A STUDY OF CHEMICALLY INDUCED PARTHENOCARPY IN CERTAIN HORTICULTURAL PLANTS, WITH SPECIAL REFERENCE TO THE WATERMELON

By

Cheong-Yin Wong

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Department of Horticulture
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V. R. Gardner

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C. H. Spurway
V. G. Grove

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Introduction

Natural parthenocarpy is of common occurrence in banana, citrus, vinifera grape, Chinese persimmon and English forcing cucumber. Furthermore induced or stimulative parthenocarpy has been observed to occur as a result of certain internal and external influences in many species and varieties. It has been shown that some sort of stimulation to the gynoecium, usually as a result of pollination and often subsequent fertilization, is necessary for parthenocarpic development. However, it was only after the discovery by Gustafson in 1936 that parthenocarpy could be induced by certain synthetic growth substances that its practical and theoretical possibilities were visualized.

Due to the fact that parthenocarpic fruits are considered desirable, efforts have been made: (a) to obtain seedless fruits by breeding or selection, (b) to induce parthenocarpic in place of non-parthenocarpic fruits and (c) to increase the percentage of parthenocarpic fruits where some occur normally. In addition, comparisons of hormone-treated flowers and fruits with regularly-pollinated ones in order to determine subsequent anatomical and physical changes and relationship have been of great interest.

The object of this study was to determine the possibility of inducing parthenocarpy by the use of synthetic growth substances in some horticultural crops, with special reference to the watermelon, to establish the following: (1) the response of different horticultural plants to parthenocarpic and apomitic phenomena, (2) the kinds and concentrations of growth substances that give best results, (3) fruit and seed development as compared with normal seed-bearing fruit, and (4) the possibility for practical application of the results obtained.

Parthenocarpy is the production of fruit without seed or with embryoless seed. When seedless fruit develops without fertilization, the condition is called vegetative, autonomic, spontaneous or "natural" parthenocarpy. If the formation of a fruit depends upon, or as influenced by, the stimulus of pollen, live or dead, on the stigmas or by the growth of pollen tubes, in the style or ovary or by hormones and other physical-chemical stimuli on or in the style or ovary, the condition is called stimulative, aitionomic or "artificial" parthenocarpy. In vegetative parthenocarpy, if all of the ovules are unable to function in fertilization and unable to develop as seeds of any sort, the parthenocarpy is obligate. If one or more ovules in an ovary are able to develop as stenospermic seed, a parthenocarpic fruit develops only when there is no pollination and parthenocarpy is hence facultative.

Stenospermocarpy is the development of fruit with aborted or partly formed seeds after there has been fertilization or at least entrance of pollen tubes into the ovules.

Review of Literature

For the sake of convenience, the papers cited in this review are arbitrarily grouped under: (1) internal factors, including natural auxins or growth substances and synthetic growth substances and (2) external factors, including temperature, photoperiodism and mechanical stimulation.

Internal Factors: Natural Auxins.-- As early as 1902, Massart (35) placed dead pollen upon the stigma of an orchid and observed a slight growth of the ovary. Hartley (19) obtained parthenocarpic fruit of tabacco by the use of *Azalea* pollen. Fitting (6, 7) using dead and living pollen and pollen extracts, was able to cause some slight growing in the ovary of several species of orchids. The swelling of the ovary, was due not to fertilization itself, but to some substance in the pollinia since alcohol or water extracts of the pollinia brought about similar effects. Winge (58) found that large fruits with sterile seeds could be produced in hops pollinated with hemp or *Urtica* pollen. Morita (37) found that pollen from several orchids extracted with hot or cold water, absolute alcohol, or ether yielded a substance which caused a slight enlargement of the gynostemium. Liabach (25, 26, 27) repeated some of Fitting's work and obtained essentially the same results. Pollinia of orchids were shown to store abundance of growth substances, which remained active for a long time. He believed that these materials are not in the pollen proper but in the adhesive layer between the individual grains. Hot water extracts of pollen or growing pollen tubes of Hibiscus schizopetalus , Anoda cristata, Abutilon hybrid, Cucurbita pepo, Strelitza reginae, Lilium speciosum, Acacia species and Hippeastrum vittatum produced swelling in the gynostemium and also gave stimulative growth of the oat coleoptile. These active substances (28) were found to be soluble in water, alcohol and acetone and insoluble in aliphatic or aromatic hydrocarbons.

In a series of attempts to produce parthenocarpy by cross pollination and other means, only some of which were successful, Yasuda (60, 61, 62, 63) obtained parthenocarpic eggplant, tomato, and pepper fruits by pollination with pollen other than their own. He also obtained satisfactory results by injecting aqueous extracts of pollen into the ovary. In cucumber and a solonaceous plant, however, parthenocarpic development did not take place in flowers that opened early in the season though it did appear at a later date. In a Japanese cucumber, "Shogoin fushinari", which rarely bears parthenocarpic fruits under natural conditions, Yasuda (64) obtained parthenocarpic fruits of normal size when cross-pollinated with other cucurbitaceous plants or the sunflower but none with solonaceous plant. In another experiment (64, 65), he found parthenocarpic cucumbers and eggplants developed when pollinated with their own pollen, at a very old or very young state. In cases where parthenocarpic fruit developed, the pollen tubes grew into the the style but did not reach the ovary. In still further work (65), though only a limited number of flowers were used, the flowers of eggplant and cucumber were emasculated and smeared with well developed pollen grains of their own plants, and the pollinated stigmas and styles were cut off from the ovaries at their summit at different periods following pollination, e. g. 24, 30, 48 hours. When the operation was delayed, 24 hours in eggplant and 9 hours in cucumber, fertilization occurred and the ovaries developed into normal seeded fruits. If the operation was so timed that the majority of the pollen tubes reached the base of the styles, some seedless fruits resulted. He concluded that the pollen grains or pollen tubes produced some chemical substances, which caused parthenocarpic development of the ovaries. Parthenocarpy, phenospermy (Stenospermy) and parthenogenesis were believed to be caused by the action of the same stimulating substance. He further concluded that parthenogenesis would take place when the pollen tube substance reaches the ovules and stimulates them without fertilization. When, on the other hand, the substance arrives at the basal portion of the styles or at the ovaries and stimulates the ovarian tissue alone, parthenocarpy would occur. Phenospermy may take place in an intermediate situation.

Cochran (2) obtained parthenocarpic peppers, variety World Beater, by placing potted plants following pollination in a cool house, 50°-60° F. His morphological study showed this condition to be due, not to lack of pollination, but rather to lack of fertilization caused by slow growth of the pollen tube down the style as a result of the relatively low temperature. By the use of pollen extracts, Gustafson (12) produced parthenocarpic fruits of eggplant, pepper, cucumber and certain ornamental plants.

Synthetic Growth Substances: Parthenocarpy induced by growth substances or hormones was first accomplished by Gustafson (11) in 1936 by treating the pistils with known hormones in lanolin paste. He was able to obtain normal-sized parthenocarpic fruits in tomato, *Petunia*, and *Salpiglossis* when the pistils were treated with indole-3n- - propionic acid. Similar treatment initiated growth in snapdragon ovaries, but did not produce mature fruits. Phenylacetic acid caused seedless tomato fruits to develop and slight growth in snapdragons, but none in tobacco. Indoleacetic acid caused seedless fruits to be formed in the tomato, *Salpiglossis*, *Petunia*, *Begonia*, pepper and eggplant. The same substance initiated ovary growth in the snapdragon, *Zephyranthes carinata*, *Agapanthus umbellatus*, crookneck summer squash, and Hubbard squash, but not in cucumber and watermelon. Indolebutyric acid caused seedless fruits to be formed in tomato, *Salpiglossis*, *Petunia*, crookneck summer squash, *Begonia*, pepper and eggplant, but produced only slight growth in the ovaries of Hubbard squash, cucumber, and watermelon. In a further study, Gustafson (13) found, of 13 new chemicals tested, only K-indoleacetate, pyrrole- -carbyxylic and pyrrole- -acetic acids induced the development of parthenocarpic fruits in several plant species. The K-indole acetate was used either as a 5 per cent lanolin paste or as a 0.2 per cent aqueous solution for injection. The tested plants were _Clarkia elegans_, _Salpiglossis variabilis_, _Godetia_ species, snapdragon, tomato, Maryland Mammoth tobacco, cucumber, apple, pepper and eggplant. All except the apple produced an enlargement of the ovary and some even reach their maturity. It was concluded that the potassium salt of indoleacetic acid is approximately as effective as the acid. There was some stimulating action or set of parthenocarpic fruits as a result of the use of pyrrole- -carboxylic acid in crookneck summer squash, eggplant and tobacco but not with pepper, tomato, watermelon and pumpkin. Some growth was observed in squash, eggplant and tobacco but none in pepper or crookneck summer squash by the use of pyrrole- -acetic acid. In comparing the relative rate of growth of tobacco fruits produced parthenocarpically by K-indole acetate and those resulting from pollination, it was found that during the first few days of development the ovaries treated with K-indole acetate grew faster that the pollinated ones but slower at a later stage. This was attributed to the fact that at first the treated ovaries had more available growth substance which later became depleted. It was assumed that the pollinated fruits grew slower during the first few days but later grew more rapidly than the parthenocarpic fruits due to the formation of a growth substance through the developing seeds. He found tobacco fruits produced by indoleacetic acid treatment were always smaller than those produced by pollination or treatment with K-indole acetate. In an experiment (13) with crookneck summer squash in which the ovule-bearing portion (blossom-end) was cut off and the cut surface then treated with growth substances, the remaining portion grew with a uniform diameter throughout their whole length, but there no special enlargement at the apex. The hypothesis was developed by Gustafson (13, 14, 16) that developing seeds favor or are even necessary to the continued elongation of the fruit. The pollen grains and probably the ovules contain a growth substance or auxin, which is synthesized or increased by the developing ovules, seeds or embryos, or which acts as a master reagent causing other substances to produce growth of one sort or another, as suggested by Went and Thimann (50, 55, 56).

