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EFFECTS OF X-RAYS UPON TULIP PLANTS WHEN IRRADIATED IN DIFFERENT DEVELOPMENTAL STAGES OF FLORAL ORGANS

By

HIROSHI MYODO

(with four text- and two plate-figures)

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Introduction

Many investigators have studied since the beginning of this century on the influence of X-rays upon plant organ development and growth. In these investigations the plant organs that were irradiated are briefly grouped into three, i. e. plant seeds, resting nutritive organs and actively growing organs.

HASKINS, C. P. and MOORE, C. N. (1935) (2) irradiated X-rays on seeds of grape fruits plant and reported that plants from rayed seeds flowered earlier than controls. Flower seeds of many species, more than seventy ranged in wide plant families, were X-rayed by JOHNSON, EDNA L. (1926 to 1936) (4) (5) (6) (7) (8) (9) (11) and

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she oberved their aftergrowth anomalies. In her observations the X-rays were injurious upon plant growth in every respect, the chief injuries being 1) decrease in total height 2) increased branching 3) irregularities of leaf shapes and development of chloropyll 4) delayed and reduced blossoming, and the susceptibilities of plants under X-rays were varied according to farmily, genus and species they belonged to.

NOGUCHI, Y. (1935) (14) observed various anomalies in leaf structure and chlorophyll distribution of Helianthus plants grown from seeds which had been X-rayed. He reported decreased chloroplast contents and enlarged cavity between cells of palisade tissue in paler parts of leaves, the minimum time limit of X-rays to cause leaf abnormalities to be 3 to 4 minutes by irradiation of 100 peak K. V., 5 ma., no screen and 30 cm of focal distance, and these injuries affected by X-rays were always partial.

Nutritive organs in resting stage have been also used to be X-rayed, and the influences on growth and organ development thereafter observed by many investigators. WEBER'S report (1922) (18) tells us that X-radiation for resting buds of lilac forced them to flower earlier than controls. JACOBSEN, M. (1923) (3) X-rayed on potato tubers in resting stage and observed increased crops in comparison with controls, while JOHNSON, E. L. (1931) (7) denied this effect using Colorado Wild Potato tubers treated by X-rays. MORGAN'S report (1931) (13) on freesia corms X-radiated was as follows: treated corms developed more achsial buds resulting in more cormels produced than controls, the textures of leaf, stem and flower became crêpe cloth like, the leaves often curled or twisted and some flowers were malformed. Accelerated growth was observed by SCAGLIA and BUSINCO (1930) (16) in Hyacinthus bulbs irradiated by X-rays of a certain dosis. On the contrary, decreased plant height and leaf number of Narcissus were reported by JOHNSON, E. L. (1936)* when she X-rayed bulbs of var. Paper White though the number of bulblets yielded from treated bulbs was almost the same as control. FURUHASHI, S. (1951) (1) carried out an interesting experiment in his master course of the College of Agriculture, Hokkaido University, and reported that the height of tulip plants from X-radiated bulbs could be controled in any degree of dwarfness if both the dosis and time of radiation

* Unpublished data referred from her paper in 1936 (10).

were considered. He treated the bulbs of Feu Brillant in the middle of October, whilst the pollen mother cells were under meiosis, 20, 60, 120, 240 and 420 minutes by X-radiation of the same conditions with the writer's present experiment. Plant heights he obtained from the above treatments were generally inversely proportioned to the time of irradiation, but from the first treatment slightly higher plants than controls were gained.

Plant organs in active stage would be more sensitive than seeds and resting nutritive organs. Many workers have X-rayed on those active organs and observed aftereffects. We can put forth as the chief investigators, JOHNSON, E. L. (1931) (6) on tomato and Helianthus, CATTEL (1931) on Triticum, KOMURO (1925) on horse bean (Vica Faba), and recently JOHNSON (1939) (11) on Salpiglossis, Phlox and Nicotiana. Especially JOHNSON's observations in tomato plants are very interesting and tell us that X-raying on the plant, before flower buds appear, often caused double blossom setting, while, if rayed after they appeared, all buds were damaged unless preparatory irradiations were not offered. Flower buds formed after treatment, however, were mixtures of normal, double and triple flowers. X-raying of small dosis shortly before flowering invited frequently complete sterile flower setting, and if they were not sterile, their fruits were of abnormal structure. Further general fruit sets of plants from seedlings X-treated were much delayed.

JOHNSON's experiment on Salpiglossis seedlings (1939) also shows us different susceptibilities for X-rays according to the stages of development of organs. If the flower buds are longer than 1 cm, normal flowers will be produced, neverthless, if they are shorter than that, abnormal flowers are apparently prevalent by a treatment of the same dosis. Anomalies in these cases are chiefly stippling, spotting and streaking of corolla and change of flower color in the early period of flowering, but later split and dissected margins of corolla tubes and dwarf blossoms are observed.

Now, RUSS, S. (15) had the opinion, early in 1919, that influences of X-rays upon plant growth are selective and differ as tissue or organ varies. JÜNGLING, O. (12) indicated also in 1920 that different species of plants or different stages of development of the same species react otherwise upon X-rays.

From the above stated facts the writer considers that, when

X-rays are radiated directly in compliance with the development of organs under consideration, the influence of treatment upon them will be more acurate than the irradiation for more or less homologous plant tissue before the differentiation of organs. Tulips flower early in spring and their leaves die in summer. Growers dig out the bulbs then and store them until autumn when they are planted in the field again. Leaves and flower elements for the next season differentiate in bulbs during this storage from summer until autumn.

Writer's treatments of X-rays were carried out during this storing period, citing the development of leaf and flower elements by checked bulbs.

Materials and Method

Three varieties of Feu Brillant (darwin tulip), Sagittarius (ideal darwin) and Mr. ZIMMERMAN (triumph tulip) were X-irradiated in the summer of 1949. In general cultivation Mr. ZIMMERMAN is the earliest to flower and shortest in plant height, Sagitarius the middle and Feu Brillant is the latest and highest among these three varieties. These tulips had been cultivated in the flower garden of the College of Agriculture, Hokkaido University, and dug out on July 9th after which the bulbs were stored under curing. 20 to 30 gm. bulbs of each variety were selected for X-treatment which was carried out on July 28, Aug. 4, Aug. 11, 25 and Oct. 8. Five bulbs of each variety were X-rayed in respective treatment. Treated bulbs were again stored in the same way as before until Oct. 8 on which day of the last treatment all bulbs treated and of control were planted in the experimental field of the flower garden above mentioned.

