DEVELOPMENT OF THE PISTILLATE SPIKELET AND FERTILIZATION IN ZEA MAYS L.¹

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INTRODUCTION

During the past five years considerable time has been given to a cytological study of the pistillate spikelet and flower of the corn plant (Zea mays). This work was undertaken with the primary idea of obtaining some facts that could be used in the advanced instruction of students in agriculture, since the cytological work that has been reported for the more common crop plants is limited and fragmentary. The lack of investigations of this kind has long been felt not only by those giving instruction to students in botany, agronomy, and plant breeding but also by those who are concerned with investigations in the practical breeding and improvement of crop plants.

REVIEW OF LITERATURE

Crozier (2)² found that the silk of corn would remain in a receptive condition and grow in length for a long time if pollination was prevented. He also found that it was not alone the forked tip of the silk that was receptive to pollen but that fertilization could be effected by the pollination of the silks after the branched tips had been removed. True (14) studied the development of corn, wheat, and oats from the time of fertilization to the maturity of the seed. He described the pistillate flower of corn only in so far as it would be of aid to him in discussing the formation of the caryopsis. Guignard (4) described in considerable detail the structure of the ovary and ovule of corn and observed the process of double fertilization but published no drawings of his observations. Poindexter (11) described the development of the pistillate spikelet of corn and discussed briefly the early stages in the development of the

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² Reference is made by number (italic) to "Literature cited," p. 264-265.
embryo and endosperm. Kuwada (9) made a cytological study of the pollen mother cells of a number of varieties of corn. He found that there was a considerable variation in the size and number of the chromosomes even in the same race. The haploid number varied from 9 to 12, the higher number as a rule being found in the varieties of sugar corn and the lower numbers in the varieties with more starch. In a later paper (10) he reported that the diploid number of chromosomes varied from 20 to 22 in the cells of the root, but that the number was constant for any one plant. Weatherwax (15-17) since this work has been in progress has reported extensively on the development, structure, and evolution of both the pistillate and staminate spikelets of the corn plant. Further mention of his work will be made in the discussion of the results reported in the present article.

EXPERIMENTAL METHODS

The varieties of corn used in this work were Pride of Saline, Freed White Dent, and Sherrod White Dent. The material was collected in the field at Garden City, Kans., during the seasons of 1914 to 1917, and at Manhattan, Kans., in 1918. All the material used in this investigation was fixed in medium chrom-acetic solution, washed, dehydrated, cleared in xylol, and embedded in paraffin in the usual manner. The sections for the most part were cut 15 to 20 microns in thickness and stained with safranin, gentian violet, and orange G. The drawings of the developing spikelet were made with the aid of a Bausch and Lomb projection apparatus, and those showing the development of the embryo sac and fertilization were made by the aid of the camera lucida.

In order to study the time elapsing between pollination and fertilization, the young ears were bagged before the silks appeared. After the silks had practically all appeared, they were hand-pollinated with freshly collected pollen. After pollination the ears were again bagged and kept covered until the specimens were collected for fixing. The ears which furnished the material for study were collected at stated hourly intervals after pollination had been made. In this manner the time elapsing between the time of pollination and fertilization could be determined.

For the study of the course of the pollen tube, the silks at certain periods after pollination were cut into short lengths and then tied into small bundles by means of fine threads. These bundles were then fixed and embedded in the same way as the other material. By cutting the bundles lengthwise, a large number of silks for a portion of their length could be obtained in longitudinal section. Since the bundles were taken consecutively from the tip of the silk to the ovary, the course of the pollen tube could be observed in any portion of the silk.
The pistillate spikelet of corn at the time the silk emerges from the husk has the appearance in longitudinal section shown in Plate 19. The two empty glumes of the spikelet are thickened at their base but are thin and membranous at their tips. The spikelet bears two flowers, but in most cases one of these aborts, so that in each spikelet there is only one functional flower. Each of the flowers of the spikelet consists of a pistil and three stamens. The stamens in both flowers, however, remain rudimentary, so that the only part of the fertile flower that functions is the pistil. The development and disorganization of the stamens as well as the development and abortion of the pistil of the sterile flower have been described in much detail by Weatherwax (16). Each flower is subtended by a lemma or flowering glume. Between the two flowers and adjacent to each other are located the two palets. The palets and lemmas are much shorter and more membranous than the empty glumes. With the exception of the pod corns, the bracts of the spikelet cease growth at the time of fertilization and thus never completely inclose the ovary. The bracts remain at the base of the grain and form the chaff of the cob. If fertilization is not effected, however, the bracts of the spikelet continue to grow in length and will completely inclose the ovary of the fertile flower. In pod corn, the bracts continue to grow after fertilization and completely inclose the mature grain.