Based on his own work and results of other investigators, Gustafson (15) proposed the hypothesis that the reason some fruits develop without fertilization if that they have a higher auxin content in the ovary at the time of blossoming. He believed that this is high enough to initiate growth processes with the result that the ovaries commence to develop even though there has been no fertilizations. He also found that the auxin content of ovules and developing seeds is much greater than that of other parts of the fruit. Moreover, he found the auxin content, in pepper at least, was much lower in the winter and spring than in the summer.

Katunsij (24) associated ovule development with a high production of auxin in the plant and attributes the pre-and post-floral movements of peduncles and scapes of some plants to the presence of a large quantity of auxin in the plant produced in the ovules. Dollfus (4) also found that the developing embryos supply a growth substance, which causes the ovarian wall or the receptacle to develop into the fruit. Meyer (36) also observed the presence of auxin in fruit. The seed material gave a greater Avena coleoptile curvature than the other parts of the fruit.

Hagemann (18) obtained parthenocarpic gladiolus by means of indoleacetic acid, but he obtained negative results from phenylacetic acid. Gardner and Marth (9) obtained parthenocarpic holly (Ilex opaca) by spraying the open blossoms with naphthalene acetic, indolebutyric, indoleacetic and indolepropionic acids. The effectiveness of the above substances followed the descending order as listed. They also found that better results were obtained by repeated applications. Moreover, parthenocarpic fruits were also produced by watering the soil around the roots during full bloom with indoleacetic acid. They also obtained some parthenocarpic fruit by introducing small quantities of indoleacetic acid in powder form into holes in the stem made with a small nail. In a pistillate strawberry, parthenocarpic fruits of normal size but with empty achenes were induced by these workers using the substances mentioned above in spray form. Negative results were obtained in the starking apple from indoleacetic acid spray and in the Brighton grape from naphthalene acetic acid treatment. In a further study, Gardner and Marth (10) found naphthalene acetamide gave even better results in inducing parthenocarpic holly than naphthalene acetic acid. K-naphthalene acetate gave results far inferior than obtained from phenylacetic acid and Na-naphthol (4) sulphonate and very little response from naphthalene-propionic acid. In studying the effect of certain growth substances on inflorescences of dates, Nixon and Gardner (40) show that one per cent naphthalene acetic acid in lanolin paste applied to Thoory date arrested senescence of the perianth and strand. Negative results were obtained from indoleacetic and indolebutyric acids. In the Deglet Noor variety, spraying with naphthalene acetic acid in aqueous solution about 10 days after pollination reduced the set by about 50 per cent.

Schroeder (42) obtained parthenocarpic fruit of the Break O' Day tomato, under greenhouse conditions, from phenylacetic, indolepropionic, indolebutyric and indoleacetic acids in aqueous solution (1-2500) and also indoleacetic acid (1-500) in lanolin paste. He also found that better results were obtained by more than one application. In an experiment with a limited number of flowers, Oleson(41) obtained full size fruit, either seedless or with slight ovule emlargements in <u>Begonia semper florens</u>, <u>Fuchsia hybrida</u>, <u>Primula hortensis</u> and tomato variety Chiswick Peach by treating the blossoms with indoleacetic and indolebutyric acids in paste form.

Aquaphor* was found to be better as a carrier than lanolin due to its higher melting point. She also tried these treatments with some other plants with negative or partial results. Zimmerman and Hitchcock (66) found vapors of methyl- -naphthaleneacetate caused parthenocarpic development of American holly, *Fushsia*, orchid (*Epidendrum O'Brienianum*) and strawberries. In these experiments, the naphthalene substances were more effective than indole and phenyl compounds for inducing parthenocarpy. Sereisky (47) obtained parthenocarpic fruits of *Chelidonium majus*, *Digitalis purpurea*, *Luffa cylindrica* and *cucurbita pepo* by means of indoleacetic acid paste. Negative results were obtained in watermelon. The parthenocarpic fruits of *Luffa* and squash reach considerable size and contained no seeds or only seed coats.

External Factors: Low or freezing temperature, if not too severe, often leads to parthenocarpic development in the pomaceous and drupaceous fruits (57, 8, 29, 3, 20). On the other hand, high temperature has been reported to cause the development of parthenocarpic tomatoes (21). Photoperiod has been found responsible for the parthenocarpic development in cucumber, *Begonia* and *Fuchsia* (51, 52, 41). Based on experiments with very limited samples of *Begonia semperflorens* and *Fuchsia hybrida*, Oleson (41) found parthenocarpic and normal fruits occur only under a long photoperiod. According to her results neither pollination

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*According to a personal discussion with Dr. Gustafson, he found no distinctive advantage in aquaphor over lanolin.

with viable pollen nor stimulation with indoleacetic, indolebutyric or phenylacetic acids was capable of inducing ovarian growth under short-day donditions.

Parthenocarpy has been induced merely by mechanical stimulation of the stigma or cut style. Wellington (54) obtained parthenocarpic fruits with aborted seed in Nicotiana by singeing the young buds with a hot platinum wire. Sokolskaya (49) was able to decrease the shedding of orange flowers (variety not stated) by removing the pistils from the unopened flowers. Twenty-two fruits were obtained from 39 treated flowers and only one from 35 flowers in the control group. Wong (59) also obtained parthenocarpic fruits of normal size in two commercial seedless oranges, Valencia and Hamlin, and two seedy varieties, Pineapple and Parson Brown, merely by cutting off two-thirds of the style and filaments before anthesis. However, in previous experiments (Wong, unpublished data) when the cut surface was made just above the ovary, the treated ovaries dropped within 10 days even when the cut surface was supplied with the growth substances, indolebutyric and indoleacetic acids.

Based on results of some twenty years investigation, Haberlandl (17) proposed the wound hormone hypothesis. According to his hypothesis when plant cells are wounded there are liberated substances capable of causing renewed growth activity in other, uninjured, cells. He divides these hormones into 3 classes: (1) hormones of embryos and of primary Meristem, (2) hormones in phloem tissue, and (3) wound and necrohormones. The two hormones under (3) are sililar except that the latter arise as a result of pronounced catabolic processes within cells not subjected to external injury, such catabolism often resulting in death of the cells. The hormones under (3) act upon the fertilized egg cell leading to division and embryo development. He believes these hormones are responsible for parthenocarpy, parthenogenesis, apogamy and sporophytic budding. Leonian and Lily (30) experimented with fungi, algae, and detached roots and shoots of corn in nutrient medium. They believe that indoleacetic acid may possibly act like a powerful stimulant or irritant in inducing the formation of large quantities of growth substances, in inducing their translocation, and in causing their concentration in injured regions. This was further proved by Loofbourow and Dwyer (33, 34), since they found when yeast was subjected to indoleacetic acid in toxic concentration wound hormones were produced.

Materials and Methods

This study was carried on in the experimental garden and greenhouse at Michigan State College, East Lansing, during the summer of 1938 and the spring and summer of 1939.

Citrullus vulgaris (Watermelon): In 1938, the varities used were Winter Sweet, Fordhook Early, Early Arizona, Favorite Honey, Harris Earliest, Best Early, Select Early, Sweet Japanese and Tough Sweet. In addition, the varities Northern Sweet, selections No. 1, 2 and 5, were used in the spring of 1939 under greenhouse culture. During the summer of 1939 the following varieties were employed: Winter Sweet, Northern Sweet, Favorite Honey, Coles Early, Fordhook Early, Early Kansas, Stone Mountain #5, Stone Mountain, Kleckley Sweet No. 6, Hawksbury, Iowa 1, Iowa 3, Iowa 5, Harris Earliest, "Yellow Melon" and six selected strains.

Cucumis sativus (cucumber): National Pickling cucumber was used both in the summer of 1938 and in the spring of 1939 under greenhouse culture.

