Station Bulletin 138 May, 1916

Oregon Agricultural College

Experiment Station

Division of Horticulture

The Pollination of the Pomaceous Fruits

III. Gross Vascular Anatomy of the Apple

BY

E. J. KRAUS
Professor of Research in Horticulture

AND

G. S. RALSTON
Research Fellow in Horticulture

CORVALLIS, OREGON

FOREWORD

This is the third contribution to our series of research bulletins entitled: The Pollination of the Pomaceous Fruits; Bulletin No. 1, Part I, Gross Morphology of the Apple, by E. J. Kraus, was published in April, 1913; Part II, Fruit-Bud Development of the Apple, known as Station Bulletin 129, was published in May, 1915.

It was our original intention to include all the bulletins dealing with the pollination of the pomaceous fruits as parts of Research Bulletin No. 1; but in order to avoid confusion on the part of librarians or others caring to index and file bulletins, it has been deemed best to publish all Oregon Experiment Station bulletins in serial number.

C. I. LEWIS,
Chief, Division of Horticulture.

GROSS VASCULAR ANATOMY OF THE APPLE

By E. J. Kraus, Professor of Research in Horticulture
and G. S. Ralston, Research Fellow in Horticulture*

Introduction

During the progress of the pollination studies by the Division of Horticulture at the Oregon Agricultural College, it became evident that various subsidiary factors, which may be more or less intimately connected with the pollination and development of the fruit, had not been sufficiently investigated. All factors that may be concerned must be thoroughly investigated before a complete knowledge of the underlying principles of fruit development can be attained. Among these subsidiary factors, one of the most important is a study of the relationship that the vascular system of the fruit bears to its development. At the present time no comprehensive data concerning the arrangement of the vascular elements of the apple fruit, or their origin in the spur, are available. The primary object in this investigation has been, not to make a complete morphological or cytological study of the vascular tissue or its physiological functions in relation to fruit development, but rather to trace the vascular system of the normal fruit from its origin in the cluster-base, through the pedicel and fleshy portion of the fruit, noting the position, divisions, connections, and terminations of the system in the fruit.

Review of Literature

A brief review of the available literature indicates that the vascular system of the apple has received attention from comparatively few investigators, though the following resume lays no claim to completeness. Beach[1] makes this statement: "Bundles of fibres or veins called fibro-vascular bundles enter the fruit through the stem. Some of them pass directly through the core along the inner edge of the seed cavities and continue on into the outer parts of the pistil. Between the seed cavities and the base of the stem other lines of fibro-vascular bundles lead off from the stem, inclose a portion of the flesh varying in form from turbinate to nearly globular, and terminate principally in that portion of the calyx tube where the stamens are inserted, though sometimes apparently below the insertion of the stamens." The same writer says also, "The vascular bundles which may be most easily followed in tracing the core line are ten in number, and occur one opposite each outer angle and alternately one opposite each inner angle of the seed cells."

Brooks[2] in discussing the vascular system of the apple remarks, "If an apple is cut in halves perpendicular to the core, ten green spots may be seen arranged in the form of a circle midway between the core and the epidermis. These are the large vascular strands of the apple. Small branches are given off from either side of them. The main branches give off comparatively few smaller ones until near the margin of the hypodermal tissue, pre-

*A part of the data presented in this bulletin was obtained by Mr. Ralston while a graduate student assistant in the research section of the Division of Horticulture and was embodied by him in a thesis, now on file in the College library, presented as part fulfillment of the requirements for the degree of Master of Science.

viously described. Here they branch profusely and anastomose in a seemingly indiscriminate manner. The veinlets from one large vein unite with those from another so that the whole surface system is closely interwoven and connected. In the small veinlets the vascular elements become finer, finally giving place to long narrow cells that seem to be transitional between the vascular tissue and that of the apple pulp."

McAlpine[3] recently has dealt more completely with the vascular system of the apple and its functions. His work comprises a detailed study of the course of the vascular system in the apple, its branchings and anastomosings as he found them. He lays particular emphasis upon the complex network of fine fibers close to the epidermis which has been briefly mentioned by Brooks in his work on Fruit Pit. McAlpine also discusses the functions of the vascular system. His description deals almost entirely with the fruit; but slight mention is made of the vascular tissue at the apex of the pedicel, and none at all of its origin in the cluster-base.

In reviewing the above-mentioned contributions in the light of the present investigations they seem rather incomplete, and evidently but partly correct. An attempt is made in this article to give a more nearly complete description of the vascular system of the apple as indicated from the present study.

