CONTRIBUTIONS TO THE ANATOMY OF THE CHENOPODIACEAE AND AMARANTACEAE. I. ANATOMY OF ALTERNANTHERA SESSILIS R. Br.

A. C. Joshi,

Department of Bolany, University of the Panjab, Lahore.

Introduction.

The Chenopodiaceæ and the Amarantaceæ are two large dicotyledonous families of world-wide distribution, though the former is better represented on the sea-shores, salt-marshes and other saline soils and the latter in the tropical and sub tropical regions of the world. As regards their systematic position most of the recent authors including Bentham and Hooker (4), Engler (8), Bessey (5), Wettstein (23), Rendle (17) and others who have tried to group the various families of flowering plants into a natural system, place them along with such families as Nyctaginaceæ, Phytolaccaceæ, Aizoaceæ, Caryophyllaceæ and Portulacaceæ under a common order Centrospermæ or Curvembryeæ, on the basis of their characteristic curved embryo. Wettstein also includes the family Cactaceæ in this order. On the other hand, Hutchinson (12) spreads these various families into three orders, Caryophyllales, Chenopodiales and Thymelacales. Nobody has, however, doubted the very close affinity between these two families. Chenopodiaceæ and Amarantaceæ. Baillon (3) has even definitely put the family Amarantaceæ under the Chenopodiaceæ. In fact, as Rendle says a differentiation between the two families is impossible and the separation into two families is merely one of convenience.

The anatomy of these families has been a subject of investigation for a long time by numerous workers. This has been due to the abnormal structure of the majority of these plants. These abnormalities affect both the primary and the secondary vascular cylinder. The ordinary dicotyledonous stem has a single ring of primary vascular bundles, but many of these plants possess additional bundles besides those of the normal ring, which from their position in the pith are called medullary bundles. The secondary vascular cylinder of these plants, both of the stem and the root, differs from that of the

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normal dicotyledons in the fact that within the active cambium zone there is more than one circle of distinct collateral vascular bundles showing a limited growth. These are embedded in an unlike tissue which is generally termed "interfascicular" or "conjunctive" tissue. According to De Bary (7) these abnormalities were first observed by Link (13) who also traced the course of the primary vascular bundles in the stem of some species of Amarantus. His work was followed by others, such as Unger (22), Regnault (26) and Sanio (18). Sanio was the first to give a complete ontogenetic development of several members of these families and he attributes the anomalous structure of the stem to the activity of a periodically active cambium which produces collateral vascular bundles and conjunctive tissue. At the conclusion of his work Sanio draws a comparison between the anomalous stem structure of the Chenopodiaceæ and the stem structure of those monocotyledons which are characterised by growth in thickness.

De Bary (7) in his Comparative Anatomy of Phanerogams and Ferns" reviewed all the previous literature and classified the diverse forms of anomalous thickening into four categories. In the first category, he placed those plants in which a "a primary ring of bundles appears in the stem and in the roots the primary axile bundle : in both there is first a normal cambium with normal products The activity of the latter then ceases and around it appear in centrifugal order, successively renewed and disappearing cambiums, each of which forms a circle of distinct vascular bundles". In his second category, "while the development of the normal ring is still proceed. ing there appears round the outer margin of the phloem, an extrafascicular ring of cambium : this remains permanently active and forms on its inner side alternately collateral vascular bundles and interfascicular tissue, on its outer side a thin layer of bast consisting only of parenchyma or no bast at all ". His third and the fourth types combine the characters of the first two types.

Morot (15) pointed out that it was impossible to maintain the two modes of growth described by De Bary and reduced them to a single type. He said that the cambium is in no case unipolar but always bipolar, forming xylem to the inside and phloem to the outside. As regards the origin of the successive cambium layers he says that a new arc of cambium arises outside the phloem face of a bundle and extends laterally, till it meets an older cambium. Accord ing to Herail (11), however, when the phloem is going to be formed, the combium branches into two, one of the branches continuing as the interfascicular cambium, the other extending to the outside of the phloem and meeting the older cambium layer.

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Georghieff (10) in his several contributions to the subject has reviewed all the earlier literature and given a fairly detailed account of the anatomy of both these families.

Fron (9, added some more to our knowledge of secondary growth, 1 ut he chiefly studied the primary vascular system and traced the course of primary vascular bundles in several genera of the Chenopodiaceæ.