Cucumis Melo var. reticulatus (muskmelon): An unnamed selection was used for the greenhouse test in the spring 1939. In addition, the variety Honey Rock was used in the summer experiment.

Cucurbita pepo (pumpkins and squashes): The following varieties of Cucurbita pepo were used during the summer of 1939: Early Prolific Straightneck, Dark Green Zucchini, Omaha, Delicata, Fort Berthol, White Bush Scallop, Table Queen and Hardin Bush.

Curcurbita Maxima (squashes): Buttercup squash was used both for the spring and summer experiments in 1939.

Cucurbita moschata: African Bell squash was used for spring, 1939, study.

In addition certain Cucurbita of uncertain species carrying U. S. D. A. Plant introduction numbers 127585, 127586, 127588, 127589 and 127590 were used.

Solanaceae: Harris Wonder pepper (capsicum frutescens) was used in 1938. The Michigan State Forcing tomato (Lycopersicum esculentum) was used in the spring of 1939 and New Hampshire Hybrid eggplant (Solanum melongena) the following summer.

Fragaria species (strawberry): An unnamed variety of the everbearing type was used.

Winter Sweet (Fig. 1), Favorite Honey (Fig. 2) and "Yellow Melon" (Fig. 3) were the three principal Watermelon varieties used in these studies. Winter Sweet, also known as Dakota Sweet, is a medium size, red fleshed melon of 9-14 pounds with about 600 seeds per fruit. It is andromoecious with occasional monoecious flowers. Northern Sweet is closely related to Winter Sweet, differing very little either in external or internal characteristics. Favorite Honey is a small, early and very prolific melon with yellow flesh. It weighs 3-4 pounds and has about 250 seeds per fruit. The strains designated selection numbers 1to 6 were derived from crosses between Favorite Honey and Winter Sweet. The seed of the "Yellow Melon" was purchased from a commercial seedman as Favorite Honey, but it was later discovered that it differed from Favorite Honey from other sources. This melon was much larger in size, averaging about 8-12 pounds, with very light lemon-yellow flesh. Its rind is exceptionally crisp and thin so the fruits crack open easily. There are about 900 seeds per fruit and the variety is andromonoecious. The sex condition of other watermelon varieties used was mostly monoecious but occasionally hermaphrodite flowers were observed.

The synthetic growth substances or chemicals used were naphthalene acetic acid, potassium naphthalene acetate, indolebutyric acid, colchicine, acenaphthene, sulfanilamide and trimethylamine, mostly in lanolin paste. Naphthalene acetic acid was also used as a spray by means of a hand atomizer.

The growth substances were thoroughly mixed with lanolin and these preparations were smeared either on the stigma, if the style was short, or on the cut surface of the style if the latter was long. If the style is more than 2 millimeters, it is desirable to cut it off about 1 mm. above the ovary and smear the lanolin preparation on this surface.* Paste prepared from growth substances were used in concentrations of 1, 2, 2.5 and 5 per cent. For spraying, 50 P.P.M. and 500 P.P.M. were used in the case of naphthalene acetic acid and 40 P.P.M. in the case of trimethylamine. Due to the fact that naphthalene acetic acid is not soluble in water, the desired amount of substance was first dissolved in a very small amount of alcohol which was added to the required amount of water.

The watermelons, cucumbers, muskmelons, eggplants and peppers used in field experiments were started in the greenhouse and transplanted to the field. Some of the watermelon seeds were pre-treated with different chemicals, e.g. colchicine, acenaphthene, ether and water for various length of time before sowing.

Usually the flowers of each variety of plant were subjected to four kinds of treatments: (1) the flowers were pollinated in the usual way, (2) they were self-pollinated by hand, (3) they were treated with the substances under investigation and (4) they were neither pollinated nor treated with the chemicals.

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*Gustafson, F. G. Communication, March 5, 1937.

Flower buds were used that were nearly ready to open but before anthesis had taken place. In hermaphroditic flowers, emasculation was carried out the day before treatment and protected with a wire cage (Fig. 4). In a later experiment, the style was cut off just above the ovary with a sharp scalpel. The cut surface was either smeared with the lanolin preparation or left without treatment as a control. Flowers so treated were not protected by cages. A careful trial by Gustafson (11), and further confirmed by the writer, showed that if pollen is placed on the cut surface of the style there never is any development of the ovary to indicate that fertilization had taken place.

Presentation of Data

The study was based primarily on watermelons, however, other cucurbits and a few other horticultural plants were also used. The investigations were carried out during three growing season (i.e. two in the field and one in the greenhouse). For the sake of convenience, the data are grouped according to the various horticultural crops.

Experiments with watermelon

The watermelon work, which was initiated in the summer of 1938, was continued in 1939 both in the greenhouse and in the field.

1938 Preliminary Test: This experiment included 9 varieties and 13 treatments. Pistils were not treated with growth substances until after each plant had developed at least one fairly good sized fruit from self-pollination. It is believed that this pollinated, seedbearing fruit may gave exerted some inhibiting effect on, or lead to an unfavorable condition for, parthenocarpic development, thus explaining the poor results that were obtained from this preliminary test. (see table 1).

Table 1. Watermelon: Fruit setting as a result of hormone treatments. Season of 1938.

Series No.	Treatment **	Number of blossoms	Number set	% set	Remarks
1 (2.5)	2.5 % indolebutyric acid in lanolin paste applied to cut style	42	0	0	
1 (5)	5.0 % " " " " "	17	0	0	
B	2.5 % indolebutyric acid paste applied to stigma	11	0	0	
D	check, no treatment except emasculation	15	0	0	
C	cut style only	7	0	0	
E	pollen applied to cut style	7	0	0	
F	Lanolin paste applied to cut style	10	0	0	
N (2.5)	2.5 % naphthalene acetic acid)N.A.A. in short)				7 of them died at about
	paste applied to cut style	10	8	80	1½ inch diameter
N (5)	5.0 % N.A.A. paste applied to cut style *	15	3	20	Fruits small and odd shape
N (2.5)	2.5 % N.A.A . paste applied to cut style *	12	4	33	
N (1)	1.0 % N.A.A. paste applied to cut style *	11	4	36	
S	self-pollinated *	10	0	0	
Sp	Stigma sprayed with 0.05 % N.A.A . solution *	2	2	100	Treated very late im the season

* The seeds for these plants had been soaked in a 0.4 % colchicine aqueous solution for 4 days at room temperature.

** The experiment included 9 varieties. No attempt was made to identify any particular variety used.

No fruits were formed where emasculated flowers were simply left unpollinated or where the styles were cut and then lanolin paste or pollen or incolebutyric acid was applied to the cut surface. On the other hand fruit development was induced by application of naphthalene acetic acid either to the stigmas or to cut style (Figure 5, 1, 6). These Watermelons were seedless and also lacked seedcoats, with the exception of those produced by the variety Harris Earliest. They varied considerably in shape and size (Figure 5, 6, 7). In general, the fruits were slightly angular or even ribbed. Some, however, were normal in shape and size. They were very solid and firm in texture and the flesh showed an intense red doloration. No difference in flavor could be detected when compared with normally pollinated fruits.

The three plants of the Winter Sweet Watermelon grown from seed which had been subjected to colchicine treatment before planting showed a typical colchicine effect, i.e. stunting early in the season, large leaves and flowers and great vigor later in the season. Although pollen was present in great abundance, it failed to induce fruit setting when the blossoms were selfed. On the other hand, hormone-treated flowers set very satisfactorily.

In a parallel experiment involving a colchicine pre-treated plants, shown in Figure 8, a small fruit was produced by self-pollination, and a large one by treatment with 1 per cent naphthalene acetic acid in lanolin paste. Both flowers were treated at the same time. The fruit from selfing dropped within 10 days, but the hormone-treated fruit continued to grow until maturity. Nevertheless, fruits containing apparantly normal seeds were formed from some open-pollinated flowers (Fig. 7B). This is believed to have been due to fertilization by nearby non-colchicine treated plants. It is a case of vicinism. These fruits were much smaller in size and slower in growth than those from the hormone-treated blossoms.

1939 Greenhouse test: About 2 dozen flower buds from Selections number 1, 2 and 5 were treated. Acenaphthene powder was first used to cover the cut styles, which were then covered with a lanolin paste containing 1 per cent naphthalene acetic acid. Four fruits of normal size were ripened (Fig. 9, 10). They ranged from 1900 to 3241 grams in weight. They were found to contain hard seedcoats of about normal size but without embryos. It is a phenomenon of stenospermy. Three small fruits entirely lacking in flesh were also produced.

1939 Field Experiment: This experiment included 21 varieties with 16 treatments. The results of hormone treatments, both in a mixture of more than one growth substance and one alone on different varieties of Watermelon, are presented in Table 2.

Table 2. Watermelons: Fruit and crop setting as a result of hormone treatments in Lanolin paste to cut style.

Summer of 1939.