When the spikelet is mature the lodicules of the fertile flower are not present or are not easily seen. According to Weatherwax (16) the lodicules in early stages of growth are present in both flowers, but those of the functional flower are crowded out before it is mature, while those of the sterile flower remain intact and can readily be observed even when that flower has a functional pistil.

The pistil of the fertile flower consists of the ovary and the elongated style or "silk." The silk is unevenly cleft at its tip, and this branched portion has been termed the stigma of the pistil by most authors. A small rounded knob or protuberance is located at the top of the ovary near the base of the silk. In the center of this knob is a funnel-shaped depression, apparently leading to the cavity of the ovary. However, an examination of a section through this region shows that the depression is only superficial and that the opening which at one time led to the cavity of the ovary has been closed. The cells composing the wall of this cavity have never completely united (Pl. 19, sc). This incomplete union of the wall of the ovary was noticed by True (14) but was first termed the stylar canal by Guignard (4). The origin of this canal will be discussed in detail when the embryonic development of the spikelet is considered.
The ovule is of a modified campylotropous type and is attached by approximately one-third of its circumference to the bottom of the cavity of the ovary. The outer coat of the ovule is incomplete and extends about half way around it. The outer coat for its whole length, with the exception of a short distance at the base, is free from the inner coat. The inner coat fits closely to the ovule and covers it completely, except in the region of the micropyle. Each coat of the ovule is approximately two cells in thickness, except in the region of the micropyle and the stylar canal where the coats may be from three to four cells in thickness. The outer coat forms a wedge-shaped projection which extends into the inner depression of the stylar canal. The inner coat also often shows such a projection, but it is never so marked as that in the outer coat (Pl. 19, ovc). This projection of the outer coat into the stylar canal has been observed by both Guignard (4) and Weatherwax (16).

The two fibro-vascular bundles of the silk traverse the walls of the ovary and unite at its base with the bundles that supply the various elements of the spikelet. Extending from each of the fibro-vascular bundles of the silk to the cavity of the ovary is a bundle of elongated cells that are rich in protoplasm and resemble very closely the sheath cells of the fibro-vascular bundles of the silk. Through these sheathlike cells the pollen tube travels to the cavity of the ovary after it leaves the sheath cells of the fibro-vascular bundles of the silk (Pl. 19, vbs, bsc).

DEVELOPMENT OF THE PISTILLATE SPIKELET

The spikelets are borne on the cob in double rows, because the spikelets are paired; and since each spikelet has only one functional flower, an even number of rows of grains is produced. It has been observed by Kempton (7), Stewart (12), and Weatherwax (15) that frequently in certain varieties both flowers of the spikelet may function, and thus two grains may be produced to each spikelet instead of one. In these varieties the grains do not always occur in regular rows on the cob but may be more or less irregularly arranged. This is due to the fact that the development of two grains in a spikelet tends to crowd the other grains in that region more or less out of alignment.

The origin of the paired spikelets is best observed by a study of the cross section of a very young cob. Such a cross section of the tip shows that it is composed of undifferentiated or embryonic cells (Pl. 20, A). A short distance back of the tip numerous projections or protuberances appear on the periphery of the cob. Each of these projections is a rudiment or primordium from which a pair of spikelets will develop (Pl. 20, B). Soon after the formation of these rudiments, each one becomes equally divided (Pl. 20, C), and from each half a spikelet develops (Pl. 20, D). The progressive development of a spikelet from its primordium is best studied in longitudinal section. The appearance of the embryonic cells
of the tip of a young cob in longitudinal section (Pl. 21, A) differs a little from that in cross section (Pl. 20, A).