Methods

The Yellow Newtown was selected for investigation, and a detailed study made of this one variety only. The preliminary work began in July, 1912, with a study of the immature fruits, which at that time were from three-quarters to one-and-one-half inches in diameter. To aid in defining the bundles, it was desirable to infiltrate them with a colored solution in order more clearly to differentiate them from the surrounding tissues. A one percent aqueous solution of eosin gave satisfactory results as a dye material. The twigs bearing the apples were brought into the laboratory and the cut end of each inserted in the dye solution. The leaves were left on the twigs, since they were thought to hasten the infiltrating of the bundles in the fruit. Subsequent dissection of the apples did not prove satisfactory, owing to the rapid discoloration of the immature apple tissues when exposed to the air, the brown color of the tissue masking the red of the eosin. To prevent the discoloration of the tissues, it was necessary to fix, dehydrate, and clear the infiltrated material. Accordingly, after the apples were infiltrated with the dye solution, they were cut into thin sections, fixed, and dehydrated in alcohol and cleared in either xylol or cedar oil. Unfortunately eosin is soluble in alcohol and washes out during the dehydrating processes. For this reason it became necessary to use a material that would be taken up into the vascular system, would be insoluble in alcohol, and would retain its color throughout subsequent treatment. Both cupric sulfate and ferrous sulfate fulfilled these conditions, and though they were not so satisfactory as eosin, they gave fairly good results. The unsatisfactory feature connected with their use is the tendency, in the case of both, to clog the vascular tissue, especially at the proximal end of the apple, and to diffuse or spread into the surrounding tissue without infiltrating the bundles anterior to the point where the clogging of the bundles occurs. An aqueous solution ranging from two to four percent proved the most efficient. The time required to infiltrate the bundles varied from twenty-four hours to four days. Later, a one percent aqueous solution of common Magdala red was used with excellent results. Thin sections of the mature fruit, ranging in thickness from one-eighth to one-fourth inch, when dehydrated and cleared, serve to show the bundles without stains of any kind. An unsatisfactory attempt was made to dissolve the tissue from about the bundles in the fruit with weak solutions of sodium and potassium hydrates. However, a two percent solution of potassium hydrate served admirably to bleach the new growth of the cluster-bases, collected when the flowers were in bloom, so that after subsequent washing, dehydrating, and clearing, the bundles were easily traced under the binocular microscope with but little necessary dissection of the overlying tissue.

It soon became evident that the origin of the bundles found in the remnants of the floral parts could not be positively determined in the partly or fully matured fruit. Again, some of the divisions of the system occur at the apex of the pedicel, and in the advanced stages of development the branches are so crowded, the space containing them so limited, and the pedicel so hard and so difficult to dissect or section, that no definite conclusions could be obtained. To overcome this difficulty, fruits in less advanced stages of development were examined. Gross dissections of these stages, as in the case of the mature fruits, were generally unsatisfactory, but since the material was soft enough to permit sectioning, a microscopic study of serial sections was possible.

The microscopic study was based upon materials collected during the latter part of February and continuously thereafter until the petals had fallen in May. Both Gilson's mixture and absolute alcohol were used for killing and fixing. The former reagent was much the better, since the material fixed in it was less brittle. In all cases the bud scales were removed to facilitate sectioning. The material was imbedded in paraffin, and the majority of the sections were cut from twenty-five to fifty microns in thickness. Either tissue paper, tied on with thread, or a very thin coating of celloidin was put over the sections to prevent them from washing off the slide during the staining processes. Magdala red (1 percent aqueous solution); safranin (1 percent in absolute alcohol); alum carmine, and Delafield's Haematoxylin were used in staining, the haematoxylin being especially valuable in differentiating the vascular fibres from the other tissues in the younger stages.

Discussion

Five distinct general regions are recognized as having place in a discussion of the vascular anatomy of the fruit of the apple. First, the cluster-base, which includes that portion of the fruiting branch extending from the base of the growth made during the year that flowering occurs to the apex of the peduncle, Figs. 1 and 2, a; second, the peduncle, which is extremely short, extends from the apex of the cluster-base to the base of the pedicel of the terminal flower, Fig. 2,b; third, the pedicel or fruit stem which extends from the peduncle slightly or sometimes some distance into the fleshy portion of the fruit to the point where the carpellary vascular system separates from that of the torus, Figs. 1, d, 14,b; fourth, the fleshy or toral portion, together with the organs which arise from it; namely, sepals, petals and stamens; fifth, the carpels. The discussion in this paper deals only with the anatomy of the pedicel, toral, and carpellary systems. The remainder have been traced but will be discussed in a subsequent paper. The flower cluster is assumed to include the flowers, branch buds, Figs. 1 and 2,c, and leaves borne within the fruit bud.

Pedicel. While an examination of the vascular systems of the pedicels of the lateral and terminal flowers shows some variation, the two are so very similar that beyond a mere enumeration of the more striking variations it is deemed sufficient simply to trace, in detail, the vascular system of the terminal pedicel and fruit.

Broadly speaking,* the vascular system of the cluster base consists of a number of vascular strands which form a complete or nearly complete woody cylinder, from which arise, in a quite definite manner, smaller strands which extend into the leaves, branches, and bracts. The main longitudinal strands, somewhat reduced in size and number, though still nearly or entirely united one with another, extend on into the peduncle, and from them arise lateral strands which serve the lateral flowers and the leaves or bracts which subtend them. The vascular cylinder becomes smaller and smaller as the successive flower systems arise from it, though the gaps so caused are almost completely filled by the smaller branches which arise from the strands on either side of them. As a result, when the base of the terminal flower pedicel is reached, usually but five prominent strands remain, and between them are many smaller fibers, Fig. 3. As has been previously mentioned, there is some variation in the terminal and lateral pedicels. The main difference is that in the case of the latter, the large bundles are more or less unequally placed, and, instead of being limited to five, are variable in number, as many as nine being found in some examples, Fig. 4. There exists, however, the same arrangement of small fibers grouped between the large bundles. Although these differences exist at the bases of the respective lateral and terminal pedicels, the number of bundles at the apex of each is substantially the same.