Series	Treatment	No. of flowers treated	Fruit No.	Set %	Crop No.	Set %	Varieties Used
N(1)	1% Naphthalene acetic acid (N.A.A.)	322	69	21.4	14	2.3	With 10 varieties
N(2)	2% Naphthalene acetic acid (N.A.A.)	402	149	37.1	29	7.2	" 13 "
KN(1)	1% K-naphthalene acetate (KNA)	306	62	20.3	5	1.6	" 11 "
KN(2)	2% K-naphthalene acetate (KNA)	309	97	31.4	16	5.2	" 12 "
NI(1)	1% each of N.A.A. and indolebutyric acid (I)	301	87	28.9	15	5.0	" 12 "
NAc(1)	1% N.A.A. plus 10% acenaphthene	430	143	33.3	31	7.2	" 10 "
KNC	1% KNA plus 0.1% colchicine	152	46	30.3	4	2.6	" 8 "
KNC(5)	1% KNA plus 0.5% colchicine	106	46	43.4	15	14.2	" 7 "
KNAcIC	1% KNA, 1% acenaphthene, 1% I and 0.1% colchicine	101	39	38.6	9	8.9	" 6 "
P	Apply about 20 grains of pollen to stigma	103	2	1.9	1	1.0	" 5 "
PKN	Apply about 20 grains of pollen to stigma plus						
	1% KNA paste to stigma	102	22	21.6	3	2.9	" 7 "
Su	1.5% sulfanilamide	50	0	0	0		
Ac	10% acenaphthene	84	0	0	0		
Ch	Check, cut style only	524	0	0	0		" 13 "
SIL	Selfing of one-lobed stigma and removing of the						
	other two lobes	29	2	6.9	1	3.5	" 5 "
S	Self-pollinated	180	80	44.4	66	36.7	

*Ovaries of flowers whose stigmas or cut styles were treated with hormones showed various responses. Some failed to develop at all, others developed into small fruits which remained on the vine but never grew normally, while still others developed into normal fruits, except for the absence of seed. Two terms, fruit set and crop set are used by the writer to describe the degree of development obtained. As used in this paper, fruit set applies to fruits which ranged from 1.5 cm. to 12.5 cm. in diameter, while crop set applied to fruits which were over 12.5 cm. in diameter.

It is clearly indicated in this table that a mixture of two growth substances gave better results than one alone. For example, when acenaphathene and naphthalene acetic acid were used in a mixture, the percentage of parthenocarpic fruits produced was 7.2 per cent as compared to 2.3% and 0% produced when naphthalene acetic acid and acenaphathene, respectively, were used alone. Indolebutyric acid was unable to produce parthenocarpic fruit at concentrations of 1.0, 2.5 and 5.0 per cent but when a mixture of 1% each of the indolebutyric acid and naphthalene acetic acid was used, 5.0% of parthenocarpic fruits of mormal size were obtained.

In these experiments, a concentration of 2% of the different chemicals used gave better results than 1%. There was some indication that the acid form of naphthalene acetic acid had a greater influence on parthenocarpic development than its potassium salt.

In order to determine if a Watermelon fruit can develop with a very limited number of seeds, about 20 grains of pollen were applied to the stigmas of a number of flowers. Only one fruit developed from the 103 flowers treated in this way. However, by adding a growth substance (K-naphthalene acetate) to the stigma followed by application of a limited amount of pollen, 3 mature fruits were obtained from 102 treated flowers (Fig. 11).

In general all the hormone-treated ovaries that did not develop into mature fruits enlarged to several times their original size, then ceased further growth, turned soft, and dried but persisted on the vine even when the plants were killed by the first frost (Fig. 12). On the contrary, the check ovaries were shed within 7-10 days. This phenomenon was forst observed in the summer of 1938.

The alkaloid colchicine, when mixed with the synthetic growth substance preparation gave an increase in the percentage of parthenocarpic fruits from any treatment, 14.2 percent, resulted from a mixture of 1 percent naphthalene acetic acid and 0.5 percent colchicine preparation. It is believed that colchicine might be considered as a growth substance from the standpoint of parthenocarpic development.

By removing two-thirds of the stigmatic surface and pollinating only the remaining portion, normal seedbearing fruits were produced.

Differences in varietal response to various hormone treatments are presented in Table 3.

Table 3. Response of Watermelon Varieties to various hormone treatments listed in table 2 *

Variety	Number Flowers treated	Fruit set		crop set	
		No.	%	No.	%
Winter Sweet	567	187	32.9	31	5.5
Northern Sweet	540	96	17.7	2	0.4
Favorite Honey	204	69	33.8	40	19.6
Coles Early	64	33	51.5	3	4.7
Early Kansas	45	10	22.2	1	2.2
Fordhook Early	94	30	31.9	2	2.1
Stone Mountain	62	26	41.9	2	3.2
Kleckley Sweet	34	15	44.1	0	
Hawksbury	83	15	18.0	1	1.2
Iowa 5	26	10	38.4	1	3.8
Selection 1	45	0		0	
Selection 2	11	5	45.4	5	45.5
Selection 3	2	0			
Selection 4	11	2	18.1		
Selection 5	58	10	17.2	4	6.9
Harris Earliest	10	2	20.0	0	
Yellow Melon	565	226	40.0	46	8.1

* With the exception of pollination, check and treatments with acenaphthene and sulfanilamide.

Table 3 shows that varieties differ greatly in their ability to produce parthenocarpic fruit as a result of these treatments. For instance, the varieties Favorite Honey and "Yellow Melon" gave high percentages of parthenocarpic fruits, but Early Kansas, Northern Sweet and Selections 1, 3 and 4 produced none or very few. Northern Sweet is considered to be closely related to Winter Sweet; however, the former variety gave a much lower percentage of parthenocarpy. Moreover, Selections 1 to 5 were all derived from a cross between Winter Sweet and Favorite Honey but only Selections 2 and 5 produced parthenocarpic fruits. Possibly this is due to genetic differences.

Table 4 presents the response of four representative varieties to the various hormone treatments. It will be noted that the responses of different varieties to hormone treatments closely agree with those shown in Table 2. For instance, naphthalene acetic acid treatment gave a better set than its potassium salt and a mixture gave more favorable results than one hormone alone.

The variety Favorite Honey gave the highest set with all treatments, but no initial development was noted when a <u>very limited</u> amount of pollen was applied. However, when pollen was added with a growth substance, fairly good results were obtained.

No initial growth was observed on the check flowers of any varieties tested. If natural parthenocarpy would occur one might expect it on Favorite Honey or "Yellow Melon" which gave the highest percentage of stimulative parthenocarpy.

Table 4. Number and percentages of fruit and crop setting in several varieties of watermelons with various hormones in Lanolin paste applied to cut styles.

Treatment	Winter Sweet			Northern Sweet			Favorite Honey			Yellow Melon		
	A*	B*	C*	A	B	C	A	B	C	A	B	C
1% naphthalene acetic acid (NAA)	85	24.7	2.4	95	5.3	0	25	16.0	12.0	70	40.0	7.1
2% naphthalene acetic acid (NAA)	64	37.5	6.3	120	29.2	0	37	48.6	35.2	98	39.7	7.1
1% K-naphthalene acetate (KNA)	39	20.5	2.6	66	6.1	0	11	27.3	18.2	102	29.4	1.0
2% K-naphthalene acetate (KNA)	27	7.4	0	78	16.7	1.3	22	27.3	13.6	55	49.1	12.7
1% mixture of NAA and indolebutyric acid	90	30.0	4.4	61	16.4	0	28	32.1	17.9	74	39.2	5.4
1% NAA plus 10% acenaphthene	181	43.1	8.3	52	17.3	1.9	10	10.0	10.0	96	38.5	29.7
1% KNA and 0.1% colchicine	26	50.0	3.8	43	23.3	0	22	22.7	4.5	15	60.0	13.3
1% KNA and 0.5% colchicine	24	16.7	0	18	33.3	0	49	46.9	24.5	11	90.9	27.3
1% each of KNA, acenaphthene, indolebutyric acid and 0.1% colchicine	31	32.3	3.2	7	57.1	0				44	38.6	13.6
Apply about 20 grains of pollen to stigma	37	0	0	32	0	0	12	0		19	10.5	5.3
Apply about 20 grains of pollen to stigma plus 1% KNA paste to stigma	32	25.0	0	15	26.7	0	15	20.0	20.0	35	17.1	0
1.5% sulfilamide	14	0		7	0		10	0		15	0	
10.0% acenaphthene	51	0		20	0							
Check, cut style only	50	0		48	0		78	0		207	0	
Hand self pollination	26	57.7	53.8	32	15.6	15.6	10	70.0	70.0	41	53.6	46.3

*A. Number of flower treated

*B. Percentage of fruit setting

*C. Percentage of crop setting

Table 5. Watermelons: Mean fruit size, shape index and weight as a result of various treatments.

