromatica*	*Curcuma amada*	*Curcuma zedoaria*
Rhizome	Profusely branched, fingers up to 4th order	Less branched fingers up to 4th order	Profusely branched, rhizome more bulbous,	Less branched, mother leaf mid-rib purple
Colour of rhizome	Yellow	Creamy yellow	Creamy white	Orange yellow
Epidermal hair	2-celled, walls thick and lignified; bases swollen (Fig. 2 C)	1 or 2 celled and branched, walls thick and lignified	Single celled, walls thick and lignified. Cell lumen irregularly occluded	2-celled, walls thick and lignified; bases swollen
Epidermis	Single layered	Single layered	Single layered	Single layered
Periderm	Absent	4-7 layers of cells	4-7 layers of cells	4-6 layers of cells
Outer cortex	20-30 vascular bundles, collateral scattered	Lesser number of collateral scattered vascular bundles	Very few collateral scattered vascular bundles	25-35 vascular bundles, collateral scattered
Inner cortex	Amphicribral vascular bundles arranged in distinct zones	Amphicribral vascular bundles arranged in patches	Amphicribral vascular bundles in distinct zones	Amphicribral vascular bundles in distinct zones
Endodermoid layer	Continuous	Continuous and wavy	Continuous and wavy	Continuous and slightly wavy layer
Cambium	Cambium with fusiform and ray initials (Fig. 1B)	Meristematic layers of cells present	Meristematic layers of cells present	Meristematic layers of cells present
Xylem	Tracheids with spiral and scalariform thickening	Tracheids with spiral and scalariform thickening	Tracheids with spiral and scalariform thickening	Tracheids with spiral and scalariform thickening
Phloem	Sieve tube, 2 companion cells and phloem parenchyma	Sieve tube, 1-2 companion cells and phloem parenchyma	Sieve tube, 2-3 companion cells and phloem parenchyma	Sieve tube, 3-4 companion cells and phloem parenchyma
Bundle sheath	Present	Absent	Present	Absent
Fibre	Absent	Few numbers present	Absent	Few numbers present
Curcumin cells	More in inner zone than outer zone	Uniformly present in both zones, but smaller in size compared to *C. longa* and *C. zedoaria*.	Very few numbers present	More in inner zone than outer zone
Lysigenous oil cells	Present (Fig. 2 B)	Present	Few numbers present	Present
Starch grains	Show variations in size and shape; number varies from 6-18 in each cell (Fig. 2 A)	Variations in size, shape and number and are densely packed in each cell	Mostly rod shaped; number varies from 5-20 in each cell	Variations in size and shape, 6-15 grains in each cell