Solereder (21) has summarised our knowledge of the anatomy of these plants from a systematic point of view.

Among the twentieth century workers who have contributed to the subject may be mentioned the names of Artschwager, Seeliger Wilson, Dastur, and Maheshwari. Artschwager (1) has investigated be stem structure of Chenopodium album. Further Seeliger (20) and Artschwager (2) have studied the anatomy of the vegetative organs of sugar eet. They find that all the secondary cambiums of this plant are genetically connected and every new cambium arises from cells cut of centrifugally by the preceding cambium. Wilson (24) has studied the course of the primary vascu'ar bundles in a number of plants belonging to these families and has tried to develop a theory about the origin of medullary bundles. He thinks these bundles to be a new formation and regards such forms as species of Amarantus to be the most advanced so far as the primary vascular system is considered. Dastur (6) has described the course of vascular bundles in the stem of Achyranthes aspera. Maheshwari (14) has very recently studied the structure and development of the vascular system in the stem of Boerhaavia diffusa, a plant belonging to the very nearly allied family Nyctaginaceæ, in which also the same types of anomalies as occur in Chenopodiaceæ and Amarantaceæ are found.

In spite of this large amount of work, however, there is still a great gap in our knowledge of these plants. It is that so far very few sustained attempts have been made to elucidate the origin and evolution of these abnormalities in the dicotyledonous vascular cylinder which are found not only in these two families but also in about 30 more. Though several critical accounts of their development are available, yet we know little about their past history, the part that they have played in the evolution of the stele of the flowering plants and their relative importance in working out the relationships of the different dicotyledonous families in any natural system of classification. On the basis of the wide distribution of these abnormalities among the dicotyledonous families, it has been generally assumed (Scott and Brebner (19), Wilson (24)) that they are a recent formation which have sprung up independently in various orders and

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have got nothing to do with the past history of flowering plants. No strong evidence, however, has been put forward in favour of such a conclusion.

The present investigation has been undertaken to see if after careful study it may be possible to know something about the history of these anomalies in the dicotyledonous axis. The order Centrospermales has been selected for such an investigation at present, since a good deal of work has already been done on this group and secondly because the writer could comparatively easily get the material required—many of these plants being common in Lahore and in the neighbouring parts of the Punjab and the Himalayas. The anatomy of *Alternanthera sessilis* R.Br., a member of the family Amarantaceae and found in all warm countries has been selected as the subject for the first paper of the series as this plant possesses a comparatively simple type of vascular cylinder and secondly because it enables us to draw up, as shall be seen later on, several preliminary conclusions.

Structure of the Shoot.

External Form. Alternanthera sessilis is a small, prostrate, pro. fusely branched herb, common in waste places and as a weed of cultivation in some areas but generally growing in dense patches near water. The stem is terete but for two shallow grooves in the young state, one on either side. The leaves are arranged in an opposite and decussate manner. Both the mature stem and the leaves are perfectly glabrous except for two lines of hair which persist in the two grooves on the stem for a long time. These grooves and lines of hair of an internode are in a line with the pair of leaves below them and like the leaves, change their position in every adjacent internode to a plane at right angles to their former position. The hair are simple multicellular and unbranched. Besides the main primary root, adventitious roots are borne abundantly on the lower nodes of both the main stem and the branches.

Structure of the Leaf. The walls of both the upper and the lower epidermal cells are straight and not wavy as is usual in dicotyledons. Stomata are present on both the surfaces but these are more abundant on the lower surface. The mesophyll is differentiated into spongy and palisade tissues and although the leaves appear to be fleshy externally, there is no distinct aqueous tissue. In the petiole there are a few layers of collenchyma just below the epidermis. Both the petiole and the midrib of the leaf are traversed by three vascular strands, which are the direct continuation of the three leaf trace bundies. These are not surrounded by any special sheaths.

Primary vascular system of the stem. The cells of the epidermis

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of the stem are greatly elongated, being 6 to 10 times as long as broad except in the region of the grooves where they are not much longer than broad. Stomata are present in a large number on the stem but only in the grooves. Just below the epidermis there are usually two or three layers of collenchyma, except opposite the two grooves. The cells of the outer cortex are rather loosely arranged and contain chloroplasts. A more or less distinct endodermis distinguished by the presence of starch grains is present.