A longitudinal section of the rudiment of a spikelet just after its appearance shows that it is composed of embryonic cells and has the general appearance of the tip of the young cob. The first differentiation to appear on the rudiment of the spikelet is the lower empty glume (Pl. 21, B). The primordium of the upper empty glume soon appears (Pl. 21, C), so that at a little later stage the two developing glumes have practically the same appearance (Pl. 21, D). The primordia of the two lemmas or flowering glumes are the next to appear (Pl. 22, A), while directly following, or frequently at the same time, the rudiments of the sterile flower and of the stamens of the fertile flower become visible. The palet of the fertile flower at this time also begins to show differentiation (Pl. 22, B), but the palet of the sterile flower does not appear until considerably later.

The primordium of the carpellate leaf or ovary wall of the fertile pistil begins to show in a short time after those of the palet and stamens of the fertile flower appear (Pl. 23, A). At this time the cells that are to compose the fibro-vascular bundles of the lower part of the spikelet begin to differentiate. The carpel grows unevenly so that when the side adjacent to the lemma extends almost one-third around the young ovule the opposite side has scarcely begun to develop (Pl. 23, A, c, c'). This more rapidly growing portion of the carpel increases in width toward the tip so that it becomes from two to three times wider than the base (Pl. 23, B). This widened portion of the carpel is composed of numerous embryonic cells which later rapidly elongate to form the silk (Pl. 24, A). When the silk is elongating, the wall of the ovary has grown up around the ovule and has almost inclosed it with the exception of a small opening toward the top (Pl. 24, A, sc). This opening has been termed the stylar canal. It, however, does not long remain open, for by the time the silk is ready for pollination, the edges of the carpel have come in close contact but have not grown together (Pl. 25, B).

About the time the silk begins to elongate, the ovule begins to invert. The cells of the ovule on the side adjacent to the palet increase in number and elongate more rapidly than those on the opposite side, thus causing the end of the ovule to turn downward (Pl. 24, B). The megaspore mother cell appears about the time the ovule begins to turn, and frequently the embryo sac has reached the 2-celled stage by the time the ovule has become completely inverted. The ovule coats grow rapidly when the ovule begins to curve, so that by the time it has reached its final position they have reached their full development (Pl. 25, A).

**DEVELOPMENT OF THE EMBRYO SAC**

About the time the ovule begins to invert, the differentiation of the megaspore mother cell becomes apparent (Pl. 24). No disorganization of any of the megaspores was noted in the three varieties of corn studied
in this experiment, although approximately 50 observations were made. This fact was also observed by Weatherwax (16) in the varieties of corn studied by him, so it seems to be the rule that all four megaspores function. In wheat (Triticum vulgare), however, Koernicke (8) and Jensen (6) report that only one megaspore functions. The same has been observed by Cannon (1) for wild oats (Avena fatua).

The megaspore mother cell increases in size until it becomes about twice as broad and from four to five times as long as the vegetative cells of the ovule (Pl. 26, A, B). The developing embryo sac remains approximately the same size as the megaspore mother cell until the eight cells are formed. At that time it has elongated but slightly while its breadth has increased to two or three times that of the megaspore mother cell (Pl. 27, B). The two polar nuclei migrate and come in contact with each other a short distance above the egg but do not fuse before fertilization takes place (Pl. 27, B, C). In scores of cases where pollination had been prevented the two polar nuclei were observed standing apart a week or more after the embryo sacs were ready for fertilization.

MATURE EMBRYO SAC

When the embryo sac is mature, it is approximately four times as long and about twice as wide as when it first reaches the 8-celled stage. It reaches its maximum size about the time the silk emerges from the husk. The antipodals begin to divide almost immediately after the 8 cells are formed, so that one very rarely finds an embryo sac that shows only 8 cells. The antipodals increase in number, apparently by indirect cell division, until they number from 24 to 36 cells at the time of anthesis. These cells often have indistinct walls, and frequently there are two nuclei to each cell. These cells are closely crowded together and give the appearance of a rather definite tissue (Pl. 28, ant). This behavior of the antipodals is characteristic of the grasses and has been noted by numerous investigators since the time of Hofmeister (5). Golinski (3) in his work with the stamens and pistil of wheat studied the antipodals with especial care in order to determine whether they played any part in the formation of the endosperm and established the fact that these cells remain intact until they are crowded out by the growing endosperm (Pl. 32, B).