At the base of the pedicel, then, the vascular cylinder appears quite similar to that of the cluster base, except that ordinarily it is not so nearly circular. In most examples, the outline is pentagonal, and one of the five main bundles is located at each of the angles of the pentagon, Fig. 3. As the bundles are traced up through the pedicel, the marked difference in size between the larger and smaller is less, though it is distinct at all times. The five principal bundles usually continue as such until near to the apex of the pedicel, or well above its middle, where each is once divided, forming ten, Fig. 5. The exact

*A full discussion will be presented in a forthcoming paper.

point where this division occurs varies greatly in different specimens. In any event, the ten bundles tend to separate so that they are equidistant one from the other, and the small longitudinal fibers remaining between them are drawn nearer to the longitudinal median axis of the pedicel. In addition, there occurs at a slight distance anterior to the base of the pedicel (the exact point varying in the individual flowers), a branching of a few small fibers from the main vascular cylinder into the pith region. These fibers extend anteriorly, and while not precisely arranged, a secondary more or less definitely located cylinder is formed within the main one, Fig. 5 svb. Beyond the point where these fibers branch from the primary cylinder, numerous others, similar in size and origin, are added either to the secondary cylinder, or are located between it and the primary. Just before the apex of the pedicel is reached, however, these small fibers and others arising from the ten large bundles previously mentioned, bend inward toward the smaller inner cylinder and a confused branching and anastomosing of all the smaller bundles occurs, thus completely eliminating any resemblance to a circular or cylindrical arrangement, Fig. 6. The ten large primary bundles draw farther apart, and at the apex of the pedicel, where they diverge into the fleshy portion of the apple, are arranged into two cycles of five each, every alternate bundle being in the same cycle. In other words, each of the five antecedents of the ten primary bundles supplies one bundle to each cycle. At the apex of the pedicel the bundles are approximately equidistant, and here they diverge into the torus following a boundary between the modified pith and cortical region, Figs. 8 and 13.

Between the point where the last of the small bundles branches from the vascular cylinder into the pith and the point where the primary bundles diverge in the proximal end of the apple, there arises from each of the five bundles which make up the outer cycle one branch that is enlarged by fibers joining it from the mass of anastomosing fibers previously described. They then continue anteriorly into the pith region of the fruit without giving to, or receiving connecting fibers from, the primary bundles, until they attain the bases of the carpels, Figs. 8, 13, 14. The exact point of origin of these fibers varies considerably; in some cases they separate from the primary bundles at approximately the same point from which the last small bundles diverge from the vascular cylinder into the pith region; in other instances they do not branch from the primary bundles until very close to the apex of the pedicel. Each of the five branches may not separate from the primary bundles at the same level in the pedicel, although the width of the zone of separation, from the origin of the first to the origin of the last, is slight. These bundles are again, and more properly, referred to in the discussion of the carpellary system.

The small strands forming a complex mass in the pith parenchyma of the pedicel, in addition to giving many branches to the five bundles which extend to the carpels, frequently unite with the primary bundles, and become greatly reduced in number before the base of the carpels is reached, Fig. 9. Thus, in all, fifteen distinct bundles (consisting of ten primary and five secondary) and a complex mass of small fibers extend from the pedicel into the fleshy portion of the apple.

Toral System

The ten primary bundles which diverge at the apex of the pedicel follow closely the so-called core line which has been shown to mark the boundary line between the modified pith and cortex. As previously pointed out, these ten bundles are arranged in two cycles: those of the outer cycle are located opposite the dorsal sutures of the carpels, and are farther from the vertical axis of the fruit, while those of the inner cycle alternate with the carpels, Fig. 10.

As indicated by McAlpine there is a ratio existing between the number of carpels and the number of primary or toral bundles. This ratio is constant in the normal fruit, the number of toral bundles being twice the number of carpels. Examples were found, however, in which the normal number of five carpels was present and the toral system contained eleven toral bundles. An abnormally placed calyx lobe was present in each example. Such calyx lobes were frequently found located at any point from close to the normal position to well inside the cavity. The extra bundle in the toral system terminated in the abnormal lobe, and did not branch to the normally placed sepals or to the stamens, though it was intimately connected with the adjacent toral bundles by connecting fibers. The additional bundle did not in any example follow the boundary line of the pith and cortical regions, but diverged into the cortex immediately above the apex of the pedicel so that it was not in either cycle of toral bundles within the fleshy portion of the fruit. The abnormal lobes were supernumerary in all the cases examined, for the regular number were present and normally placed. This differs from the report of Bonns[4] who found only four calyx lobes normally placed when an abnormally placed lobe was present.

Cortical Region. From the ten primary toral bundles arise large branches which extend outward into the cortex. As seen in the mature fruit, these branches divide comparatively little until well toward the epidermis, where they subdivide into relatively large branches which anastomose not only with the other fibers from the same, but also with branches from the adjacent, toral bundles, Fig. 17. Thus there is formed a network of large fibers which in turn give rise to innumerable smaller fibers which again subdivide and anastomose profusely, so that the tissue close to the epidermis is densely filled with a network of fine fibers, some of which terminate in the subepidermal tissue as long narrow cells transitional between vascular and pulp tissue. Many fine fibers also extend from the primary bundles toward the periphery of the fruit, branch but little, and either anastomose with the large branches or else terminate free in the pulp tissue in the same manner as the foregoing. No vascular elements were found to extend into the layer of cells which makes up the epidermis.

At a point approximately opposite the upper end of the carpels the primary bundles leave the immediate boundary of pith and cortex, the bundles of the outer cycle diverging farther into the cortex than do those of the inner. The final termination of all the bundles is either in the sepals, petals or stamens, as described in the following paragraphs.