A section of an internode, a little behind the apex shows that there are 8 primary vascular bundles (Text-fig. 1). These have the usual structure, being collateral, open and endarch, but they are not all equidistant from the centre of the stem. Two of

Fig. 1.-T. S of a very young internode, showing the 8 primary vascular bundles and the position of the primary cambium

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In this and the following diagrams, phloem is represented by dots, cam ium by a single line of cells, parenchyma white, lignified conjunctive tissue a brous elements of the xylem by black, primary xylem vessels by circles on the white back-ground and secondary xylem vessels by spaces in the black.

Fig. 2. Diagram showing the course of the primary vascular bundles in the stem. Darker lines represent the groove opposed bundles and the dotted lines the medullary course of the bundles.

them, situated opposite the two externally visible grooves, are nearer the centre than the other six bundles lying on their sides. They are, however, all equidistant from the circumference of the stem and run in the same line throughout the length of an internode. On coming down to a node, however, the groove opposed bundles fork

to form the common ramular and foliar gaps on either side. Their forked halves receive the branch traces which have the form of two brackets in a transverse section, and some branches from the lateral bundles of the leaf traces on the outside and then run through the pith to meet each other. The remain og six bundles of the upper internode also gradually pass inwards and join these. All of them coalesce and give rise to the two groove-opposed bundles of the lower internode, the remaining six bundles of which are formed by the new incoming leaf traces-each leaf trace consisting of three bundles. The whole course of the primary vascular bundles in the stem of Alternanthera sessilis as split down on one side and spread out in one plane is diagrammatically sketched in text fig. 2, where the darker lines represent the groove-opposed bundles, light lines the remaining bundles and the dotted lines the medullary course of the bundles. The point of entrance into the central cylinder of the three bundles making up the leaf trace is indicated by a curved line. In order to avoid confusion branch traces and branches from the lateral hundles of the leaf traces to the forked groove-opposed bundles are not shown in the figure. It shows that out of the eight primary vascular bundles of an internode, six are the direct continuations of the leaf trace bundles entering at the next higher node while the remaining two groove-opposed bundles are formed from all the primary vascular bundles of the next higher internode, branch traces and certain branches received from the lateral bundles of the leaf traces entering at the next higher node.

The Primary Cambrum. The primary cambium or the first cambium in the stem of this plant becomes distinct very early in the history of the organ. Even two or three nodes below the apical growing point, as the cortex and the pith are differentiating by the enlargement and rounding off of the cells cut off by the apical meristem, and xylem and phloem have begun to be formed from the procambial strands, a layer of cells intervening between the cortex and the pith becomes distinct due to the different behavior of its cells these do not enlarge, their cytoplasm remains dense and nuclei large. In fact, this layer of cells does not lose any of the characters of the meristematic tissue and from its activation later on the first cambial ring is formed.

The position of this primary cambium in an internode with regard to the position of the primary vascular bundles is very interesting. It is shown in text figs. 1 and 3. These figures show that the interfascicular cambium joins with the intrafascicular cambium of six bundles as in normal dicotyledons. But the interfascicular cambium fails to join with the intrafascicular cambium of the two bundles lying opposite the two grooves seen on the outside of the

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stem. This may be mechanically due to their position away from the ring inwards. The interfascicular cambium here bridges over the bundles—the two strips of interfascicular cambium on each side of the bundles here are united by a strip of extrafascicular cambium developed just outside their phloem in the region of the pericycle. In this way the first completed cambial ring in an internode of *Alternanthera sessilis* is partly normal and partly abnormal when compared with normal dicotyledons. It is made up of segments of intrafascicular, interfascicular and extrafascicular cambium.

All the parts of the primary cambial ring begin to function at the same time, but not in the same manner. The intrafascicular portions form xylem to the inside and phloem to the outside quite in the normal way, but it is not so with the extra fascicular and



Fig. 3. A part of fig. 1 showing the position of the cambium in the region of the groove-opposed bundles.

Fig. 4.-T. S. of an ordinary internode.