The egg increases in size until its width is almost half that of the embryo sac. It is decidedly balloon-shaped and becomes aveolar in appearance. The synergids are more or less lunar-shaped and are considerably longer than the egg. They have dense cell contents and take the stain much deeper than the egg. (Pl. 28, e, sy). The nuclei of the synergids may disintegrate before fertilization or may remain clear and distinct until it has taken place. In most cases the synergids do not remain long intact after the egg is ready for fertilization. Where
fertilization is delayed they lose their identity and can not be distinguished from the surrounding cytoplasm.

The polar nuclei are embedded in a strand of cytoplasm that extends from the antipodals to the egg, while the greater part of that portion of the embryo sac is taken up by two large vacuoles. The nucleoli of the polar nuclei are the largest in the embryo sac. The two polar nuclei remain in close contact but do not fuse until fertilization has taken place.

SILK AND THE POLLEN TUBE

The end of the silk is cleft into two branches of unequal length. This branched portion of the silk has been termed the stigma by most authors in their description of the corn flower (Pl. 29, A). The silk, however, is receptive to pollen for at least the greater portion of its length; so it would appear that Weatherwax (16) is correct in asserting that the term stigma can be applied to the branched tip of the silk only in a morphological sense and not with the understanding that it is the only portion of the pistil on which the pollen grains may germinate.

Numerous hairs are borne on the silk in rather definite areas for its entire length (Pl. 29, A). These hairs appear for the most part on the edges of the silk and are more numerous near its tip than farther down. The hairs may be branched or unbranched and the upper ends of the cells that compose them stand out from the hair (Pl. 29, B), thus forming a rough surface upon which the pollen grains easily lodge. The origin and development of these hairs have been described in detail by Weatherwax (15), who observed that each hair originates from a single epidermal cell of the silk.

Two fibro-vascular bundles extend the entire length of the silk and terminate in the branched tip (Pl. 29, A). A cross section of the silk shows that it is grooved on both its upper and lower surfaces and that the vascular bundles are located near its edge (Pl. 30, A). Each bundle contains from three to six xylem elements (Pl. 30, B). The conducting tissue of the fibro-vascular bundles is surrounded by narrow, elongated cells that are characterized by very dense cytoplasmic contents and elongated flattened nuclei (Pl. 30, C). It is between these dense cells that the pollen tube travels down the silk.

The pollen grains vary in shape from spherical to ellipsoidal, and each grain has a germ pore (Pl. 29, C). The protoplasm of the pollen grain is very dense, and often it is difficult to distinguish the nuclei. The two sperm nuclei are formed before the pollen is shed (Pl. 32, A). This supports the statement of Strasburger (13) that the division of the generative nucleus in the pollen grain is a constant character for all the grasses.

A few hours after the pollen grains lodge on the hairs of the silk, the pollen tube emerges from the germ pore (Pl. 29, D). Three ways have
been observed by which the pollen tube may gain access to the sheath cells of the fibro-vascular bundles of the silk. Shortly after the pollen tube appears, it may penetrate a hair and through it gain entrance to the fibro-vascular bundle region (Pl. 29, D); or the tube may continue down the outside of hair to its base and then enter the silk and penetrate to the cells surrounding the bundle. Frequently pollen grains that fall directly on the smooth portion of the silk germinate, and the pollen tube penetrates the silk. These instances, however, are exceptions. Practically all pollen tubes that function are from pollen grains that fall on the hairs of the silk.

The end of the pollen tube is greatly enlarged as it pushes its way between the dense sheath cells of the bundle (Pl. 29, E). In its passage down the silk the tube causes but very little disturbance in the position of the cells, so that after the tube disappears the cells quickly return to their normal form and position. The pollen tube, so far as I have observed, does not extend the full length of the silk at any time. It is very difficult to locate it a short distance back of its growing region. It appears that the older portions of the tube are absorbed by the surrounding cells, while the growing part of the tube apparently is nourished by the dense sheath cells. Arriving at the base of the silk, the pollen tube pushes its way between the sheathlike cells that extend from the bundle of the silk to the cavity of the ovary (Pl. 19, vs). After it enters the ovary cavity the tube twists and coils in its passage along the coats of the ovule until it reaches the micropyle. After passing through the micropyle, the tube works its way between the cells of the ovule and enters the embryo sac (Pl. 28, pt). The protoplasm of the pollen tube is very dense, so that it is very difficult to locate the sperm nuclei. I have never observed them in the tube except after it had entered the embryo sac.