TABLE 1. Height of noses (young flower stalks) on each day of treatment. in mm. (averages of three bulbs)

Varieties	July 28	Aug. 4	Aug. 11	Aug. 25	Oct. 8
Feu Brillant	0.8	1.0	1.2	3.0	17.0
Sagittarius	1.0	1.2	1.2	2.7	13.0
Mr. ZIMMERMAN	0.5	1.2	3.0	3.5	10.0

The X-ray machine used in this experiment is "Yakumogo" with molybden target manufactured by Shimazu Co., Japan, and installed in the Plant Breeding Institute of the College of Agriculture, Hokkaido University. Dosis for every treatment was 75 K.V., 2 ma., no filter, distance from the target to bulbs 45 cm., and seven hours intervening 30 minutes for every 2 hours.

Sizes of noses (young flower stalks) in bulbs on every day of treatment were estimated by means of checked bulbs which are tabulated and figured in Table 1 and plate figure 1. From July 9, the day of harvesting, to the end of that month new leaves were formed in all varieties, but noses stayed much short. Though more or less different in their beginning and finishing times, according to varieties, floral organs differentiated and developed successively in the bulb during August, and in these periods also the noses grew very slowly. After finishing the formation of floral elements, however, the growth of noses was accelerated considerably. Leaf and flower bud differentiation of the three varieties were examined in several stages making micrtome sections of which three figures of Feu Brillant respectively on July 28, Aug. 11 and Aug. 28 are demonstrated in platefigure 1. From these examinations the writer observed that flower buds of Feu Brillant began to differentiate on Aug. 11, and those of Sagittarius and Mr. ZIMMERMAN were both, on Aug. 4, in a somewhat advanced stage already differentiating primordia of stamens.

Observation and estimation of these X-radiated and control plants were carried out in the next season and further once more in the successive season.

Observation and Estimation

A: *Terrestrial Organs*

1: Emergence of bud: The emergence of young leaves on the surface of soil from the bulbs treated July 28 happened almost at the same time as with control, but Aug. 11 and Aug. 28 treated bulbs were somewhat delayed and Aug. 4 and Oct. 8 treated ones were very delayed in their leaf emergence. This delay could hardly retrieve thereafter. Especially Oct. 8 treatment prevented decidedly the elongation of flower stalk and leaf and produced dwarf plants many of which could not flower or were much delayed in

their flowering. Bulbs X-radiated on Aug. 4 were also delayed in their emergence of leaves and some of them could not emerge above the soil surface. This marked injury by X-rays was especially prevalent for Mr. ZIMMERMAN.

2: Anomalies in leaves : There were noticeable unevenness of chlorophyl distribution and thickening of leaves from the beginning of their emergence in spring in all individuals of treatments. As the plants grew these anomalies did not disappear and the leaves became crêpe cloth like, the paler parts along the leaf veins were very similar to the mosaic caused by virus disease, but the stripes were much narrower, more greenish white in color and thicker than virus diseased leaf (plate II, 9–11).

3: Anomalies in flower organs: There appeared in treated plants mainly pleiomery, meiomery of perianth lobe, stamen and carpel, stripening and dissection of perianth lobe, phyllody of perianth, petalody and fasciation of stamen, solution of pistil, destruction of ovary etc. Severe injury often caused an abscission or abortion of flowers.

4: Plant height: According to JOHNSON, E. L. (1936) (10) one of the typical injuries of X-ray radiation upon plant is dwarfishness. FURUHASHI, S. (1951) (1) reported that tulip plants are easily prevented in their growth by X-rays. In the present experiment the writer observed that the developmental stage of flower elements is one of the most critically important factors for decreasing the height of plant by X-rays. X-ray irradiations of the same dosis can variously influence the growth of tulip plant in compliance with the stages of development (Textfigure 1).

5: Anomalies in bulbs: Scales of old bulbs were frequently remaining around the new bulbs when they were dug out. Bulbs that could not sprout by severe injury remained until next harvesting time without their central buds. Scales of the newly formed bulbs from X-treated plants were always thicker and stiffer than control.

6: Detailed Descriptions: These anomalies above mentioned were present or absent, slighter or heavier according to varieties and times of treatment. A general view of these anomalies was classified in Table II. In this table the number of mark + shows the severity of injury. Somewhat detailed explanations will be offered below.

TABLE II. General view on anomalies in some organs of X-radiated plants. + shows the presence of anomalies.

	Anomalies in leaves					Anomalies in perianth				
Dates of Treatment	July 28	Aug. 4	Aug. 11	Aug. 25	Oct. 8	July 28	Aug. 4	Aug. 11	Aug. 25	Oct. 8
Feu Brillant	+	++	+++	+++	++	+	+	+	+++	++++
Sagittarius	+	++	+++	++	++	+	+	++	+++	++++
Mr. ZIMMERMAN	++	+++	+++	++	++	+	+++	+++	+++	++++
	Anomalies in stamen					Anomalies in pistil				
Feu Brillant	+	+++	++++	+	++++	+	++	++	+++	++++
Sagittarius	+	++	+++	+	++++	++	++	++	++	++++
Mr. ZIMMERMAN	++	++	++	++	++++	+++	+++	+++	+++	++++

Table II shows that the degrees of anomalies on leaves are severest in Aug. 11 and Aug. 25 treatments for Feu Brillant, Aug. 11 for Sagittarius and Aug. 4 for Mr. ZIMMERMAN. These times of X-treatment for all three varieties were when the elongation of noses had already begun and the formation of floral elements had almost been completed in the bulbs. Severe injury in leaves caused abnomal features of curious stiffness, narrowing, curling and dwarfishness. Leaves from the bulbs of all three varieties treated Oct. 8 were small but not so severe in chlorophyl unevenness, curling and puckering as in those treated at the above mentioned dates. July 28 irradiation, on the contrary, inflicted the slightest injuries in every respect in all varieties, nevertheless apparent unevenness of chlorophyl distribution was seen.

Somewhat heavier injuries than in July 28 treatment were perceived in leaves of Aug. 25 treated bulbs, when the Primordium of pistil was developing in Feu Brillant and all floral elements had been formed in Sagittarius and Mr. ZIMMERMAN. Injuries in leaves from the X-ray irradiated bulbs were different in degrees according to varieties although the times of treatment, when heaviest injury occurred, were the same in the three varieties, regarding their flower bud development, and accordingly earlier for the variety whic hdevelops early its flower bud.