Stamens. From each of the five primaries of the *outer* cycle arises one branch from the inner or pith side. The point where this branch originates varies in individual examples; it ranges from the apex of the pedicel to the distal end of the carpels. If this branch arises at the former point, it may pass through the pith region to a slight extent, but closely follows the course of the primary bundle from which it originated. In any event, these five branches continue upward and terminate one in each of the five stamens of the inner cycle. Very often as many as three bundles are given off in a manner similar to the stamen branch, but if this occurs the additional bundles either coalesce with the primary bundle from which they branched or pass out into the cortex. The remaining fifteen stamens (the normal apple has twenty) receive branches from the toral bundles of the *inner* cycle in the following manner. Two fibers branch near together from the inner or pith side of each of these primary bundles slightly below the point where the branches for the inner cycle of stamens separated from the outer cycle of primaries. These strands, of which of course there are ten in all, extend slightly inward and finally terminate one in each of the outer cycle of ten stamens. Slightly anterior to the point where the separation of these two bundles occurs, one more branch arises from each of the five inner primaries. Each of these last five fibers extends between the first two fibers arising from the same primary. The latter five end, one in each of the middle cycle of five stamens, Figs. 15 and 16.

Petals. The petals derive their vascular supply from the inner cycle of primaries. After the subdivisions to the outer cortical region and the strands which extend into the middle and outer cycles of stamens have been given off, each primary is drawn close to the calyx tube and divided into three parts. The central strand terminates in a petal which is opposite the bundle from which the division originated. The two lateral divisions extend into and terminate in the sepals, as will be discussed presently, Figs. 15, 16. The strand extending into the petal divides into numerous subdivisions which anastomose profusely and form a complete vascular network, somewhat resembling that of the leaf system.

Sepals. The vascular system of each sepal is derived from both the outer and inner cycle of primaries. There are three main strands entering each; the median bundle is in each case the direct termination of one of the bundles of the outer cycle. The lateral bundles are approximately equal in size, though smaller than the median. Each of the laterals is derived as a branch of the adjacent inner primary, just before the latter enters a petal, as mentioned above. More specifically, each of the inner primaries gives off two distinct lateral branches just before it attains the base of the petal. One of these branches extends into the sepal to the right, and the other into the sepal to the left, of the petal in which the bundle terminates, Figs. 15, 16. In some examples each of these lateral bundles is increased by having combined with it, a small branch, which arises from the outer primary just before it enters the sepal. In all examples the median and lateral bundles are closely connected throughout the sepal by conspicuous branches.

Pith Region. The tissue between the cortical and carpellary regions, previously designated as modified pith,[5] is devoid of vascular tissue except for the passage through it of the carpellary system from the apex of the pedicel to the carpels, and perhaps an occasional branch swinging in for a short way from the toral system. It is in no sense supplied with a vascular network such as is found in the cortical region or the fleshy portions of the carpels.

Carpellary System

The carpellary system consists mainly of fifteen prominent bundles, three for each carpel, and a number of much smaller bundles above the pedicel apex. This system is derived from two sources. First, five prominent strands arise, one from each of the outer primary toral bundles just after or immediately before they leave the apex of the pedicel and swing out away from the central axis, as previously outlined in the discussion of the pedicel, Figs. 8, 13. To these, numerous fine bundles are often united from the interlacing mass of small fibers near the center of the pedicel. Each bundle passes, more or less obliquely, in through the pith, one to the base of each carpel, proceeds up along the dorsal suture, and ends in the style just below the stigma. Numerous lateral branches are given off in the region of the carpel cavities, and these anastomose with similar bundles from the placenta bundles, Fig. 15. Attention already has been directed to the small, fine fibers which originate from the main vascular cylinder and bundles of the pedicel, swing in toward its median longitudinal axis, and thus form a smaller secondary cylinder and a complex, almost dense anastomosis at the apex of the pedicel. Slightly above, or anterior to this network, these fibers again extend longitudinally and are grouped into a definite ring and star shape. Some few join with the five large dorsal capellary bundles just mentioned above, some enter the carpels directly, but most of them unite to form ten comparatively large strands which are first distinctly noticeable as occurring in pairs at the inner angles of the star, below the carpel bases, Figs. 7, 9. By the gradual union with them of the other small fibers, just mentioned as occurring between the pedicel apex and carpel base, they are considerably increased in size, and they extend upward one into each of the infolded carpel edges or placentas, and end in the style close to the stigmatic surface. One prominent bundle arises from each of them about midway up the carpel cavity and extends into the ovule, while other branches arise laterally and anastomose with strands from the dorsal bundle to make up the vascular network of the carpels themselves, Fig. 17.

Literature Cited

[1] Beach, S. A. Apples of New York, Rept. of the N. Y. Agric. Exp. Sta. for the year 1903, Vol. 1, pp. 35, 36, 1905.

[2] Brooks, Chas. The Fruit Spot of Apples, Twenty-ninth Rept. of the N. H. Coll. of Agric. and the Mech. Arts., 1908.

[3] McAlpine, D. The Fibro-vascular System of the Apple (Pome) and its Functions, Proc. Linn. Soc. N. S. Wales, Vol. XXXVI, Part 4, Pl. XXI-XXV, pp. 613-625, 1912.

[4] Bonns, W. W. Orchard Notes, Bul. 199, Maine Agric. Exp. Sta., 1912.

[5] Kraus, E. J. The Pollination of the Pomaceous Fruits, Research Bul. No. 1, Part 1, Div. of Hort., Ore. Agric. Col. Exp. Sta., 1913.