If pollen is supplied abundantly, a great number of pollen tubes start to grow down the bundle regions of each silk. However, as one examines the silk from the tip downward, the number of pollen tubes becomes smaller and smaller, so that when the cavity of the ovary is reached only one pollen tube is to be observed. In nearly a hundred observations no more than one pollen tube was seen in each ovary cavity.

The growth of the pollen tubes is very rapid, and under ordinary conditions they reach the embryo sacs of all the ovules on the ear in 24 hours after pollination. In order to do this the longest tubes must grow in that time approximately 6 inches, a distance that equals 1,500 times the diameter of the pollen grain.
FERTILIZATION

After the entrance of the pollen tube into the embryo sac, it expands so that the width of its tip is approximately one-third that of the embryo sac. The pollen tube extends into the embryo sac until the tip is near the polar nuclei. The wall of the tube is dissolved, giving the nuclei free access to the embryo sac. One of the sperm nuclei fuses with the egg and another with one of the polar nuclei (Pl. 31). Then the two polar nuclei fuse at the time the sperm nucleus enters one of them or shortly afterwards. Traces of the pollen tube in the embryo sac remain for a long time and do not disappear until crowded out by the developing endosperm and embryo. Fertilization takes place in from 26 to 28 hours after pollination, or in a few hours after the pollen tube reaches the embryo sac.

DEVELOPMENT OF THE EMBRYO AND ENDOSPERM

Almost immediately after fertilization, the endosperm nucleus begins to divide; and in 10 to 12 hours the nuclei of the endosperm may number 20 or 30, arranged around the periphery of the embryo sac (Pl. 32, A). Many of the nuclei have two nucleoli. The nucleus of the fertilized egg does not divide very rapidly. When the nuclei of the endosperm number as high as 20 or 30, the egg nucleus has just undergone its first division (Pl. 32, A). The cells of the endosperm increase very rapidly, and within 36 hours after fertilization they completely fill the embryo sac (Pl. 32, B). The antipodals remain intact and increase in number but are soon crowded out by the encroaching endosperm cells. By the time the endosperm completely fills the embryo sac the embryo consists of only from 14 to 16 cells (Pl. 32, C).

SUMMARY

In a study of the pistillate spikelet and the process of fertilization in the corn plant (Zea mays) the following facts were noted:

EMBRYO SAC.—In the formation of the embryo sac there is no disorganization of the megaspores, and all four function. The three antipodal cells rapidly increase in number, apparently by indirect cell division, until they number from 24 to 36 at the time the embryo sac is mature. These cells have rather indistinct cell walls and frequently contain two nuclei. The two polar nuclei come into position just above the egg and remain in close contact with each other but never fuse before fertilization has taken place. The egg becomes reticulate, stains very lightly, and is decidedly balloon-shaped.

POLLEN TUBE.—Practically all the pollen tubes that function come from the pollen grains that lodge on the hairs of the silk. The tubes may enter the hairs directly and through them gain access to the interior of the silk, or they may follow the hairs to their base and then penetrate the silk. After the pollen tubes are once inside the silk they work their
way between the cells to the fibro-vascular bundles. Each silk has two fibro-vascular bundles. These bundles are surrounded by sheath cells which are characterized by their extremely dense contents and large, flattened nuclei. It is between these cells that the pollen tube travels down the silk. Arriving at the base of the silk, the pollen tube works its way between the sheathlike cells that extend from the fibro-vascular bundle of the silk to the cavity of the ovary. The tube enters the ovary cavity and twists and coils in its passage along the ovule coat until it reaches the micropyle. The tube then pushes between the cells of the ovule until it reaches the embryo sac. The growth of the pollen tubes is very rapid, so that they reach the embryo sacs of all the ovules of the ear in 24 hours after pollination. To do this some of the tubes must grow a distance of approximately 6 inches in the course of the 24 hours. The pollen tubes apparently do not extend the full length of the silk at any given time but are absorbed a short distance back of their tip by the cells between which they pass. A great number of tubes start down a given silk; but the number of tubes becomes less and less as the base of the silk is approached, so that by the time the cavity of the ovary is reached only one tube is to be observed. The two sperm nuclei are formed in the pollen grain before the pollen tube appears.