Various anomalies of perianth affected by X-rays are mentioned above. These anomalies were different in degrees according to X-treated times and variety. It was from the later treatment

for Feu Brillant than for Sagittarius and Mr. ZIMMERMAN that the injuries of equal degree occurred when all three of them underwent the same doses of X-rays. The irradiations offered before Aug. 11 for Fen Brillant caused dissection, decrease of number of perianth lobes and stripening of white color in some flowers, but all flowers opened normaly.

All flowers from Aug. 25 treated bulbs, however, showed severe dissection and stripening. Flower bud abscission and flower abortion were prevalent in plants from bulbs treated on Oct. 8.

In Sagittarius X-treatment on July 28 had already caused stripeing of pink color on some perianth lobes. More stripes and decrease of number in perianth lobes (plate II, 7) were seen on bulbs treated on Aug. 4. Severe stripening, more flowers with insufficient perianth lobes and broken out lobes were present in plants from Aug. 11 treated bulbs. Somewhat heavier injuries than above were seen in plants from Aug. 25 treatment.

Thus the degree of injuries affected by the same dosis of X-rays went high up according to the delay of treatment. Flower bud could open at any rate until Aug. 25 treatment, but those from Oct. 8 treatment were almost abscissed and none of them could open normaly.

Mr. ZIMMERMAN showed earlier and heavier injuries than Sagittarius. In this variety two flowers out of five from bulbs X-radiated on July 28 had five perianth lobes, one had eight lobes (Plate II, 6) some flowers had broken lobes (Plate II, 8) Later irradiations on bulbs of Aug. 4, Aug. 11 and Aug. 25 had caused injuries of successively higher degrees, phyllody of perianth (Plate II, 5) and abortive flowers appearing from Aug. 25 treatment.
All flower buds from bulbs Oct. 8 treated could not open, they were abortive or abscissed early.

Slight or severe injuries were perceived also on stamens according to the times when mother bulbs were X-rayed. In Feu Brillant flowers from bulbs X-rayed on July 28 were generally normal, but one flower had a filament adhering to ovary. One stamen was abortives and two were petaloid in flowers from Aug. 4 treatment. Two flowers had more stamens than normal and one from Aug. 11 rayed bulbs had six abortive stamens. Flowers from Aug. 25 treatment had almost normally developed stamens, but one with four.

As the last X-radiation rendered all flowers abortive, so their stamens were also non functional.

Anomalies in stamen of variety Sagittarius went a similar course to Feu Brillant, but a little more severely affected. Normal development of stamen but an abortive one were seen in July 28 treated plants. Aug. 4 treatment decreased the number of stamens in two flowers to four and five. Two flowers with abortive stamens and five with insufficient number of stamens (3, 3, 4, 5, 5 stamens) appeared from Aug. 11 treated plants. (some bulblests drew up flower stalks and flowered) Slight injuries were seen in flowers from Aug. 25 irradiation, except one with meiomerous and one with abortive stamens.

All flowers were abortive and could not open from Oct. 8 treated bulbs.

Earlier apperance of stamen anomalies than in the other two varieties were observed in Mr. ZIMMERMAN. In the flowers from July 28 treated bulbs there appeared already some with degenerated, pleiomerous and fasciated stamens. All stamens of some flowers were abortive from Aug. 4 treatment. Two flowers with similarly abortive stamens were seen also in plants treated both on Aug. 11 and Aug. 25. The last treatment of X-rays made all flowers unable to open, and their stamens were wholly abortive.

Anomalies of pistil caused by X-irradiation were also varied according to the developmental stages of floral elements when X-rayed, and to the susceptibilities of the varieties.

In Feu Brillant all flowers from bulbs treated on July 28 were normal but one with a two-carpellate ovary, and among those of Aug. 4 treatment one was with four carpels and two were abortive. Two flowers with two-carpellate ovary and one with abortive ovary appeared from Aug. 11 treatment.

Solution of ovary was seen in flowers of plants treated Aug. 25, but all flowers and accordingly pistils became abortive in plants from bulbs in the last time of treatment (October 8).

Earlier and heavier injuries of pistil appeared in the variety Sagittarius. Two flowers with two-carpellate ovaries and an abortive one appeared in Aug. 4 treated plants, and four flowers out of five were with two-carpellate ovaries and one with solution of ovary in Aug. 11 treated plants. Injuries of approximately the same degree with Aug. 11 treatment were seen in Aug. 25 treated

plants and none with normal ovaries appeared. The last irradiation forced all flowers, and accordingly all pistils, to abortion (Plate II, 1—4).

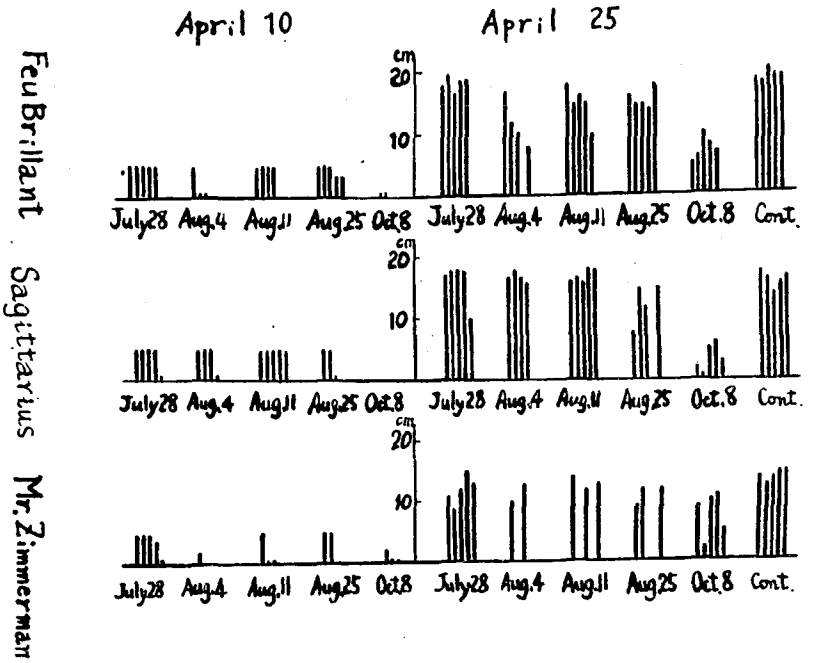
Mr. ZIMMERMAN was considered as the most susceptible variety to X-rays among these three, and their pistillary anomalies appeared to be more severe than in the other two varieties from all irradiations.