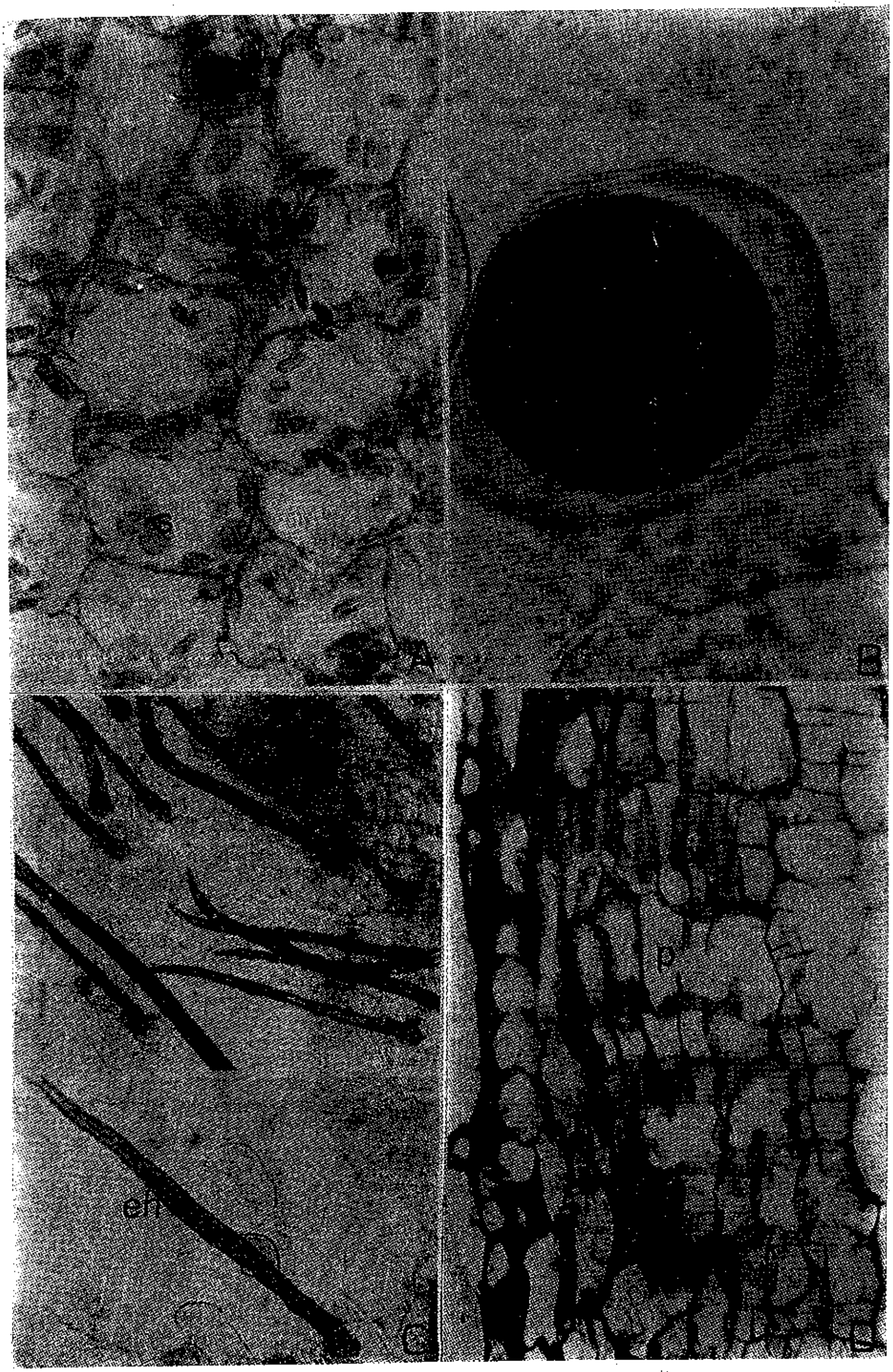

Fig. 2. C S of rhizomes of *C. longa, C. aromatica,* and *C. zedoaria*
A. Starch grains in *C. aromatica* (x 200) B. Oil cell in *C. longa* (x 400) C. Epidermal hairs in *C. longa* (x 200) D. Periderm layers in *C. zedoaria* (x 200) (eh-epidermal hairs; oc-oil cell; p-periderm layers; s-starch grains)

arrangement of primary vascular bundles, secondary vascular bundles, orientation of endodermoid layer, number and shape of starch grains, number and size of curcumin cells, etc. Primary vascular bundles are abundant and scattered in both outer and inner zone in *C. longa* and *C. amada;* the number is less in *C. zedoaria* and very few in *C. aromatica.* The endodermoid layer forms a continuous ring in *C. longa* and is more or less circular in *C. amada.* But in *C. aromatica* and *C. zedoaria* this layer is discontinuous and wavy in nature. Due to the broken nature of endodermoid layer, the secondary vascular bundles are arranged in patches in these two species and not as a continuous zone as in *C. longa* and *C. amada.* At maturity, the number, size and shape of starch grains vary among species and this is an important distinguishing feature of the species. Maximum number and size of curcumin cells are found in *C. longa.*

The unique and constant feature of monocotyledonous vascular anatomy is the existence of a well developed inner system and an outer system and an intermediate zone inbetween. In *Curcuma* rhizome, the intermediate zone is meristematic and in *C. longa,* these meristematic layers are associated with true cambium cells having ray initials and fusiform initials. Chakraverti (1939) had earlier reported fugacious cambium in turmeric that was present below the endodermoid layer. It is short living, and may vary from 2-6 cell layers. It soon disappears almost completely, leaving behind a ring or crowded bundles which Engler & Prantle (1899) referred earlier as *Die stark in die Augen springende Kreislinie.* The tissue at the interface between the cortex and the central cylinder is of particular interest and there are many different views regarding this intermediate zone. De Bary (1877) used the term 'cambium' and Kumar (1973) described it as a meristematic 'cambium like zone' separating the outer and inner system. Tomlinson (1969) held that the lack of cambium in the monocotyledons may provide evidence of previous cambial activity now almost lost in the evolutionary history. Earlier workers had given many terms to these meristematic layers but none of them pointed out the fusiform and ray initials of cambium. This cambium zone produces secondary vascular bundles and parenchyma cells centripetally to form a distinct zone or patches of secondary thickening.

Without contradicting the phylogenetic possibility pointed out by Tomlinson (1969), the present authors are inclined to interpret the presence of true cambium in *C. longa* as an adaptation for rhizome growth and development.

Apart from this, the number of companion cells associated with sieve tube in a vertical row is relatively high and the highest number was recorded in *C. zedoaria.* Increase in number of companion cells is directly proportional to metabolic translocation and deposition of reserve substances (starch). This was also considered as an identifying character among the species.

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