PLATE 1

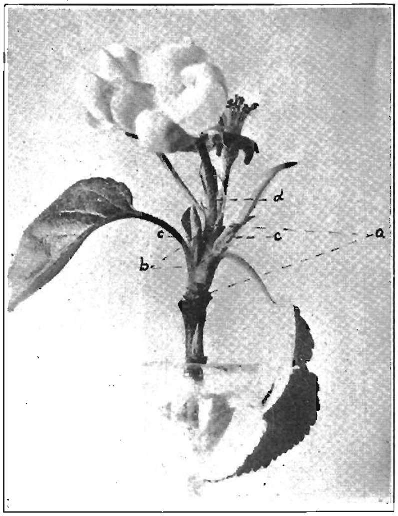

Figure 1. Flower cluster in bloom. (a) cluster base, (b) peduncle, (c) leaf shoots, (d) pedicel.

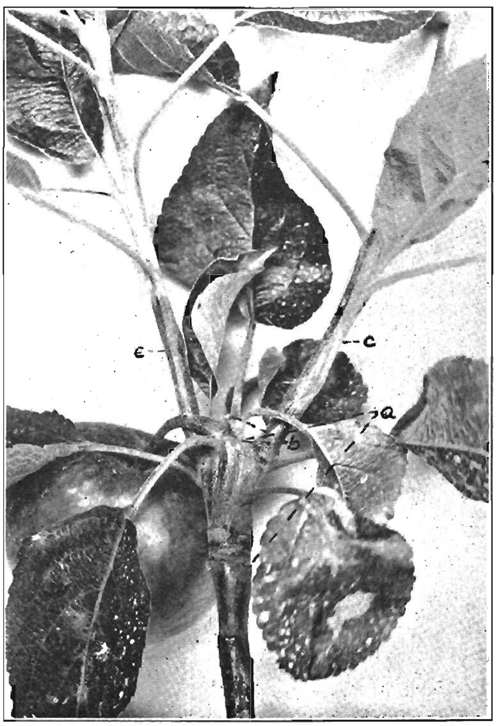

Figure 2. A similar cluster collected when the fruit was nearly mature. Letters the same as for Figure 1.

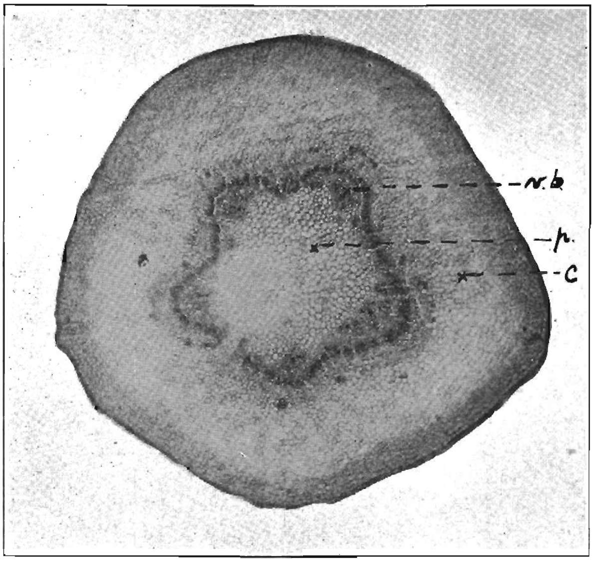

Figure 3. Cross section of terminal flower pedicel near its base. Collected March 19, 1913. (p) pith, (v b) vascular bundles, (c) cortex. Note the distinctly angled appearance of the vascular ring which is not continuous but made up of five large and many smaller bundles.

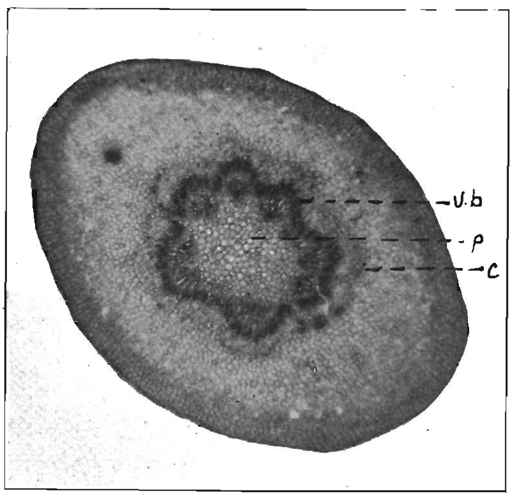

Figure 4. Cross section of lateral flower pedicel near base. Collected April 17, 1913. The greater number of prominent bundles is usual for the lateral pedicels. Letters the same.

PLATE 3

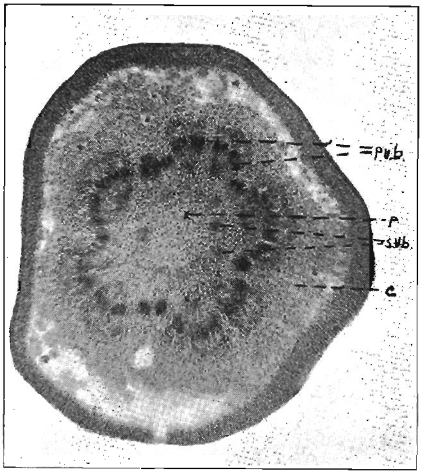

Figure 5. Cross section of terminal pedicel a short distance below its apex. Collected March 19, 1913. Note that the main bundles of the outer cylinder are each once divided, forming ten, and the smaller inner circle of bundles, which have branched from them forming a secondary cylinder within the pith. (p) pith, (s v b) secondary vascular bundles of pedicel, (p v b) primary vascular bundes of pedicel, (c) cortex.