So severe were the injuries that one flower with degenerated pistil, one with five-carpellate ovary and one with abortive pistil were observed already in July 28 treated plants. Anomalies of pistil in plants treated Aug. 4 were nearly of the same degree as in those of first irradiation. All flowers of Aug. 11 treated plants had abnormal pistils of four abortive and one soluted pistils. Among the five plants treated on Aug. 25, however, one with normal and the other with abortive and degenerated pistils were seen. By the last irradiation all flowers could not open and pistils were also wholly abortive.

Floral elements develop acropetaly and bracteole, perianth (outer ones and inner ones), stamens (also in two whorls), and pistil (normaly three carpellate) are successively formed. But the times when every element develops are varied for different varieties. Among the three varieties under this experiment the flowering time in spring is the earliest for Mr. ZIMMERMAN, for Sagittarius the middle, and the latest for Feu Brillant. These characteristic flowering times for every variety are approximately parallel to the time when the floral elements develop in the bulb. Beginning of perianth differentiation is almost at equal time for Mr. ZIMMERMAN and Sagittarius, but the former completes its formation of all elements earlier than the latter. Somewhat later than these two varieties begins the differentiation of perianth in Feu Brillant.

From the above mentioned anomalies of the floral organs affected by X-rays, which differ strikingly in their degrees according to the times of treatment, we can understand that there is a stage of development of every floral element most susceptible for X-rays which is common to the three varieties, and accordingly varieties which develop earlier their floral elements show anomalies in earlier applications of X-rays than others in later varieties.

Effects of X-radiation upon growth of tulip plants are shown in textfigure 1 which is figured from the estimations on April 10 and 25.



Text fig. 1. Comparative measurements in plant height of each treatment and control on April 10 and 25, 1950.

Plant height from July 28 treated bulbs were more or less normal. Feu Brillant grew five centimeter high for all five plants on April 10, and 17 to 20 centimeter on April 25 which measures approximately the same with controls. Of Sagittarius four plants grew 5 centimeter high, one was beginning to emerge on April 10, and, on April 25, the former four had grown up to 17 to 18 centimeter which measures were slightly better than controls and the latter one to 10 centimeter. Mr. ZIMMERMAN had suffered slightly heavier injuries than Sagittarius, three out of five plants attained 5 centimeter, one 4 centimeter, and the other one was at the beginning of emergence on April 10. At April 25 estimations all of them grew 9 to 15 centimeter, being a little inferior to controls.

In contrast with the treatments of July 28, Aug. 11 and Aug. 25, the second treatment on Aug. 4 was much injurious for the plant growth. One of five plants of Feu Brillant from the treatment on Aug. 4 attained the normal height of 5 centimeter, but two others were still at the beginning of emergence, and the re-

maining two did not appear on April 10. They grew to 8, 10, 12 and 17 centimeter high respectively on April 25, but one plant did not appear to the end.

Three out of five plants of Sagittarius grew 5 centimeter, one appeared on the soil surface, and the other one did not come out on April 10. On April 25, however, all of four plants attained 16 to 18 centimeter which measures were almost equal to the control. One plant that had not appeared on April 10 did not come out to the end. Mr. ZIMMERMAN suffered much severe injuries and only one out of five plents came out and was 2 centimeter high, but the remaining four did not appear on April 10. On April 25 two plants of 10 and 13 centimeter were seen, but the other three were absent.

Plants that were treated on Aug. 11 grew and attained heights slightly inferior to controls, except Sagittarius, which were approximately equal to control. In Mr. ZIMMERMAN two out of five plants did not appear. Aug. 25 treated plants reacted similarly to those in the third treatment, but in Sagittarius plants suffered much more injuries. In the fifth irradiation on Oct. 8 when all floral elements had been formed completely and their axis were elongating, heights of plants were restrained decidedly for all varieties as seen in textfigure 1.

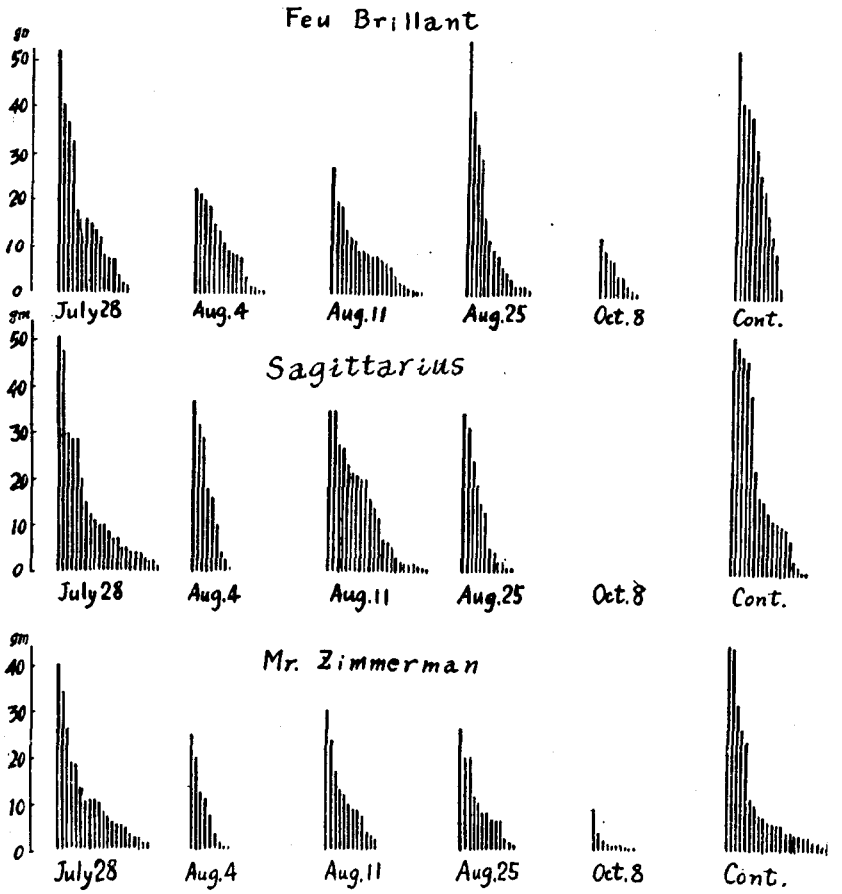
B: Yield of Bulbs.

Because the production of bulbs is related closely to the growth of the terrestrial organs, the effects of X-rays upon yields of bulbs are considered to be very striking. JOHNSON, E. L (1931) (7) treated tulip bulbs by a small dosis of X-rays and reported that no increase of yields was seen, but that the average number of bulbs yielded from X-rayed bulbs was slightly (3,4%) greater than controls. MORGAN, W. P. (1931) (13) treated freesia corms by X-rays and saw an increased number of achsial buds grown from irradiated corms.