Fig. 5. An abnormal position of the cambium opposte a groove opposed bundle.

inter fascicular portions. The extra-fascicular portions of the primary cambium ring first cut off to the inside a few layers of cells, about five or six, which remain parenchymatous, enlarge, round off and merge into the ground tissue. Later on these form xylem to the inside and phloem to the outside. The growth in this region as compared with the other portions of the cambial ring is very rapid and soon two collateral bundles of xylem and phloem are formed to the outside of the two primary groove-opposed bundles. The interfascicular cambium similarly forms to the inside first a few layers of parenchyma which merge into the pith and later on fibrous interfascicular tissue which connects all the primary vascular bundles and secondary bundles formed opposite the two grooves into one continu-

ous ring of lignified elements and then after some time a few groups of xylem vessels here and there. To the outside, the interfascicular cambium forms only one or two layers of parenchyma except where it has formed xylem vessels to the inside Here it gives rise to phloem, so that collateral bundles are formed. The net result of this type of growth is the formation of a ring of vascular tissue which looks like the vascular ring of ordinary dicotyledons except that two of its bundles lack primary xylem and inside which two additional bundles are situated (Text-lig. 1). This is the structure of the ordinary internodes of the stem of Alternanthera sessalis. The internal bundles run in the same line throughout the length of an internode but in an adjacent internode they take up a position in a plane at right angles to the one which they occupied before and thus assume a false resemblance with the true medullary bundles such as Dastur (6) has described in the stem of Achyranthes aspera. They are not formed from pith cells but only assume a pseudo-medullary position due to the peculiar position and mode of activity of the primary cambial ring.

A few exceptional cases were noticed where the inter-fascicular cambium had joined the intra-fascicular cambium of the groove opposed primary vascular bundles. This condition, however, in no case persists for a long time, such a cambium soon becoming inactive and replaced by a new are of cambium developed in the pericycle (Textfig. 5). As all the cells cut off by this temporary abnormal cambium in the inter-fascicular region remain parenchymatous and merge into the ground tissue, no record of its existence is left in the mature plant.

On the approach of a node, the inter-fascicular cambium begins to pass out and ultimately separates from the intra-fascicular cambium. The first complete cambial ring, in the region of the node, is entirely extra fascicular.

The phloem as usual consists of sieve tubes, companion cells and phloem parenchyma. There is no hard bast. The primary and the secondary phloem do not differ in structure and merge into each other. The primary and the secondary xylem, however, can always be distinguished in a transverse section of the stem. The vessels of the primary xylem are scattered and separated by thin-walled cells, while those of the secondary xylem are separated by fibrous elements of the same nature as make up the lignined inter-fascicular tissue.

The Secondary or the Supernumerary Cambiums. A cross section of the base of the stem (Text-fig. 6) shows that here the vascular tissue is not arranged in a single ring as in the ordinary branches but there are a number of annular zones or rings of vascular tissue, one lying to the outside of another. All the rings may not always be

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complete as there often appear smaller or larger segments here and there and so lead to the union and anastomosing of the different rings. On the inner side of the innermost ring are situated the two apparently medullary bundles. The size of the vascular zones and the distance between the adjacent zones decreases as one passes to the periphery from the centre of the cross section. At the extreme outer end of the vascular cylinder, a multiseriate cambium is still active and forming new tissues.

Each ring is composed of numerous collateral bundles joined together by fibrous conjunctive tissue and since this tissue takes the same stain as the xylem and the fibrous elements of the xylem are of the same type and there is no parenchyma in secondary xylem, the whole vascular zone looks like a complete ring of wood. The adjacent vascular rings are separated by parenchyma (Text-fig. 7).



Fig. 6.-T. S. of the base of the stem.

The development of these vascular rings is due to the activity of a series of cambiums succeeding one another. We have previously seen that the first cambial ring or the primary cambium forms wood and conjunctive tissue centripetally and centrifugally phloem only in the vicinity of vessels and one or two layers of parenchyma in the inter-fascicular region. It is from these few layers of parenchyma that the next or the first secondary cambium takes its origin. Outside the fascicular regions since there is no such parenchyma the secondary cambium arises either from the pericycle or rarely from the phloem parenchyma itself.

Once initiated the secondary cambium functions like the primary cambium. Centripetally it forms in the beginning several layers of parenchyma which separate the outer vascular zone from the inner vascular zone and later on proceeds to the formation of the fibrous conjunctive tissue and xylem vessels at certain places. Centrifugally the cambium cuts of one or two layers of parenchyma, the cells of which enlarge and round off a little but

do not lose their radial arrangement. It is from these parenchyma cells that the next outer cambial ring takes its origin. The development of the phloem may take place simultaneously with the differentiation of xylem vessels but generally it is a little belated. Text-fig. 8 shows that it is entirely centrifugal in its development from the cambium and it is formed only opposite to those places where the cambium has formed previously xylem vessels to the inside, so that collateral bundles are formed. After the differentiation of the xylem and the phloem, the cambium may persist in between the two, though never in an active state or may be used up in the formation of phloem



Fig. 7.-A part of Fig. 6, showing the tissues of two vascular zones.