Variety	Treat-ment	No. of fruits	Diameter (Cm.)		Maximum size	Shape Index	Weight (gms.)
			Polar	Equa-torial			
Winter Sweet	N(1)	5	16.3	13.4	19.5 x 16.4	82%	1551
	N(2)	4	16.3	14.3	17.4 x 15.9	88	1481
	KN(1)	1	14.1	13.6		97	1205
	NI(1)	4	17.2	14.0	18.2 x 14.9	80	1653
	NAc(1)	14	15.9	13.7	19.0 x 17.2	86	1452
	KNC	1	21.0	16.9		80	2821
	KNAcIC	1	25.1	15.1		60	2600
	S	6	19.9	19.5	25.0 x 23.0	98	3169
Northern Sweet	KN(2)	1	15.1	11.0		73	857
	NAc(1)	1	23.1	16.6		72	3070
	S	8	22.4	20.9	23.5 x 22.7	93	4195
Favorite Honey	N(1)	3	13.9	13.0	16.3 x 12.0	93	1133
	N(2)	13	14.7	12.1	17.4 x 13.8	82	1089
	KN(1)	2	16.5	12.9	17.1 x 13.6	78	1455
	KN(2)	3	13.8	11.1	15.1 x 13.1	81	983
	NI(1)	5	19.0	14.0	24.9 x 14.1	74	1628
	NAc(1)	1	15.0	12.0		80	1300
	KNC	1	12.6	10.3		82	733
	KNC(5)	10	14.2	12.3	21.8 x 17.7	87	1158
	PkN	3	22.3	15.3	23.0 x 19.7	69	2374
	S	2	18.3	15.8	18.9 x 15.9	86	2062
Coles Early	N(2)	1	18.9	15.1		80	2080
	NI(1)	2	23.0	18.0		78	3521

Early Kansas	KN(2)	1	17.5	12.0		69	920
Fordhook Early	KN(1)	1	21.4	19.2		90	3972
	NAc(1)	1	19.2	13.8		72	1810
Stone Mountain	KNAcIC	2	14.9	12.3		83	533
Hawksbury	N(2)	1	23.2	12.8		55	1679
Iowa 5	KN(2)	1	24.0	19.4		81	4008
Selection 2	N(2)	2	19.9	17.1	20.2 x 18.7	86	2379
	KN(2)	2	15.6	15.6	16.1 x 19.0	100	1893
	NAc(1)	1	13.8	12.1		88	894
	S	1	21.2	21.0		99	3850
Selection 5	N(1)	1	16.0	13.5		84	
	N(2)	1	15.0	11.0		73	1008
	KN(2)	1	14.6	12.6		86	1023
	NAc(1)	1	13.8	11.8		86	1034
Yellow Melon	N(1)	5	21.2	19.4	25.6 x 23.0	91	3603
	N(2)	6	18.4	16.5	21.9 x 21.2	90	2631
	KN(1)	1	15.6	13.6		87	1439
	KN(2)	7	21.4	20.0	24.1 x 22.3	94	3512
	NI(1)	4	20.0	16.8	22.8 x 18.5	84	2535
	NAc(1)	10	18.0	16.1	24.3 x 22.8	90	2617
	KNC	2	18.6	18.2	20.2 x 19.5	98	3142
	KNC(5)	3	16.9	15.1	19.4 x 16.9	90	1985
	KNAcIC	6	15.4	14.3	17.6 x 17.1	92	1701
	P	1	15.1	11.8		78	959
	S	12	21.1	19.9	26.6 x 23.8	95	4048

* Shape Index = $\frac{\text{Equatorial Diameter}}{\text{Polar Diameter}} \times 100$ (53)

The varietal responses of Watermelons to barious treatments with respect to fruit size, shape index and weight are presented in Table 5.

It has been shown that the size of fruit depends on at least several interrelated factors e.g. number of fruits per vine, time of set, seedless vs. seeded fruit (38, 48). Although the means represent a limited number of fruit measurements they do indicate that the average size and weight of the parthenocarpic fruit was less than that of pollinated seed-bearing fruits. However, parthenocarpic fruits of normal size or even larger than those from pollination were obtained in some varieties, such as Favorite Honey and "Yellow Melon", when their ovaries were treated with certain growth substances. Moreover, many fruits of normal shape were produced as a result of parthenocarpic development, as indicated by the shape indices.

Most of the parthenocarpic fruits that developed into full size were normal in appearance except that they lacked seed. On the other hand, some fruits which can be induced to set parthenocarpically, do not respond in a normal way to the growth substances, as indicated by abnormal development of their various tissues. Their flesh (placentae) is lacking or only partially developed (Fig. 13) or a light margin may occur in the place of contact between placental regions (Fig. 14); there is often an increase in the thickness of r ind and intense coloration, and a slightly triangular or even ribbed shape may develop (Fig. 5, 6). Comparisons between self-pollinated and parthenocarpic Watermelons from all hormone treatments with respect to rind thickness, flesh color, hollowness, and stylar

Table 6. Some physical comparison of parthenocarpic and pollinated seedbearing watermelons.

Variety	Treatment	Thickness of rind (mm.)	Flesh Color*	Hollowness	Stylar Scar tissue
Winter Sweet	Pollination	9.5-4.7	red (Vermilion 18/2)	Hollow	sunken
	Hormone	15.9-8.6	Deep red (Signal Red 719/2)	Solid to hollow	protruding
Yellow Melon	Pollination	9.2-4.3	pale yellow (Aureolin 3/3)	Hollow	sunken
	Hormone	12.8-7.0	orange yellow (Lemon Yellow 4/1 to Tangerine Yellow 9/3	Mostly solid	protruding

* The color description was based on the Horticultural color chart prepared by the British color council (1).

Table 7. Watermelons: Varietal Response in seed and seedcoat development as shown by self pollinated and parthenocarpic fruits.

Variety	Treatment	Seed. Size (mm.)	Seed. Weight (1) (grams)	Seedcoat Size (mm.)	Seedcoat Weight (gms)	Color & Texture
Winter Sweet	Pollination	12.1 x 7.2	7.744			black, hard
	Hormone (2)	0		10.0 x 6.0	1.562	black, hard
	Hormone (3)	0		0		
Northern Sweet	Pollination	12.0 x 7.4	7.350			yellow, hard
	Hormone	0		10.0 x 6.0	1.556	
Favorite Honey	Pollination	11.0 x 7.2	5.040			brown, hard
	Hormone	0		9.8 x 6.2	2.075	" "
	Pollination + Hormone	10.8 x 7.2		9.3 x 5.7	1.490	" "
Coles Early	Pollination	13.5 x 8.5	9.025			black, hard
	Hormone	0		10.4 x 5.5	1.345	light yellow, soft
Early Kansas	Pollination	14.0 x 8.8	12.120			brown, hard
	Hormone	0		14.0 x 5.8	1.100	yellow, papery
Fordhook Early	Pollination	13.0 x 8.0	10.105			light yellow, hard
	Hormone	0		9.2 x 5.4	.830	" " , papery
Iowa 5	Pollination	13.5 x 8.0	9.120			light yellow, hard
	Hormone	0		8.5 x 5.0	.708	" " , papery
Selection 2	Pollination	12.2 x 8.0	10.517			black, hard
	Hormone	0		10.2 x 6.4	1.725	" "
Selection 5	Pollination					
	Hormone	0		9.8 x 5.9	1.178	light brown to semi-hard
Stone Mountain	Pollination	13.8 x 8.5	11.352			yellow, hard
	Hormone	0		8.7 x 4.9	.300	yellow, papery
Hawksbury	Pollination	12.5 x 7.0	8.000			black, hard
	Hormone	0		8.0 x 4.0	.275	brown, papery
Yellow Melon	Pollination	9.6 x 6.3	5.283			dark brown, hard
	Hormone	0		6.3 x 3.8	.342	light yellow, papery
Early Arizona	Pollination	12.3 x 8.1	12.140			black, motting, hard
	Hormone	0				

Explanation to Table 7

1. Weights of seed and seed-coats are calculated on air dry condition and given in grams per 100 seeds from a composite sample of from 100 to 500 individuals.
2. A composite sample of all the hormone treatments and of different concentrations and combinations.
3. The seeds from these plants had been soaked in a 0.4% colchicine aqueons solution and from the Summer 1938 data.

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scar tissue are shown in Table 6. The rind of the hormone-treated fruits was almost twice as thick as that of the pollinated ones (Fig. 15, 16). The coloration was more intense in the parthenocarpic fruits. The texture was very solid and firm but less juicy, especially in the Winter Sweet variety, when the seeds were pretreated with colchicine (Fig. 17). Another outstanding difference between these two types of fruits was their stylar scar tissue. The fruits which developed from applying the growth substance to the cut style showed a distinctive protruding stylar scar tissue (Fig. 1). This is believed to be an outgrowth of the cells from that particular region due to the stimulation from the growth substance and possibly also from Wound hormones.

The varietal responses with respect to the size and weight of seeds and seedcoats as well as color and texture of seedcoats from self pollinated and parthenocarpic fruits in Watermelons are presented in Table 7 and figures 18 and 19.