The writer used three varieties of tulip and treated their bulbs by a considerably great dosis of X-rays whilst floral elements were developing. By these treatments no decided increase in the weight of bulbs newly formed was seen, but in some varieties the number of bulbs yielded was considerably high. Data of these results are classified and shown in Table III and textfigure 2.

Some heavy mother bulbs (52,5 and 55,0 gm.) newly produced draw our attention in this figure in July 28 and Aug. 25 treatments for Feu Brillant. These big bulbs were constructed, upon closer observation, with thick scales, and the greater weight was considered to be due to this thickness of scales. Total weight of new bulbs from five mother bulbs of each treatment, however, was wholly inferior to control but July 28 radiation for Feu Brillant, where a slight gain (only 0,1%) in yield over controls was estimated (see Table III).

The increase or decrease of numbers of yielded bulbs was related with the time of irradiation. Irradiation of unsuitable times,



Text fig. 2. Weight of bulbs yielded in 1950 from X-treated and control plants. Each lot is from five mother bulbs.

TABLE III. Weight of individual bulbs yielded in
(weights in each column are of

Dates of Treatment	July 28	Aug. 4	Aug. 11
Feu Brilliant	18,0 52,5 32,5 37,0 40,5 16,0 12,0 16,0 27,0 15,0 7,5 13,5 8,0 1,5 7,0 2,0 Total Wt. 306,0 No. 16	22,0 23,5 15,0 11,0 20,5 1,5 8,5 8,0 19,0 0,5 8,5 1,0 13,5 3,5 9,0 1,5 Total Wt. 166,5 No. 16	14,5 19,0 20,0 27,5 6,5 12,0 9,0 9,0 8,0 6,0 11,5 4,0 0,5 1,0 2,0 8,5 0,7 0,5 8,0 0,5 7,5 2,5 Total Wt. 178,7 No. 22
Sagittarius	49,5 47,0 29,0 28,5 15,0 6,5 29,5 20,0 12,0 4,0 5,0 9,5 11,0 8,0 1,0 4,5 3,5 9,5 7,0 4,0 2,5 2,5 1,5 Total Wt. 310,0 No. 23	29,5 32,0 37,0 18,0 16,0 10,0 4,0 2,0 0,5 Total Wt. 149,0 No. 9	23,0 27,5 35,0 27,0 35,5 20,0 14,0 21,0 21,5 19,5 6,5 2,5 1,5 15,5 0,5 5,0 1,5 11,5 3,0 1,0 7,0 1,5 1,0 Total Wt. 302,0 No. 23
Mr. ZIMMERMAN	18,0 18,5 34,0 40,0 26,0 10,5 10,0 13,5 10,5 10,5 5,0 6,5 2,5 5,5 8,0 4,5 2,5 1,5 5,0 1,5 3,0 Total Wt. 237,0 No. 21	20,0 25,0 7,5 12,5 1,5 10,5 3,5 0,5 Total Wt. 81,0 No. 8	30,0 12,0 8,5 24,0 13,0 7,5 8,5 17,0 3,0 8,5 14,5 1,5 9,5 Total Wt. 157,5 No. 13

Percentages of gain or loss

Feu Brilliant	Total Wt. 0,1 No. 45,4	— 45,4 45,4	— 41,5 100,0
Sagittarius	Ttal Wt. — 14,4 No. 27,7	— 58,8 — 50,0	— 16,6 27,7
Mr. ZIMMERMAN	Total Wt. — 8,4 No. — 8,6	— 68,7 — 65,2	— 39,1 — 43,4

1950 from X-radiated mother bulbs in gm.
new bulbs from one mother bulb).

Aug. 25	Oct. 8	Control
10,0 55,0 40,0 32,5 29,5	17,5 12,5 8,0 2,5	40,5 43,0 32,5 41,5 53,5
5,0 6,0 12,0 19,0 16,5	10,0 7,5	27,0 23,0 9,5 18,5
2,0 2,0 3,5 2,0 8,5	4,5 2,5	14,0
1,0	4,5	2,5
	1,0	
Total Wt. 244,5	Total Wt. 70,5	Total Wt. 305,5
No. 16	No. 10	No. 11
19,0 34,5 24,0 31,5		47,5 50,5 46,5 52,0 39,5
2,0 13,0 5,0 15,0		17,0 12,0 16,5 10,5 23,0
4,5 1,5		7,5 11,0 13,5 3,0
1,0		10,0 1,5 0,5
0,5		0,5
Total Wt. 151,5	Total Wt. —	Total Wt. 362,5
No. 12	No. —	No. 18
11,5 2,0 26,5 20,0	1,0 1,0 9,0 3,5	24,0 44,5 32,5 45,0 26,5
8,0 20,0 10,5	1,0 1,5	3,5 10,0 4,0 11,5 8,0
6,5 1,5 8,0	0,5 1,5	0,5 6,5 4,0 6,0 7,5
6,0 6,0	0,5 0,5	6,0 3,0 1,5 6,0
1,0		0,5 1,5 3,5
		3,0
Total Wt. 127,5	Total Wt. 20,0	Total Wt. 259,0
No. 13	No. 10	No. 23

in yield of bulbs

− 19,9	− 76,9	—
45,4	− 9,0	—
− 58,2		—
− 33,3		—
− 50,7	− 92,2	—
− 43,4	− 56,5	—

for example Aug. 4 and Oct. 8, made the plants often unable to sprout, while if it was offered in suitable time the numbers of newly formed bulbs were very great. Feu Brillant for example is a low productive variety, and the number of bulblets produced from a 20 to 30 gram mother bulb is generally one or two (cf. Table III). Irradiations dated July 28, Aug. 4 and Aug. 11, as shown in Table III and textfigure 2, raised strikingly this number. The number of new bulbs yielded from five control bulbs was 11, while 22 newbulbs were produced from Aug. 11 treatment, and 16 from July 28, Aug. 4 and Aug. 25. Only 10 bulbs were produced from Oct. 8 treatment where one plant could not sprout. Similar increasing effects on bulb numbers were recognized for Sagittarius in July 28 and Aug. 11 treatment, but Aug. 4 and Aug. 25 irradiations decreased considerably the number, and from Oct. 8 treatment no measurable bulbs were obtained. Mr. ZIMMERMAN is a productive variety and the numbers of yielded bulbs from all treatments were inferior to control. This decreased number is also due to the high susceptibility for X-rays of this variety by reason of which one to three plants out of five in each lot could not sprout except after treatment of July 28.