Fig. 8.—Diagram showing the formation of phloem by a secondary cambium. 9.-Diagram showing the origin of a new cambium.

Fig. 10.-Diagram showing the tissues formed to the inside by the new cambium.

either in the very beginning or a little later. The next outer cambium is formed generally simultaneously with the formation of the phloem. It may be a little belated in other cases. Every next outer cambium arises from the parenchymatous cells cut off centrifugally by the preceding cambium (Text-fig. 9) and functions in the same way, first forming centripetally a few layers of parenchyma and later on the lignified zone for fig. 10) and centrifugally a few layers of parenchyma and phloem. All the supernumerary cambiums are not formed almost simultaneously as Artschwager (2) has described in

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Beta vulgaris but the next outer cambium arises only when the preceding one has finished its activity.

Since all the cambiums arise from the cells cut off by the preceding cambium, they all stand in direct lineage with the first primary cambium and are genetically connected. This is clearly shown even by the arrangement of tissues in the mature condition. All the cells of the secondarily formed tissues whether parenchymatous or lignified starting from the inner extremity of the vascular cylinder and leading up to its outer extremity, where a multiseriate cambium is still active and forming new tissues, are in more or less radial rows (Text-fig. 7).

As every cambium cuts off a few layers of parenchyma centrifugally, these go on accumulating to the outside of the vascular zone and ultimately form a very prominent zone of radially arranged parenchyma separating the vascular cylinder from the primary cortex on the outside (Fig. 14, though from the root, shows exactly the same thing).



Fig. 11.-T. S. of the base of another stem (a part).

This is the normal course of events but some variations of great morphological interest may be mentioned. Ordinarily when a cambial ring becomes inactive, a complete ring or a big are of cambium is formed to its outside. Not uncommonly, however, the new cambium arises only to the outside of the phloem and becomes after a longer or shorter period connected laterally with the pre-existing inter-fascicular cambium, the activity of which does not slacken and which goes on forming new tissues as before without any change in their destination. In this case parenchyma is formed only opposite the phloem, while on its sides lignified elements go on forming uninter-1935-7

rupted. This leads to the union of the various vascular rings by lignified elements in relation to the position of phloem (Textfig. 11). Another variation though of not so great an importance but as common as the preceding one is that generally when any cambium has begun to form lignified elements after the formation of parenchymatous ones, it goes on forming lignified elements alone till its activity comes to a stop. But sometimes lapses occur and in the midst of lignified elements one can very commonly see cells scattered or in larger or smaller groups which have not lost their parenchymatous character and have refused to become lignified.

The lignified 'inter fascicular-tissue . or the 'conjunctive tissue' as it is called, of various vascular zones is of the nature of septate fibres. These are connected through various intermediate forms with the parenchymatous tissue that separate the different vascular zones (Text-fig. 12).

Inflorescence. The inflorescence of Alternanthera sessilis is a very small structure with only poorly differentiated vascular system. There is a ring of 4-6 weak vascular strands in the axis from which traces to the spirally arranged flowers are given off.

Structure of the Root.

In its primary structure the root of Alternanthera sessilis resembles the ordinary dicotyledonons root, but in secondary thickening it agrees in main with its own stem. A transverse section of the primary root just behind the apex (fig. 25) where the differentiation of the primary tissues is almost complete, shows an epidermis and a cortex of about five or six layers. There is no distinct endodermis The central

Fig. 12 —Elements of the conjunctive tissue, showing a gradual iransition between the parenchymatous and fibrous elements.

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cylinder is made up of a diarch xylem plate with alternating phloem groups and is bounded externally by a single layer of pericycle. The outermost cells of the xylem and the phloem directly abut on the pericycle. The phloem is separated from the primary xylem plate by a single layer of parenchyma—the interstitial parenchyma. The development of the xylem can be very easily followed from a cross section. The protoxylem or the first xylem elements are formed at two places adjacent to the pericycle and situated directly opposite each other. Further differentiation proceeds centripetally until the two protoxylem points meet in the centre to form the primary xylem plate. All further formation of xylem is of secondary nature, being formed by the primary cambium.