These data show that no seed was developed in any of the hormone-treated fruits, though seedcoats were developed to various degrees. The varieties Winter Sweet (Fig. 17(2), 18(3)(4)).

Northern Sweet, Favorite Honey (Fig. 20: 1, 2, 3, 4, 5) and Selection 2 (Fig. 19: 10, 11) produced what appeared to be normal seeds; however, none possessed an embryo. Some varieties, e.g. Yellow Melon (Fig. 18: 1, 2, Fig. 16), Fordhook Early (Fig. 18: 5, 6), Stone Mountain (Fig. 18: 8, 9), etc. possessed only very small papery seedcoats. Attention is called to the fact that pre-treatment of the seeds with proper dosage (0.4% for 4 days in the variety Winter Sweet in this case) of colchicine prevented development of the integuments into seedcoats in the parthenocarpic fruits. On the other hand, neither mixing the colchicine powder with the growth substance (K-naphthalene acetate) in the paste applied to the cut style of the blossom nor applying the substance to the flower produced from stem which has been painted with colchicine paste, prevented seedcoat development. A test involving pre-treatment of the seeds with acenaphathene and other chemicals indicated that they did not prevent the development of empty seedcoats.

Experiments with Cucumber

In the American type cucumber such as the National Pickling variety, a constriction of the stem-end or blossom-end is due to seedlessness of that particular portion (Fig. 21). Vegetative parthenocarpy seldom occurs in this variety (44,43,45). An experiment was conducted with this variety in an attempt to secure seedless fruits of normal straight shape by means of growth substances.

There were 8 series of treatments. All of the treated blossoms were covered with wire cages before anthesis and were left covered for 4 to 6 days after treatment. Naphthalene acetic acid was the only hormone used on the cucumber. The results obtained are given in Table 8.

Table 8. National Pickling cucumber: Fruit Setting as a Result of Hormone Treatments, 1938.

Treatment	Number of Blossoms	Number Set	Percent Set
2.5% naphthalene acetic acid (NAA) in lanolin paste applied to cut style cap	30	13	43
1.0% NAA in lanolin paste applied to cut style cap	32	24	75
5.0% NAA in lanolin paste applied to cut style cap	25	5	25
No treatment except nipped-off stigma	30	3	10
No treatment and no pollination	44	5	11
1% NAA paste applied to stigma	11	6	54
Self-pollinated	15	8	53
Female flower sprayed with 0.05% NAA Solution with a hand atomizer *	42	14	33

*This treatment was used near the end of the season, which may account for the low percentage of set.

Although the number of samples was not large enough to permit any conclusive statement, the results indicate that naphthalene acetic acid did induce parthenocarpic fruits of normal size and shape, either when the hormone was applied in lanolin paste of 1 to 5 per cent concentration or as a 0.5 per cent aqueons solution. Cross and longitudinal sections of a self pollinated seed-bearing cucumber and a stimulative parthenocarpic fruit are shown in Figure 22 and 23. Hard viable seeds were present in the pollinated fruits (Fig. 23:2, Fig 24:7) but only soft, small, and undeveloped "ovules" (Fig. 23:1, Fig. 24:8) were found in the parthenocarpic ones. Attention is called to the second treatment in Table 8 in which the hormone-treated flowers gave a higher percentage of set than those produced from selfing.

In the spring of 1939 under greenhouse conditions about one dozen flower buds of the same variety were used in a further test. After the stigma and corolla were removed, the style cap was sprayed with naphthalene acetic acid and trimethylamine in concentrations of 500 p.p.m and 40 p.p.m., respectively. Three of the flowers were treated with 1 percent naphthalene acetic acid paste. Straight fruits of normal size having undersized seedcoats without embryos were obtained. One fruit which was produced by spraying with naphthalene acetic acid at a concentration of 500 p.p.m. on April 26th was picked on June 19th. This fruit weighed 1132 grams and was 26.5 cm. in length.

Experiments with _Cucurbita pepo_

In the spring of 1939 an unnamed pumpkin of this species was used in the greenhouse. Four flowers were treated with acenaphthene and 1% naphthalene acetic acid paste applied to the cut style on May 3rd. Three "fruits" reach the size of 5.0 x 4.9 cm., then turned soft and finally dropped on May 16th. The two check flowers dropped when their ovaries had attained a size of 1.8 x 2.0 cm. Apparently the ovaries were stimulated by the treatments and growth was initiated but for some reason the fruits were unable to continue their development.

In the summer season (1939), 8 varieties were used in further tests. The results with Early Prolific Straightneck and Dark Green Zucchini squash are shown in Tables 9 and 10.

The flowers used in this study were limited in number, but they indicated that both varieties are susceptible to parthenocarpic development. No external differences could be detected between normal and parthenocarpic fruits of squash. Though these two varieties belong to the same species, Cucurbita pepo, the integuments did not undergo the same degree of development in their parthenocarpic fruits. There were small sized, soft textured seedcoats present in the Early Prolific Straightneck (Fig. 24 (3) (4), 25) but none in the Dark Green Zucchini variety (Fig. 24 (5), 26).

Other varieties used in this experiment but with a more limited number of flowers (from 10 to 20 blossoms) were: Top of the Market, Hardin Bush, Omaha, Delicata, Table Queen, and Fort Berthol. One mature fruit of Top of the Market was obtained by treatment with 2% K-naphthalene acetate paste. No seeds or empty seedcoats were present in this fruit. One fruit of Hardin Bush was obtained from the same hormone treatment but dropped when it reach the size of 12.5 x 11.0 cm. Very little growth was observed in the treated ovaries of Fort Berthol, Omaha and Delicata varieties.

Experiments with Cucurbita maxima

In the spring of 1939, Buttercup squash was grown in the greenhouse. The cut styles of a few flower buds were treated with acenaphthene, followed by 1 percent naphthalene acetic acid paste, and another group were treated with naphthalene acetic acid alone. Flowers were treated on April 30th and the fruits matured about June 10th. Seven externally normal fruits were produced (Fig. 27). When cut open, it was discovered that no seeds had developed (Fig. 28, 24:6). The placental region of the parthenocarpic fruits was more restricted and they had a much thicker recepticle and pericarp than normal seedbearing fruits. Moreover, stylar tissue was fully developed. One undersized fruit was produced from treatment with 1 percent naphthalene acetic acid.

In the summer of 1939 further experiments with the same variety were conducted. The results are shown in Table 11.

Table 9. Early Prolific Straightneck squash: Fruit and Crop Setting as a Result of Hormone Treatment in Lanolin Paste to cut Styles.

Series No.	Treatment	No of Flowers Treated	Fruit Set		Crop Set	
			No.	%	No.	%
KN(1)	1% K-naphthalene acetate	3	3	100	3	100
KN(2)	2% K-naphthalene acetate *	10	10	100		
KNC(.5)	1% K-naphthalene acetate and 0.5% colchicine	4	1	25	1	25
CH	check, cut style only	2	0	0		

* Blossoms treated very late in the season and killed by first frost.

Table 10. Dark Green Zucchini squash: Fruit and Crop Setting as a Result of Hormone Treatments in Lanolin Paste to cut Styles.

Series No.	Treatment	No. of Flowers Treated	Fruit Set		Crop Set	
			No.	%	No.	%
KN(1)	1% K-naphthalene acetate	5	2	40	2	40
KN(2)	2% K-naphthalene acetate *	8	7	87		
NAc(11)	1% NAA and 10% acenaphthene	2	1	50	0	
KNC(.5)	1% KNA and 0.5% colchicine	2	1	50	1	50
KNAcIC	1% KNA, 1% acenaphthene, 1% indole-					

	butyric acid and 0.1% colchicine	10	4	40	1	50
CH	Check	2	0	0		

*Blossoms treated very late in the season and killed by first frost.

Table 11. Buttercup Squash: Fruit and Crop setting as a result of Hormone Treatments in Lanolin Paste to cut styles.

Series No.	Treatment	No. of flowers treated	Fruit Set		Crop Set (1)	
			No.	%	No.	%
KN(1)	1% K-naphthalene acetate	12	9	75	5	42
KNI	1% each of naphthalene acetic acid & indolebutyric acid	7	1	14	0	
NAc(1)	1% naphthalene acetic acid and 10% acenapthene	9	2	22	0	
NAc	1% naphthalene acetic acid and 10% acenapthene (2)	10	9	90	9	90
KNC	1% K-naphthalene acetate and 0.1% colchicine	11	9	82	7	64
KNc(.5)	1% K-naphthalene acetate and 0.5% colchicine	7	3	43	1	14
KNAcIC	1% K-naphthalene acetate, 1% acenaphthene, 1%					
	indolebutyric acid and 0.1% colchicine	10	5	50	1	10
Ch	check, cut style only.	7	0	0	0	

(1) By the criteria of (1) loss of semi-glossy green color in the rind and presence of yellow color near the ground portion (2) full size and (3) toughness of the rind.