C: Growth in the Second Year

As already mentioned yielded bulbs from all X-radiations in 1949 had their bulb scales thick and stiff as compared with controls. The writer cultivated them one year more, and observations and estimations were continued during this second year. Bulbs yielded in summer were stored normaly and planted in the fall of 1950. In the first experiment 20 to 30 gram bulbs were used, but in the second year suffiecent bulbs of ample weight were not available, and 10 to 20 gram bulbs were used. Oct. 8 treatment was so destructive, and no noticeable bulbs were obtained so that the experiment for Oct. 8 treated bulbs was abandoned, except Feu Brillant.

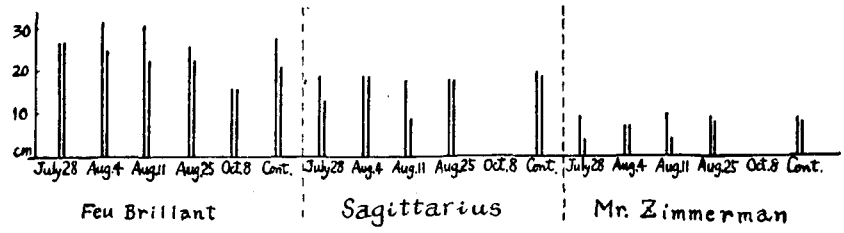
Estimations of plant heights in May 18 and yield of bulbs harvested on July 12 were classified and shown in Table IV and textfigures 3 and 4. Various anomalies in the terrestrial organs recognized in the previous season were not noticed in the second season, except two examples which were one Sagittarius plant treated July 28 having pinkish stripes on perianth lobes and one

TABLE IV. Weight of individual bulbs yielded in 1951 from plants whose mother bulbs had been X-radiated in 1949. (in gm)

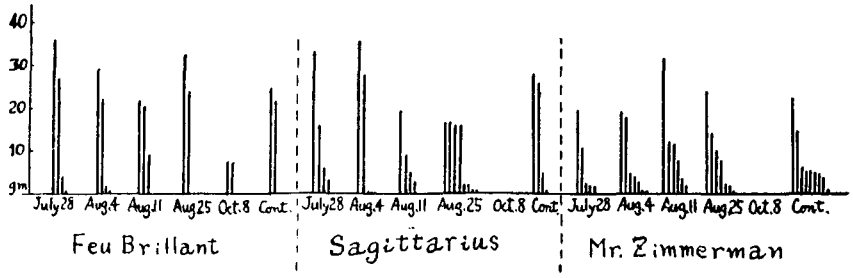
Date of Treatment	July 28	Aug. 4	Aug. 11	Aug. 25	Oct. 8	Cont.
Feu Brillant	36,0 27,0 0,2 4,5 Total Wt. 67,7 No. 4	29,5 22,0 1,5 0,5 Total Wt. 53,5 No. 4	21,5 20,0 9,0 Total Wt. 50,5 No. 3	24,0 32,5 Total Wt. 56,5 No. 2	7,5 7,5 Total Wt. 15,0 No. 2	21,5 24,5 Total Wt. 46,0 No. 2
Sagittarius	33,0 16,0 6,0 3,5 Total Wt. 58,5 No. 4	35,5 27,5 0,5 0,5 0,5 Total Wt. 64,5 No. 5	9,0 19,0 5,0 3,0 Total Wt. 36,0 No. 4	16,5 16,5 16,0 16,0 2,0 2,0 1,0 1,0 Total Wt. 71,0 No. 8	 Total Wt. — No. —	26,0 27,5 1,0 5,0 Total Wt. 59,5 No. 4
Mr. ZIMMERMAN	19,5 11,0 2,5 2,0 2,0 Total Wt. 37,0 No. 5	19,0 17,5 3,5 5,0 0,2 4,0 0,2 Total Wt. 49,4 No. 7	12,0 31,0 11,5 7,5 3,5 2,0 Total Wt. 67.5 No. 6	23,5 14,0 8,0 10,5 2,5 0,5 2,0 Total Wt. 61,0 No. 7	 Total Wt. — No. —	21,5 14,5 6,0 5,5 5,5 4,5 5,0 4,0 0,5 Total Wt. 67,0 No. 9

Percentages of gain or loss in yield of bulbs

Feu Brillant	Total Wt. 47,1 No. 100,0	16,3 100,0	9,7 50,0	22,8 0,0	−67,3 0,0	
Sagittarius	Total Wt. −1,6 No. 0,0	8,4 25,0	−39,4 0,0	19,3 100,0	— —	
Mr. ZIMMERMAN	Total Wt. −44,7 No. −44,4	−26,2 −22,2	0,7 −33,3	− 8,9 −22,2	— —	



Text fig. 3. Comparative measurements in plant height of each treatment and control on May 18, 1951.



Text fig. 4. Weight of bulbs yielded in 1951 from X-treated (in 1949) and control plants. Each lot is from two mother bulbs (10 to 20 gm.).

Mr. ZIMMERMAN plant treated Aug. 25 with petaloid pistil.

It is clear from the above mentioned figures that the plant heights are slightly greater than control in Feu Brillant treated in early times, neverthless in the other two varieties they are either approximately equal or inferior to controls.

In the second year also big bulbs were produced from bulbs treated on July 28, Aug. 4, Aug. 25 in Feu Brillant, July 28 and Aug. 4 in Sagittarius, and Aug. 25 in Mr. ZIMMERMAN. The total weight of yielded bulbs from each X-radiation, except Oct. 8 were more or less susperior to control in Feu Brillant, while in Sagittarius Aug. 4 and Aug. 28 treatments gave more total weight than control, the other treatments, however, gave less weight. Mr. ZIMMERMAN yielded decreased total weight of bulbs from all treatments, except Aug. 11 where it was nearly equal to control.

Greater numbers of bulblets than control were also gained in this year by every treatment, but in Aug. 25 treatment for Feu Brillant, and July 29 and Aug. 11 for Sagittraius they were equal to controls (Table IV). In contrast with these two varieties Mr.

ZIMMERMAN, which is productive and X-ray susceptible, produced always smaller numbers of new bulbs.

Anomalies of thickness of X-treated bulbs were no more recognized in bulbs produced this year; they were all normal in every respect.