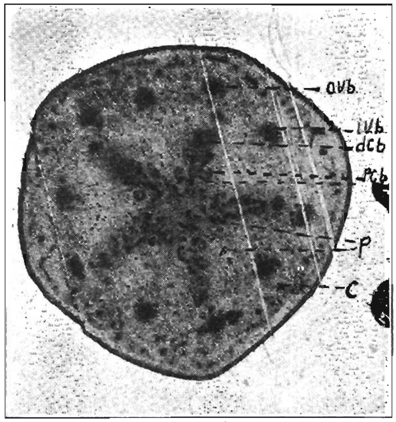

Figure 7. Cross section immediately below the carpels. Note the star-shaped grouping of many small fibres in the region below each carpel (p) pith region. (c) cortical region, (p c b) placental carpellary bundle, (d c b) dorsal carpellary bundle, (o v b) and (i v b) respectively outer and inner primary toral bundles.

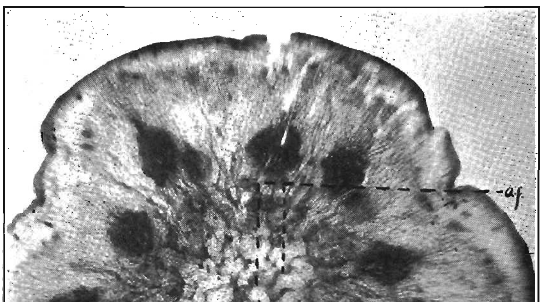

Figure 6. Cross section very slightly anterior to the apex of the pedicel. Collected May 5, 1913. Note the ten primary toral bundles diverging in two cycles, and the anastomosing fibres in the pith region. (p) pith region, (a f) anastomosing fibres, (o v b) and (i v b) respectively outer and inner primary vascular bundles of torus.

PLATE 4

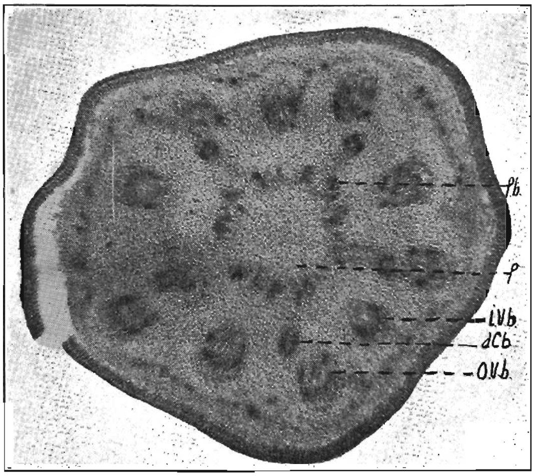

Figure 8. Cross section between apex of pedicel and base of carpels. Collected March 19, 1913. This section was made between regions represented in Figures 6 and 7. Note the small fibres again arranged in a circle and the dorsal carpellaries, each of which arose from the outer primary to which it stands opposite. (p) pith region, which also extends outward to the primary toral bundles. (o v b) and (i v b) respectively, outer and inner primary toral bundles, (d c b) dorsal carpellary bundles, (p b) the beginning of the placental carpellary bundles.

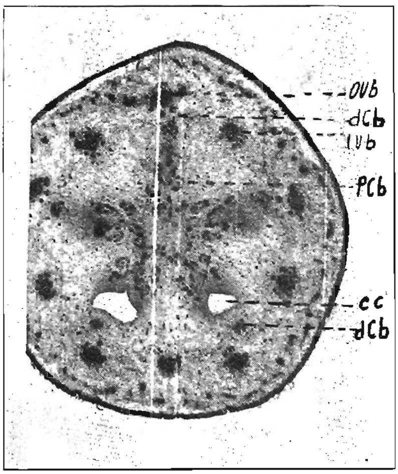

Figure 9. Cross section through the base of the carpels, showing the cavities in two cases. Collected March 19, 1913 The greater number of the small fibres are united either with the placental or dorsal carpellary bundles. (d c b) dorsal carpellary bundle, (p c b) placental carpellary bundle, (c c) carpel cavity, (o v b) and (i v b) respectively, outer and inner primary toral bundles.

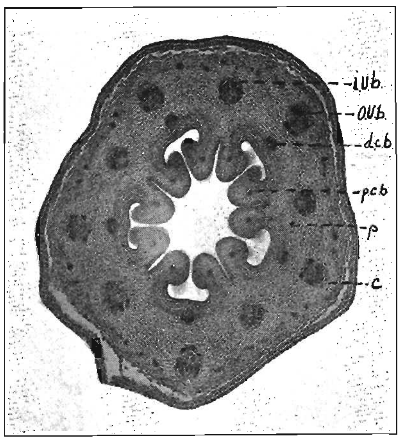

Figure 10. Cross section through the middle of a young fruit. Collected March 19, 1913. Note the well-developed carpellary cavities around the central cavity; no ovules are shown, though they were well advanced at this time. (c) cortical region, (p) pith region, (p c b) placental carpellary bundle, (d c b) dorsal carpellary bundle, (o v b) and (i v b) respectively, outer and inner primary toral bundles. Smaller secondary cortical bundles are also visible.