(2) Application of abundance of acenaphthene to the cut style, then covering with naphthalene acetic acid paste. This treatment was conducted in the spring of 1939 in the greenhouse.

Experiments with <u>Cucurbita</u> <u>moschata</u>

In the spring of 1939, the African Bell variety was used in the greenhouse. Out of four flowers treated with acenaphthene and 1 per cent naphthalene acetic acid paste, three normal fruits were obtained. One good fruit was also produced from naphthalene acetic acid treatment. The flowers were treated May 8th and fruits were picked July 6th. One of them weighed 3270 grams (Fig. 29). Fairly good size seedcoats which were soft in texture were present (Fig. 30, 24 1 2).

Experiments with <u>Cucumis</u> <u>melo</u> var. <u>reticulatus</u>

In the spring 1939 about one dozen flowers of an unnamed selection of muskmelon were used which gave three mature fruits. Figure 31 shows a parallel experiment from a pair of flowers; the small fruit developed from a flower treated with 1 per cent naphthalene acetic acid and the large fruit from one treated with a combination of acenaphthene and naphthalene acetic acid. Both flowers were treated April 30th. The fruit produced from naphthalene acetic acid ceased growing about May 22nd, turned yellow, then soft. This fruit weighed 9 grams and had a diameter of 5 centimeters when picked. The one from the acenaphthene and naphthalene acetic acid treatment continued to grow until reaching a length of about 14 centimeters, when it was accidentally picked by some unknown person. Neither seeds nor seedcoats were present.

In the summer of 1939, 35 flowers of the Honey Rock variety were treated with 1 and 2 per cent each of naphthalene acetic acid and its potassium salt and a mixture of 1 per cent naphthalene acetic acid and 10 per cent acenaphthene. Only negative results were obtained.

A limited number of flowers of cucurbits of uncertain species carrying U.S.D.A. Plant Introduction numbers were treated with various growth substances but no parthenocarpic fruits developed.

Experiments with Solanaceous Plants

Pepper (Capsicum annum): In the summer of 1938, various tests were made on the Harris Wonder variety. Twenty-four fruits out of 25 blossoms developed parthenocarpically as a result of 1 per cent naphthalene acetic acid treatment (Fig. 32). Four fruits developed following spraying the stigmas with 0.05% naphthalene acetic acid. Out of 7 flowers, the styles of which were cut but given no further treatment, 4 formed fruits which were seedless. Possibly parthenocarpy in this instance may have been due to the stimulating effect of some wound hormone from the cut style or might be due to vegetative parthenocarpy. The treatment was started very late in the season and all the plants were killed by frost before the fruits were able to reach full maturity. However, all partly grown, hormone-treated fruits were seedless and normal in shape.

Tomato (Lycopersicum esculentum): The variety Michigan State Forcing was used for this study. Only 15 flowers were employed. All the flowers were emasculated before treatment and naphthalene acetic acid was the only growth substance used. The results are presented in Table 12.

No seed were developed in these parthenocarpic fruits. Most of them were solid in the placental region.

Table 12. Tomato (M. S. Forcing): Fruit Setting as A Result of Hormone Treatments

Treatment	No. Flowers treated	No. Fruits Set	Range in Weight (grams)
Spray with naphthalene acetic acid solution 500 p.p.m.	9	9	33-69
Spray with naphthalene acetic acid solution 50 p.p.m.	3	3	42-60
Apply 1% naphthalene acetic acid paste to cut style	3	3	133-150

It was observed that fruits resulting from an aqueous spray were much smaller in size than those produced from the paste treatment. A great many of the parthenocarpic fruits showed internal break down at the blossom end, with the appearance of blossom-end rot.

Eggplant (<u>Solanum melongena</u>): The variety New Hampshire Hybrid was used for this study in the spring of 1939. The flowers were treated late in the summer, and the fruits were still small when picked because of frost. The largest of the six fruits that formed parthenocarpically reached a size of 11.5 x 10.2 cm., from treatment with a mixture of 1 per cent naphthalene acetic acid and 10 per cent acenaphthene. Fruits from treatment with a mixture of 1 per cent each of naphthalene acetic and indolebutyric acids were somewhat smaller. There appeared to be no external differences between pollinated and hormone-induced fruits (Fig. 33). However, the normally-pollinated fruits seemed to grow more rapidly. On sectioning, only minute lines showed where the locules would normally have been and there were no signs of ovules (Fig. 34). The one control dropped with a week after the style was cut off.

OVERSIZED IMAGE

OVERSIZED IMAGE

OVERSIZED IMAGE

Remarks

age over 20 mm. diam.,
. diam., akene large w
. diam., akenes withou
. lop-sided.

Experiments with Strawberry

In the late fall of 1938, potted plants of an unnamed everbearing strawberry were used for fruit setting experiments. About two dozen flower buds were treated. Un-opened hermaphrodite flowers were first emasculated, then sprayed with naphthalene acetic acid in concentrations of 50 and 500 p.p.m. with a hand atomizer. Parthenocarpic fruits of normal size containing achenes that appeared normal were obtained; however, the latter were found to be entirely lacking in embryos. Some of the treated receptacles made only a slight initial growth, which soon ceased, and achnes rarely developed on them.

In the spring of 1939, a further experiment was conducted, the results of which are presented in Table 13.

Table 13. Strawberry: Fruit Setting as a Result of Hormone Treatment.

Treatment	No Flowers Treated	No Fruits Set	Remarks
Spray with naphthalene acetic acid 500 p.p.m.	12	12	Average over 20 mm. diam., akenes small and embryoless.
Self hand pollination	1	1	26 mm. diam., akene large with embryos.
Open pollination	5	2	22 mm. diam., akenes without embryos.
Check, emasculation only	4	1	14 mm. lop-sided.

V. Discussion

Of the many varieties of watermelons, it was found that they vary greatly in their parthenocarpic development. Due to the fact that some parthenocarpic fruits developed as a result of hormone treatment but for some reasons fail to reach maturity, the results were classified into two groups as "fruit set" and "crop set". The varieties Favorite Honey and "Yellow Melon" gave very high percentages of normal sized, parthenocarpic fruits that attained full maturity, but none or very few were obtained in the case of Early Kansas and Northern Sweet. Although the variety Northern Sweet is closely related to the variety Winter Sweet (also known as Dakota Sweet), there is a much higher percentage of parthenocarpic development in the latter. Moreover, Selections 1 to 5, all derived from the same parantage, gave varying results. Parthenocarpic fruits were obtained from Selection 2 and 5 but none from the Selection 1, 3, and 4. These data indicate that parthenocarpic response to growth substances is a hereditary trait, varying with varieties entirely in dependently of their other characteristics. This might be due to variations in the amount of natural growth substances present in the ovaries of the different varieties.

In Watermelon, it was observed that about 20 grains of pollen applied to the stigma at the time of anthesis failed to result in the setting of fruit. This may be due to the fact that the growth substances produced from the very few ovules or embryos developed was not sufficient for fruit development. If the hypothesis that the growth substances may act as a master reagent or regulate metabolic processes to cause other substances to move to the part where growth takes place, as postulated by Went, Thimann, Gustafson and Murneek, why do not such ovaries or "fruits" continue to grow and reach their maturity? However, when a growth substance was added to the above treatment, mature fruit was produced and it contained less than 20 viable seeds and also many empty seedcoats.

Whether the use of growth substances for the induction of parthenocarpic fruit on a commercial scale will prove possible remains to be seen. It seems to the writer that development and perfection of such methods might revolutionize certain phases of horticulture in the future. American holly is normally dioecious, and the necessity for male plants in commercial plantings would be eliminated if parthenocarpy can be induced in a practical way. Parthenocarpic berries have been produced by spraying or gasing the flowers and also by watering the soil during blooming with the growth substances. Even in existing plantings such a method might prove of value as a means of insuring a high degree of fruitfulness. A practical method of inducing parthenocarpy might be of value with other dioecious plants especially bittersweet, date and muscadine grape.

With tomatoes grown in northern regions for greenhouse culture, artificial pollination or tapping is usually necessary for fruit setting. Often, however, only a small proportion of the flowers set fruit because of cloudy weather and short days which are not favorable for optimal fruiting (22,23). Loehwing(31 and 32)has suggested that this is due to the different light requirements for sporogenesis (viable pollen) and sporangium (anther) formation. It would be highly desirable if a practical method of inducing parthenocarpy by treatment with spray, vapor, or growth substances in other form could be developed.

One of the difficulties in growing American cucumber in northern regions in the Winter season arises because of the scarcity of staminate flowers during short days (5). It has been shown by the writer, that parthenocarpic fruit of normal size can be produced by spraying the pistillate flowers with a growth substance. This might have some practical possibility.