Discussion

Some investigators have treated nutritive plant organs as potato tubers, freesia corms, Narcissus, Hyacinthus, tulip bulbs etc. by X-rays and observed the influence upon organ development and growth thereafter. The results obtained by them, however, are in many respects not identical. JOHNSON, E. L. (1926 to '39) (4) (5) (6) (7) (8) (9) (11) X-radiated on many plants of various families and reported that the X-rays were always injurious to plant growth, the degrees of injury being various for different species of plants. She pointed out depressed catalase activity and respiration by reason of injury, reported that the shape of cells of radicle tip from seedlings which had suffered heavy injuries showed elongation, great vacuolation or entire absence of protoplasm and the absence of nuclei from many cells. Increased xylem and suberin development were observed. In contrast with JOHNSON's opinion, SHULL, C. A. and MITCHELL, J. W. (1933) (17) took the opinion that X-rays had a stimulative effect upon plant growth only when the dosage and screens were proper and short irradiation was used. These stimulations were the result of increased respiration and increased sugar content in treated plants.

JÜNGLIG, O. (1920) (12) reported that the effects or X-rays upon plants were very different according to their growing stages. JOHNSON's experiments on tomato (1931) (6) and Salpiglossis seedlings (1939) (11) showed coinciding results with that of JÜNGLING.

These conditions should be considered also for the X-radiation on nutritive organs. The diverse results in treatments of potato tubers, tulip bulbs and freesia corms are considered to be agreeable if these conditions were accepted. JOHNSON, E. L. (1931) (7) X-rayed twice repeatedly upon tulip bulbs of Pride of Haarlem and Barone de la Tonnaye in the first experiment, and Sieraad van Flora and White Qeen added in the second experiment. These irradiations were carried out in the fall directly before planting them, and the

dosages of X-rays were in both cases 7½ inch spark gap, 7ma., 1 mm aluminium filter, with 19 inches distance and 1 minute, which are very small doses. Her results tell us that no anomalies of organs, no gain of yield over controls and no noticeable increase of plant height were perceived but a slightly greater number of yielded bulblets than control.

Tulips differentiate their flower elements during summer and autumn and this period should be considered to be much complicated in organ development. The bulb is a mass of rather homologous tissues when it is harvested, but after storage it becomes one of much complicated organs. The writer's experiment shows that X-treatments during this storage offered very different results according to the stages of development when they were X-rayed.

Results show that the anomalies in leaves, floral elements and growth of flower stalks are very different in degree and character according to the times of treatment, and their appearance is earlier in the earlier flowering varieties. This shows the direct relation between X-radiation and organ-primordia then present, independently of the different susceptibilities of varieties.

Much inferior yields of bulbs were observed from the plants whose terrestrial organs had decidedly suffered by X-rays, for example those of Oct. 8 and Aug. 4 treatments. But approximately equal yields of bulbs and superior number of bulblets to controls were gained from some treatment in which the terrestrial organs had not suffered heavily. X-treatment before the beginning of differentiation of floral elements is most likely to raise the production of bulblets.

Primordia of bulblets develop readily during the storage in summer and autumn, and the X-treatments in this experiment are considered to be in the early stages of development of bulblets. Bulbs grown from these bulblets had more or less curiously thick bulb scales which is a similar phenomenon to the thick foliage leaves from X-treated bulbs.

Plants from these thick scaled bulbs were almost normaly growing in the second year, and bulbs newly produced from them became normal again. A slight increase of plant height in Feu Brillant and increased number of bulblets observed in the previous season was also noticed in considerably high degree in the second year.

Anomalies of organs observed in plants from bulbs X-radiated in the previous fall were properly temporal in character, and in individuals of the successive generations these anomalies disappeared readily. Ontogenetically speaking, however, the tulip bulb survives two years fully; the primordium of the new bulb is formed in summer time inside of its mother bulb and grows up in its size and weight until next summer, a flower bud then is formed which flowers in the successive spring, the bulb decays until autumn, and new bulbs take the place of it. According to the life cycle of tulip bulb above stated, influences of X-radiation are considered to continue for two seasons. FURUHASHI, S. (1951) (1), on the other hand, reported in his paper that influences of X-rays could be observed directly after treatments as cytological injuries.

This experiment is devoid of observations on the effects of X-rays upon root initiation and growth which will be sure to be susceptible to X-rays and to be indirectly related to the growth of plants. The characteristic anomalies, of organs above mentioned, however, will be independent of root growth.

Summary

1. X-rays were irradiated on tulip bulbs of three varieties of Feu Brillant (darwin), Sagittarius (ideal darwin) and Mr. ZIMMERMAN (triumph) from July 28 to Oct. 8, 1949 during which period their floral elements developed in the bulbs. Plant growth and yield of bulbs newly formed in the next and the second seasons were observed and estimated.

2. Degrees of injury affected by treatments of equal doses of X-rays were strikingly varied according to the different stages of development of floral organs, the most injurious stage being considered to be in the elongating period of floral axis after completing the formation of flower organs and also when the floral elements were differentiating the plant were considerably susceptible. In contrast with these stages, low susceptibilities were seen in stages before floral elements began to differentiate and shortly after they had completely developed.

3. More or less anomalies were observed in all plants from every irradiation. Generally speaking X-treatment was injurious for plant growth but in some times of treatment plant growth, the weight

of yielded mother bulbs and numbers of split bulblets were superior to controls, and these effects were observed also in the second season.
4. Injuries and preferale effects above mentioned, however, disappeared readily in the successive generations and were considered to be entirely temporal.
5. The suitable dosis of X-rays for stimulating the plant growth is therefre considered to be closely related to the stages where the plant under experiment stands.

The writer wishes to express his thanks to Prof. Dr. S. NAGAO for facilities offered for using the X-ray machine. Thanks are due to other researchers in the Institute of Plant Breeding of the College of Agriculture, Hokkaido University, for their kind suggestions, and especially to Mr. T. MORI, now in Sendai, for his elaborate operation of the machine.

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* References were taken from JOHNSON's paper in 1936 (10).

Explanation of Plates

Plate XI

Development of noses and floral elements in three varieties of tulip in 1949.