Fertilization.—The pollen tube enters the embryo sac and pushes its way upward until its tip is near the polar nuclei. The tip of the tube expands until it is approximately one-third the width of the embryo sac. The wall of the tube seems to dissolve, giving the sperm nuclei access to the embryo sac. One of the sperm nuclei fuses with the egg, and at about the same time the other fuses with one of the polar nuclei. The two polar nuclei fuse at the time the sperm nucleus enters one of them or shortly afterwards. The pollen tube persists in the embryo sac until it is crowded out by the developing endosperm and embryo. Fertilization occurs in from 26 to 28 hours after the silks have been pollinated.

Endosperm and Embryo.—The endosperm nucleus soon divides, and in from 10 to 12 hours after fertilization the endosperm nuclei may number as high as 30, arranged around the periphery of the embryo sac. Within 36 hours after fertilization the cells of the endosperm completely fill the embryo sac. The nucleus of the fertilized egg does not divide for some time, so the endosperm may number 20 or more cells before the first division of the egg takes place. When the cells of the endosperm completely fill the embryo sac, the embryo numbers only 14 to 16 cells.

LITERATURE CITED


(3) GouNski, St. J. 

(4) Guignard, L. 

(5) Hofmeister, Wilhelm. 

(6) Jensen, G. H. 

(7) Kempton, James H. 

(8) Köhnercke, Max. 

(9) Kuwada, Yoshinari. 


(11) Poindexter, C. C. 
1903. The Development of the Spikelet and Grain of Corn. In Ohio Nat., v. 4, no. 1, p. 3-9, pl. 1-2. Bibliography, p. 6-7.

(12) Stewart, Alban. 

(13) Strasburger, Eduard. 

(14) True, Rodney H. 

(15) Weatherwax, Paul. 


PLATE 19

Longitudinal section of the pistillate spikelet of corn at the time the silk is ready for pollination: r, rachilla; g, lower empty glume; g', upper empty glume; l, lemma or flowering glume of the fertile flower; l', lemma or flowering glume of the sterile flower; pa, palet of the fertile flower; pa', palet of the sterile flower; sf, sterile flower; st, rudimentary stamen of the fertile flower; ova, ovary of the pistil; co, cavity of the ovary; sk, silk or style; sc, stylar canal; vbs, one of the fibro-vascular bundles of the silk.

Through the sheath cells that surround the bundle the pollen tube travels down the silk; vsc, sheathlike cells through which the pollen tube travels from the vascular bundle to the cavity of the ovary; vb, fibro-vascular bundles that supply the parts of the spikelet; ov, ovule; ovc, ovule coats; mic, micropyle; es, embryo sac. X 45.

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PLATE 20

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PLATE 20

A.—Cross section of the tip of a very young cob.  X 300.

B.—Portion of a cross section of a young cob just back of the tip, showing the rudiment or primordium from which a pair of spikelets will develop.  X 300.

C.—Cross section of a rudiment at the beginning of its division into equal parts.  X 300.

D.—Cross section of a pair of spikelets in the process of development.  X 300.
PLATE 21

A.—Longitudinal section of the tip of a young cob. \( \times 300 \).

B.—Longitudinal section of the rudiment or primordium of a spikelet just back of the tip of a young cob: g, primordium of the lower empty glume. \( \times 300 \).

C.—Longitudinal section of the developing spikelet, showing the primordia of the lower and upper empty glumes: g, lower empty glume; g', upper empty glume. \( \times 300 \).

D.—Longitudinal section of the developing spikelet at a little later stage than C: g, lower empty glume; g', upper empty glume. \( \times 300 \).
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PLATE 22

A.—Longitudinal section of the developing spikelet: g, lower empty glume; g', upper empty glume; l, primordium of the lemma or flowering glume of the fertile flower; l', primordium of the lemma or flowering glume of the sterile flower; sf, primordium of the sterile flower. X 300.

B.—Longitudinal section of the developing spikelet: g and g', empty glumes; l and l', lemmas or flowering glumes; sf, primordium of the sterile flower; st, stamen of the fertile flower; p, palet of the fertile flower; pp, primordium of the pistil. X 300.
PLATE 23

A.—Longitudinal section of the developing spikelet at the time the carpel or ovary wall has begun to develop: g and g', empty glumes; l and l', lemmas; sf, sterile flower; p and p', palets; st, stamen; c and c', rudiment of the carpel or ovary wall; c' is the more rapidly growing part of the carpel. X 300.