The secondary and the adventitious roots both differ from the primary root in being triarch instead of diarch (Text-fig. 13), otherwise their primary structure and further secondary growth is exactly like that of the primary root.



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Fig. 13.—A part of the T. S. of a young secondary root showing the central vascular core.

The cambial activity in the root like that in the basal portion of the stem embraces two phases; (i) the differentiation and growth of the primary cambium and (ii) the development of the secondary cambiums. The primary cambium only forms the innermost central star-shaped core of vascular tissue, (figs. 13, 15, and 23), while the secondary cambiums form a large number of super-numerary vascular rings one after another (figs. 14 and 15).

The primary and the first secondary cambiums develop very early in the history of the root. A small seedling in which only the cotyledons have unfolded shows both these cambiums. The primary cambium arises by the axial elongation and tangential division of the parenchyma cells in between the primary xylem and the phloem (fig. 24). It becomes visible at first in the region of the two phloem poles but gradually extends laterally over the protoxylem poles. In

the latter case, the divisions which give rise to the cambium, take place in the pericycle. This primary cambium develops xylem and phloem as any other cambium would do (fig. 23). The xylem developed from it unites with the metaxylem of the primary wood. The zone in front of protoxylem remains free from secondary wood. Here the cambium forms parenchymatous tissue only. These are the two primary vascular rays. The secondary phloem which is formed simultaneously with the secondary xylem, like the xylem becomes continuous with the primary tissue and indistinguishable from it. Such activity of the primary cambium leads to the formation in the centre of the adult root of a bilobed vascular zone (fig. 15) or in the adventitious or secondary roots of a trilobed one. Secondary rays gradually begin to appear inside the secondary vascular tissue and the whole thing assumes the appearance of a star-shaped central core but two or three primary rays remain wider than any other that may be developed afterwards and at their inner ends the first protoxylem elements may be distinguished (Text-te, 13).

While the primary cambium is still active, the secondary cambium is formed outside in the pericycle opposite the phloem pcles and from a layer of cells cut off by the primary cambium to its cutside, opposite the protoxylem poles (fig. 23). These cells enlarge, divide again and again and so form a ring of collateral vascular bundles separated from the central core by several layers of parenchyma. The sequence of the formation of the various tissues is as follows: the secondary cambium first of all forms several layers of parenchyma centripetally which separate the next outer vascular zone from the central core and then xylem in certain restricted regions. Xylem consists of vessels and fibres. Centrifugally it forms two or three layers of parenchyma which are the seat of origin of the next outer cambium and phloem opposite the xylem strands. The inter-fascicular tissue all remains parenchymatous For this reason a ring of collateral vascular bundles separated by parenchymatous rays is formed. All the next outer cambiums arise as the activity of the preceding one comes to an end from the cells cut off centrifugally by the preceding cambium as in the stem and so stand in direct lineage with the first secondary cambium.

Each of these cambial rings functions like the first secondary cambium as described above. But one change takes place in the nature of the inter-fascicular tissue as one proceeds from the innermost vascular ring towards the periphery. In the innermost rings the individual vascular bundles are separated from one another by parenchymatous inter-fascicular tissue (fig. 15) but as one passes to the exterior the various bundles of the rings begin to be joined by

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lignified elements of the nature of septate fibres, as is the case in all the rings of the stem (figs. 14 and 15).

The phenomena of secondary growth in the hypocotyl are like those of root and the stem, showing a gradual transition between the

In the stem the periderm is formed only in the basal portion In the root, however, it is found in every part and develops very early in the history of the organ, by the conversion of cells just below the epidermis by tangential divisions into a band of meristematic tissue the phellogen or the cork-cambium. From this cork-cambium are formed by reciprocal division cork cells to the outside and phelloderm cells to the inside. The number of the latter, however, is very meager compared with the number of the cork cells, since the former are constantly sloughed off and must be replaced. On the whole, the performed needs to be a very thin layer of suberized cells, being less than ten cells thick.

Clustered crystals of calcium ozalate are a common feature of all parts of the plant.

Mining insects very commonly attack this plant in Lahore These bore through and destroy the vessels. The plant reacts to such injury, by the formation of cork round the affected bundles.

Structure of the Seedling.