PLATE 5

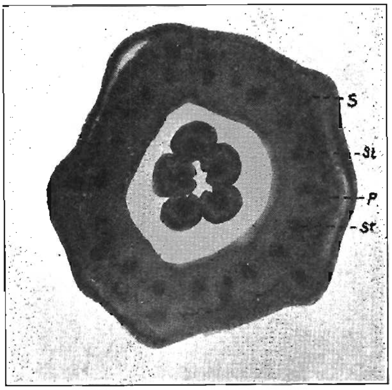

Figure 11. Cross section just below the base of the petals. Collected March 19, 1913. Note the styles at center and the cavity enclosed by them. (st) bundles which extend into the twenty stamens, (s) sepal bundle, (p) petal bundle.

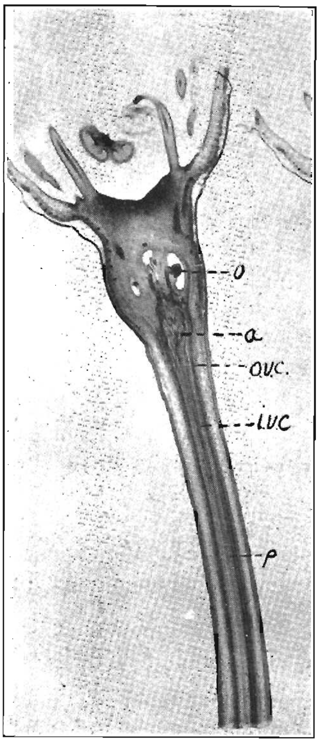

Figure 12. Longitudinal section, taken just previous to blooming. (p) pith, (i v c) inner vascular cylinder, (o v c) outer vascular cylinder, (a) region of anastomosis, (o) ovule.

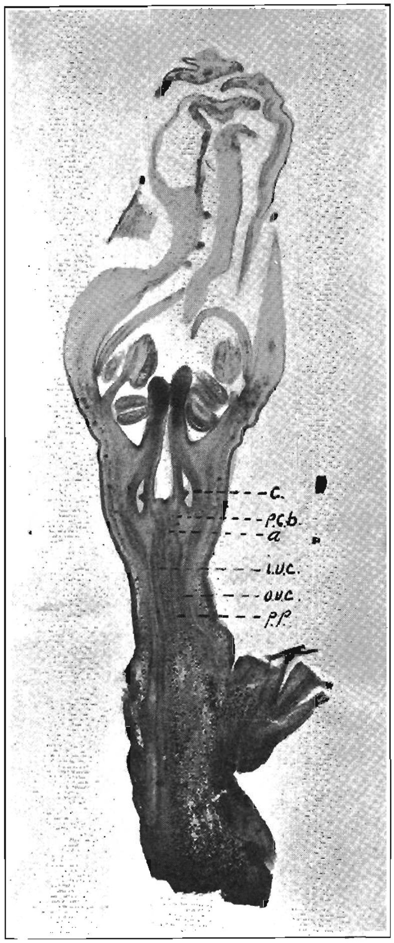

Figure 13. Longitudinal section approximately through the center. Collected March 14, 1913. Note particularly the branching and arrangement of bundles in the pedicel, especially near the base and at the apex where the primary toral bundles diverge, the origin of the dorsal carpellary bundle from the primary toral, at the right, the confluence of the smaller bundles to form the placental bundles and the pith region below and around the carpels. The base of a lateral pedicel is shown at the lower right, arising in the axil of a bract. (p p) pith of pedicel, (o v c) outer vascular cylinder, (i v c) inner vascular cylinder, (a) region of anastomosis, (p c b) placental carpellary bundle, (c) carpel.

PLATE 6

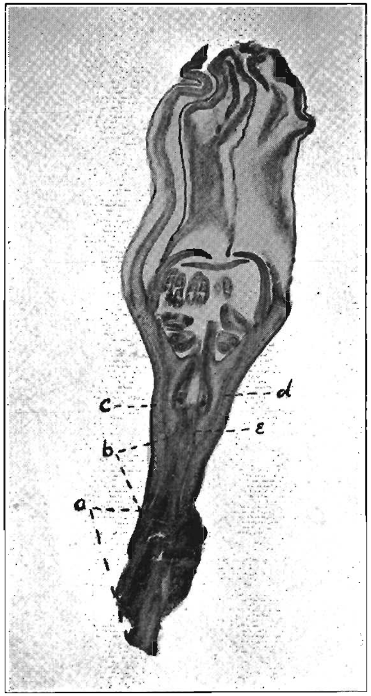

Figure 14. Longitudinal section approximately through the middle. Collected March 14, 1913. Note the distinctness of the separation of the toral and carpellary systems. (a) peduncle, (b) pedicel, (e) dorsal carpellary bundle, (c) cortical region of torus, (d) primary toral bundle, one branch of which ends in a petal, and the other in a stamen.