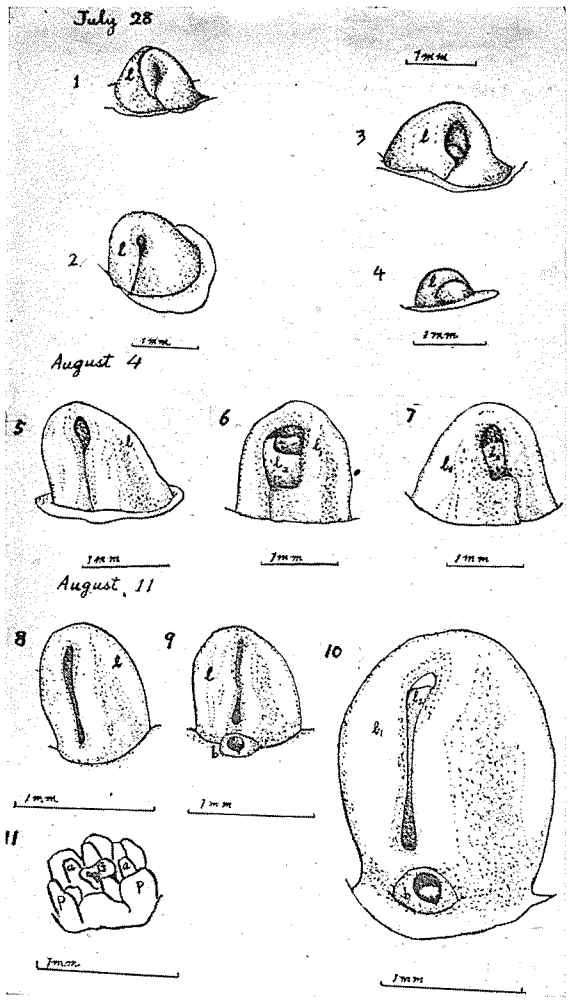
1 ~ 4: July 28, noses of Feu Brillant (1 and 2), Sagittarius (3), Mr. ZIMMERMAN (4).
5 ~ 7: August 4, Feu Brillant (5), Sagittarius (6), Mr. ZIMMERMAN (7).
8 ~ 10: August 11, Feu Brillant (8), Sagittarius (9), Mr. ZIMMERMAN (10).
11: Flower bud of Mr. ZIMMERMAN on August 11.
12 ~ 14: Flower bud differentiation of Feu Brillant as viewed in longitudinal sections. (scales in 10μ). 12: July 28 13: Aug. 11, 14: Aug. 28.
l: leaf l_1: the first leaf l_2: the secsnd leaf
a: stamen G: pistil p: perianth g: growing point
b: primordium of new bulb

Plate XII

Anomalies in leaf and flower organs.

1 ~ 4: Flowers of Sagittarius
1: Normal flower with six stamens and a three-carpellate syncarpous ovary
2: Solution of carpels
3: Four-carpellate ovary and four stamens
4: Two-carpellate ovary
5: Phyllody of two perianth lobes (Sagittarius)
6: Pleiomerous flower of perianth (8 lobes) (Mr. ZIMMERMAN)
7: Meiomerous flower of perianth (4 lobes), stamen (four) and carpel (two) (Sagittarius)
8: Dissection of perianth lobes (Mr. ZIMMERMAN)
9 ~ 11: Leaves of Mr. ZIMMERMAN
9: Normal leaf
10: The thick crêpe cloth like leaf from X-treated bulb
11: Mosaic leaf inflicted by virus disease

all scales in centimeter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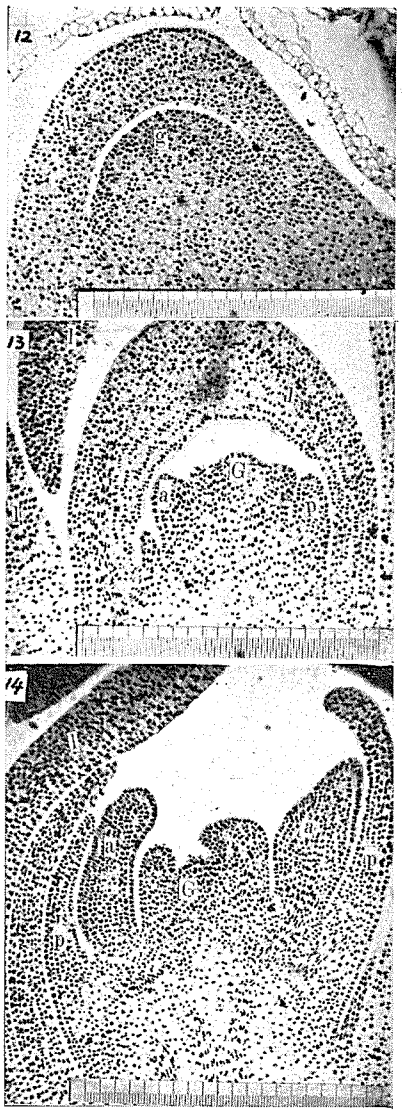
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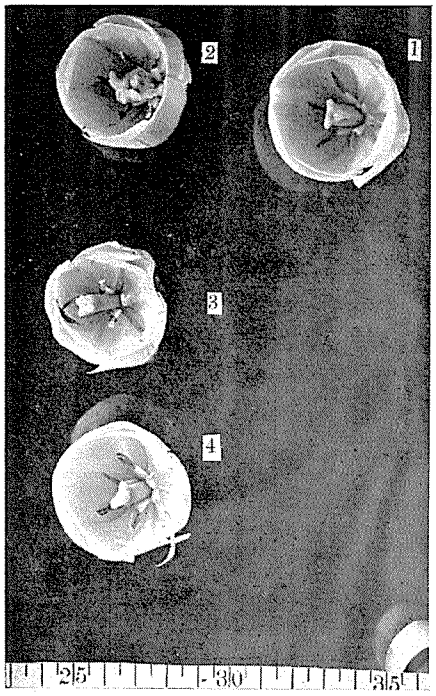
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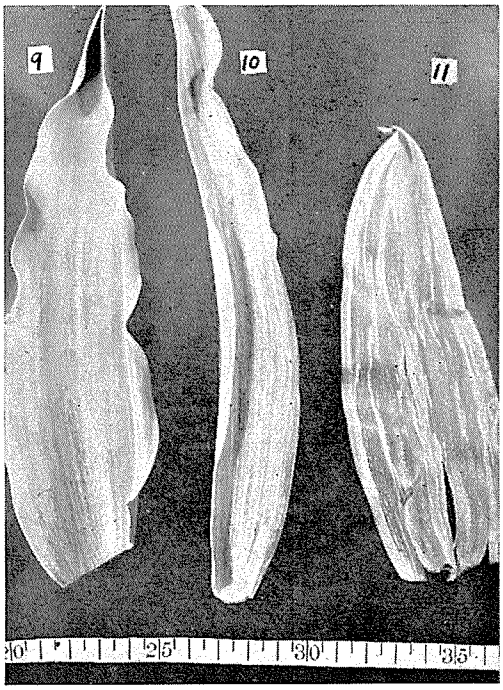
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