The seedlings of Alternanthera sessilis show as usual four parts namely, the cotyletons, the epicotyledonary portion, the hypocotyl and the roo. The cotyledons are elliptical with lamine nerowed a the base to form a short petiole and stomata are present on both the surfaces. Their mosophyll is differentiated into spongy and miliade tissues. The two are however, commonly separated by more or less regular, one two or three layers of nonchlorophyllcus cells which are somewhat elongated parallel to the surface of the blade (fig. 16). In the centre of the midrib is situated a single collateral bundle which gives off lateral branches. The latter run in the parenchymatous cells intervening between the palisade and spongy tissues which seem to act as a sort of sheath for these lateral branches of the central bundle.

At the base of the cotyledon, its single median bundle divides into two (fig. 17). The two phloem and the metaxylem halves move wide apart but the protoxylems curve outwards (fig. 18), and form an exarch xy lem plate which is the direct continuation of one of the protoxylem poles of the root. In this way when the cotyledons join the axis their vascular supply consists of two collateral bundles and a small exarch xylem plate in between the two (fig. 19.)

The epicotyledonary traces do not take any essential part in the root-stem-transition but merely attach themselves to the cotyledonary traces either very abruptly (fig. 20) or step by step, the epicotyledonary traces first uniting among themselves and then fusing with the cotyledonary traces (fig. 21). The root structure is formed by the inward progression and meeting in the centre of the exarch xylem plates which have already been differentiated in the cotyledons (figs. 22 and 23). The phloem portions of the cotyledonary traces move towards the sides of this xylem plate and those of the opposite cotyledons join and so give rise to a diarch primary cylinder.

Summary.

1. The stem of Alternanthera sessilis possesses in addition to the ordinary ring of bundles, two additional bundles situated internally to the former. These bundles run in a straight line throughout the length of an internode but in every adjacent internode they always arrange themselves at right angles to their former position, just as Dastur has described in Achyranthes aspera. The internal bundles of Alternanthera sessilis, however, unlike those of Achyranthes aspera, are only apparently medullary. Near the growing point there are no bundles internal to any other bundles. Their formation in the mature stem results from the peculiar position of the first cambial ring (which is extrafascicular opposite two of the bundles of the primary vascular ring that later on become the internal bundles and normal in the rest) and its mode of functioning,—forming first several layers of parenchyma before forming lignified elements.

2. At the node the internal bundles fork and their forked halves after receiving the branch traces, certain branches from the lateral bundles of the leaf traces and one by one the rest of the primary bundles of the upper internode, run through the pith in opposite directions to meet each other and so give rise to the internal bundles of the lower internode in a plane at right angles to their former position. The rest of the primary bundles of an internode are the leaf traces entering at the next higher node.

3. In the ordinary branches of *A. sessilis* all the vascular tissue, except the two internal bundles, is arranged in a single ring. But at the base of the stem and in the root several concentric rings of vascular bundles are formed by a succession of secondary cambiums, each arising from cells cut off to the outside by the preceding cambium.

4. The conjunctive tissue in the stem of this plant in all the vascular rings is fibrous, while in the root it is parenchymatous in the

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inner and fibrous in the peripheral rings. The fibrous tissue is connected through various intermediate forms with the parenchymatous ground tissue that separates the different rings.

5. The chief feature of the stem-root-transition is that the single cotyledonary bundle divides into two and these in between themselves form the protoxylem poles of the root even at the base of the cotyledon itself.

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Explanation of the Plates.

PLATE I.

- Fig. 14. Outer portion of the transverse section of an old primary root.
- Fig. 15. Central portion of the same.

PLATE II.

Fig. 16. Transverse section of a cotyledon of the seedling.

- Figs. 17, 18, and 19. Transverse sections of the base of the cotyledon at various levels from above downwards, showing the branching of the cotyledonary bundle and formation of an exarch xylem plate.
- Fig. 20. Transverse section of the hypocotyl region of a seedling
- Fig. 21. Transverse section of the hypocotyl region of another seedling.
- Fig. 22. Transverse section of the hypocotyl at a lower level than in figs. 20 and 21.

Figs. 23, 24, & 25. 'Transverse sections of the primary root of a seedling; fig. 25, just behind the apex, showing the primary structure; fig. 24, further behind than fig. 25 showing the origin of the primary cambium; fig. 23 still turther behind, showing the result of the activity of the primary cambium and the origin of the first secondary cambium.