B.—Longitudinal section of a developing ovary: c and c', developing ovary walls; c' is the portion of the carpel from which the style or silk will develop; ov, ovule; ovc, primordium of the inner ovule coat. X 300.
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PLATE 23

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PLATE 24

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PLATE 24

A.—Longitudinal section of the fertile pistil at the time the silk has started to elongate: ovw, ovary wall; sc, stylar canal; ovc, ovule coats; ov, ovule; ms, megaspore mother cell; sk, silk. × 300.

B.—Longitudinal section of the fertile pistil at the time the ovule has started to invert: ovw, ovary wall; sc, stylar canal; sk, silk; ovc, ovule coats; ms, megaspore mother cell. × 300.
A.—Longitudinal section of the inverted ovule: ov, ovule; ovc, ovule coats; es, embryo sac; mic, micropyle; co, cavity of ovary.  X 250.

B.—Section through the stylar canal, showing its structure shortly before the silk emerges from the husk. The union of the two edges of the carpel will eventually be more complete near the top than is here shown.  X 250.
PLATE 26

A.—Cross section of the megaspore mother cell. $\times 800$.
B.—Longitudinal section of the megaspore mother cell. $\times 800$.
C.—Longitudinal section of the 2-celled embryo sac. $\times 800$.

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PLATE 27

A.—Longitudinal section of the 4-celled embryo sac. $\times 800$.

B.—Longitudinal section of an 8-celled embryo sac at the time the polar nuclei have started to migrate. $\times 800$.

C.—Longitudinal section of an 8-celled embryo sac after the polar nuclei have migrated. $\times 800$. 
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Pistillate Spikelet and Fertilization in Zea mays L.

PLATE 23

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PLATE 28

Longitudinal section of a mature embryo sac just previous to fertilization: e, egg; sy, synergids; p, polars; ant, antipodals; pt, pollen tube; m, micropyle; v, vacuole; c, cytoplasm; ov, ovule coat. × 520.
PLATE 29

A.—End of a silk: p, pollen grains; v, fibro-vascular bundles; h, hairs. × 35.

B.—Tips of the hairs of the silk. It is on these hairs that most of the pollen grains lodge. × 250.

C.—Section of a pollen grain showing the germ pore and the relative size of the vegetative and sperm nuclei. × 250.

D.—Single hair of the silk, showing the general manner in which the pollen tube penetrates the sheath cells of the fibro-vascular bundle of the silk: p, pollen grain; h, hair; pt, pollen tube; sc, sheath cells of the fibro-vascular bundle. × 250.

E.—Longitudinal section of a fibro-vascular bundle of a silk, showing the position of the pollen tube as it grows down the silk: sc, sheath cells; x, xylem elements; p, parenchyma cells of the silk; pt, pollen tube, showing the enlarged tip. × 250.
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PLATE 30

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A.—Cross section of a silk near its base, showing the position of the fibro-vascular bundles. \( \times 220 \).

B.—Cross section of a fibro-vascular bundle of the silk: x, xylem elements; sc, sheath cells; pt, pollen tube. \( \times 650 \).

C.—Longitudinal section through the sheath cells of the fibro-vascular bundles: sc, sheath cells; pc, parenchyma cells of the silk. It is between the sheath cells that the pollen tube works its way down the silk. \( \times 650 \).
PLATE 31

A.—Vegetative and sperm nuclei of the pollen grain: vn, vegetative nucleus; sn, sperm nuclei. $\times 1,100$.

B.—Longitudinal section of the lower portion of the embryo sac at the time of fertilization, reconstructed from two sections: pn, polar nuclei fusing; sn', sperm nucleus fusing with a polar nucleus; e, egg; sn, sperm nucleus in the egg; pt, pollen tube; syn, synergid; v, vacuole. $\times 1,100$. 
Pistillate Spikelet and Fertilization in Zea mays L.
PLATE 32

A.—Longitudinal section of the embryo sac 12 hours after fertilization: end, endosperm nuclei; e, egg in which one of the daughter nuclei has already divided; ant, antipodals.  $\times 520$.

B.—Longitudinal section of the embryo sac 36 hours after fertilization: end, endosperm; emb, embryo; ant, antipodal tissue.  $\times 110$.

C.—Longitudinal section of the young embryo at the stage shown in B.  $\times 800$. 