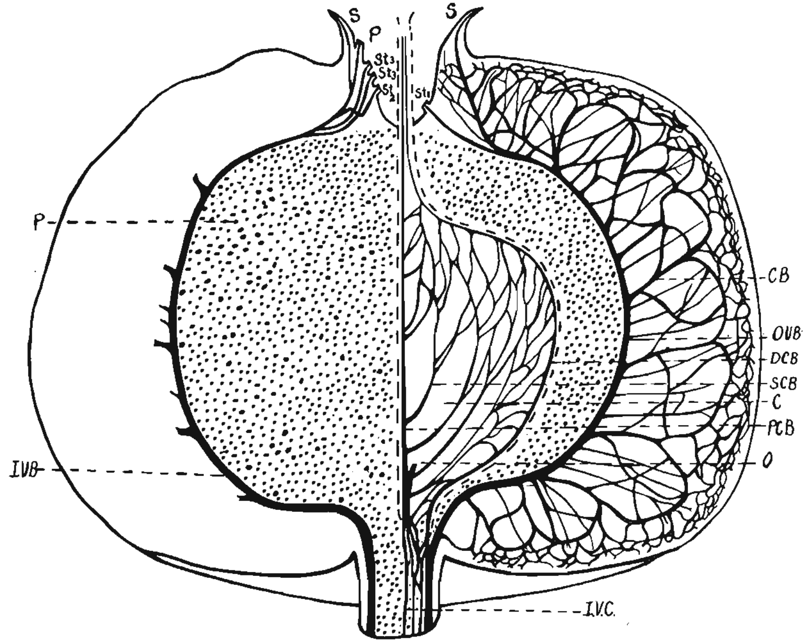

Figure 15. Diagram illustrating distribution of bundles in the torus and pedicel apex. Note the separation of carpellary and toral systems, the region of anastomosis below the carpels, and endings of bundles. (i v c) inner vascular cylinder, (o) bundles supplying ovule, (p c b) placental carpellary bundle, (c) carpel, (s c b) net work of secondary carpellary bundles, (d c b) dorsal inner primary toral bundles, (c b) secondary cortical bundles, (s) bundles to sepal, (st_1 st_2 st_3) bundles to first, second and third cycles of stamens, (p) bundle to petal, (p dotted) pith region.

PLATE 7

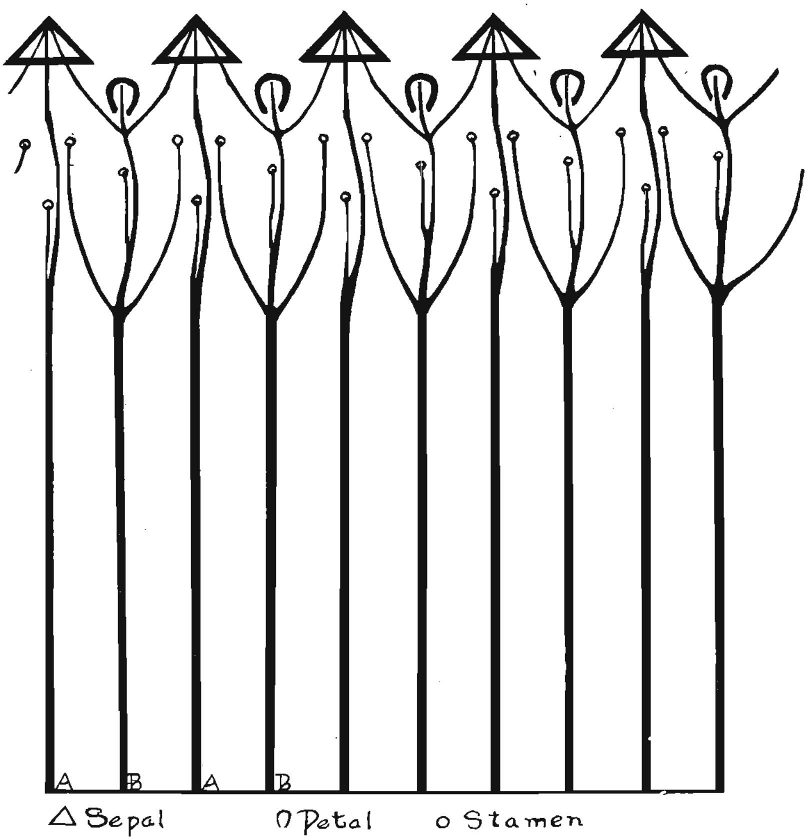

Figure 16. Diagram of toral system of bundles and terminations. (A) outer primary toral bundle, (B) inner primary toral bundle.

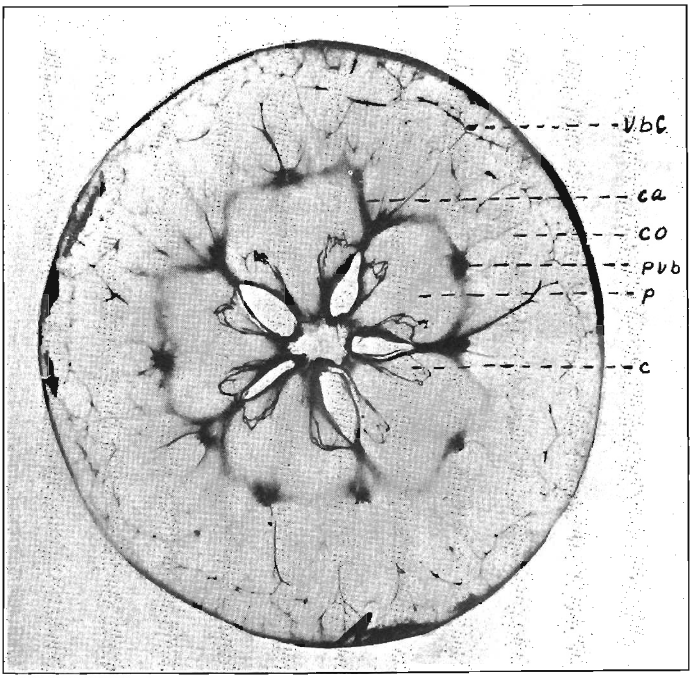

Figure 17. Cross section of mature Hubbardston apple. (v b c) vascular bundle of cortex; (c a) cambial area; (c o) cortical region; (p v b) primary vascular bundle; (p) pith; (c) carpel. Natural size..