Seedlessness in Watermelon would undoubtedly be considered highly desirable from the commercial standpoint and seedless fruits would be in great demand if they could be produced economically. Parthenocarpic fruits of normal size have been obtained in many varieties from different growth substances. Attention is called to the fact that seedcoats of various degrees of development are usually present in the parthenocarpic fruits, with the exception of those produced on plants grown from colchicine-treated seeds. This indicates that there is a possibility of obtaining parthenocarpic fruits without seedcoats. Other parthenocarpic cucurbits that might prove to have commercial value are the Buttercup and summer squashes.

It would undoubtedly be highly desirable to be able to induce on a commercial scale parthenocarpic fruits, or assist setting, in the little explored field of tropical and subtropical fruits, especially the Annonaceae, pomegranate, guava, mango, litchi and wampi.

The means of producing stimulative parthenocarpy might supply us with information concerning the mechanism of fruit development, physiology, and evolution. However, the techniques that we use at present time are far from perfect and requires more exploratory work.

Summary

Studies of induced parthenocarpy by the use of growth substances in certain horticultural plants with special reference to the Watermelon were carried on at Michigan State College, East Lansing, during the Summers of 1938 and 1939. The Work was supplemented with greenhouse experiments during two seasons.

In preliminary experiments initiated in the summer of 1938, parthenocarpic fruits of Watermelon, cucumber and pepper were obtained by applying the growth substances in lanolin paste or spraying with aqueous solutions. In view of the promising results obtained from these trials, fairly extensive experiments with Cucurbitaceae and Solanaceae were conducted in the following season.

No parthenocarpy, vegetative or stimulative, other than that due to hormone treatments, occurred in the watermelons and other Cucurbita species tested, with the exception of cucumber and pepper.

It was found that a very limited number of pollen grains did not cause the watermelon to set fruit. However, by adding a growth substance, mature fruits were obtained.

Watermelon flowers treated with growth substances which did not set parthenocarpic fruits persisted on the vine, apparently because the substances prevent the formation of an abscission layer.

No apomitic seed of any sort developed in the parthenocarpic fruits produced from growth substances.

A mixture of two growth substances gave better results than one alone. Some substances, e.g. indolebutyric acid, acenaphthene,

sulfaniamide, were usable to induce parthenocarpy when used alone, but gave favorable results when mixed with other substances.

Indolebutyric acid ranging from 1 to 5 per cent, acenaphthene 10 per cent, and sulfaniamide of 1.5 per cent, each in lanolin paste, were unable to induce parthenocarpic development in watermelon.

Naphthalene acetic acid had a greater effectiveness on parthenocarpic development than its potassium salt and other growth substances.

There were great variations in fruit size and seedcoat development among these parthenocarpic fruits. Normal sized hard seedcoats were occasionally present in some fruits. However, seedless fruits of normal size which lacked seedcoats were present in many species or certain varieties within the same horticultural group.

Pre-treatment of the watermelon seeds with proper dosage of colchicine prevented the development of integuments into seedcoats on parthenocarpic fruits. Mixing the colchicine with a growth substance in the paste applied to the cut style did not prevent such seedcoat development.

There is some of the possibility of producing seedless fruits in some horticultural plants by the use of growth substances. However, technical difficulties in certain plants remain to be solved before the idea can be put into commercial use.

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Explanation of Figures

Fig. 1. Winter Sweet watermelon: A side and blossom-end view of a parthenocarpic fruit produced by treating the style with naphthalene acetic acid in lanolin paste before anthesis. Note the marked protruding stylar scar tissue in the blossom-end portion. The flower was treated on August 15th and reached its maturity on Sept. 30, 1938.

Fig. 2. Favorite Honey watermelon: (1), from self-pollination with about 20 grains of pollen and with a K-naphthalene acetate paste added, (2), from naturally pollinated pistil.

Fig. 3. "Yellow Melon" watermelon: A parthenocarpic fruit induced from a mixture of naphthalene acetic acid and acenaphthene paste.

Fig. 4. Wire cages used for preventing uncontrolled pollination after emasculation.

Fig. 5. Harris Earliest watermelon: A pear-shaped parthenocarpic fruit produced from naphthalene acetic acid treatment.

Fig. 6. Early Arizona watermelon: A ribbed fruit produced from naphthalene acetic acid. Placental region or flesh was lacking in the fruit.

Fig. 7. Winter Sweet watermelon: A, longitudinal section of naphthalene acetic acid treated fruit; B, a cross section of an open pollinated fruit. Note the absence of seedcoats in A. The seed from which the plant was grown was soaked in an 0.4% colchicine solution for 4 days.

Fig. 8. Winter Sweet watermelon: A typical pair of colchicine treated plants. The small fruit was from self-

pollination; the large one was treated with naphthalene acetic acid paste. Both were treated at the same time. The one from selfing dropped within 10 days, but the hormone treated fruit continued to grow until maturity.

Fig. 9. Selection 2 watermelon: (1), A parthenocarpic fruit produced from a mixture of naphthalene acetic acid and acenaphthene and (2) from open pollinated fruit.

Fig. 10. A hormone-induced parthenocarpic fruit of Selection 2 watermelon in the greenhouse.

Fig. 11. Winter Sweet watermelon: The small fruit (p 85) was from hand self-pollination with about 20 grains of pollen, the large fruit (PKN7) was produced from K-naphthalene acetate in addition to 20 grains of pollen. Both were treated at the same time. P85 dropped in about 10 days, but PKN7 continued to grow until maturity. Note the different in the size of fruits.

Fig. 12. A few hormone-treated "ovaries" that did not develop into mature fruits, though they enlarged to several times their original size, then ceased further growth, dried up and persisted on the vine even when the plants were killed by the first frost. This is believed to be due to the preventing the formation of the abcission layer by the growth substance.

Fig. 13. A longitudinal section of a pair of parthenocarpic fruits showing partially developed placentae as a result of hormone treatment.

Fig. 14. A cross section of a parthenocarpic fruit showing the absence of seeds and seedcoats and also the pre-

sence of light margins in the place of contact between placental regions.

Fig. 15. Winter Sweet watermelon: S, A cross section of self-pollinated fruit; H hormone treated fruit. Note the differences in the thickness of rinds, lack of seeds or seedcoats and also the hollow cavities in the placentae.

Fig. 16. "Yellow Melon" watermelon: H, A cross section of a hormone produced fruit; P, from a self-pollinated fruit. Note the presence of small papery and soft seedcoats in H.

Fig. 17. Winter Sweet watermelon: Two watermelons produced from naphthalene acetic acid treatment. The one without seeds and seedcoats grew on a vine produced from seed pre-treated with colchicine; the fruit on the right produced what appeared to be seeds, but which were in reality undersized seedcoats. The seeds from which this plant was grown was given no such pre-treatment. Note the greatly thickened rind in both cases as compared with those fruits produced from self-pollination in Fig. 15:S.

Fig. 18. Watermelon seeds: Normal seeds from self-pollination as indicated in 1,3,5,7 and seedcoats from hormone treatment, 2,4,6,8 in various varieties of watermelons listed below: 1,2 are Yellow Melon; 3,4 Winter Sweet; 5,6 Fordhook Early; 7,8 Stone Mountain; 9,10 Iowa 5. Note only empty seedcoats except with for different degrees of development in the hormone treated fruits.

Fig. 19. Watermelon seeds and seedcoats from self-pollination and hormone treatment: (1) Favorite Honey from selfing, (2) from a mixture of naphthalene acetic acid and

indolebutyric acid treatment, (3) from a mixture of K-naphthalene acetate and colchicine treatment, (4) viable seeds obtained from K-naphthalene acetate and about 20 grains of pollen and empty seedcoats in (5); (6) Coles Early from selfing and (7) from hormone treatment; (8) Hawksbury from selfing and (9) from hormone treatment; (10) Selection 2 from selfing and (11) from hormone treatment.

Fig. 20. Favorite Honey watermelon: P, A cross section of a self-pollinated fruit showing the presence of good seeds; H, A hormone induced fruit with apparently normal seeds which were actually only empty seedcoats.

Fig. 21. National Pickling cucumber: A side and longitudinal view of a straight and a stem-end constricted fruit from open-pollination. Note the presence of well developed seeds from the blossom-end to stem-end in the straight fruit and the absence of seeds in the constricted region.

Fig. 22. National Pickling cucumber: a longitudinal section of typical naphthalene acetic acid-treated cucumber, showing the"undeveloped seeds", compared with open-pollinated cucumber in the shape and size.

Fig. 23. National Pickling cucumber: (1) A cross section of a hormone-treated fruit, (2) an open-pollinated fruit.

Fig. 24. Some cucurbit seeds and seedcoats from self-pollination and hormone treatment: (1) seeds of <u>cucurbita moschata</u> from selfing, (2) seedcoats from hormone treatment; (3) Early Prolific Straightneck squash from selfing and (4) from hormone treatment; (5) Dark Green Zucchini from selfing; no ovules or seedcoats remnants were present in the hormone-

treated fruit; (6) Buttercup squash from selfing; no ovules or seedcoat remnants were present in the hormone-treated fruit; (7) National Pickling cucumber from selfing and (8) from hormone treatment.

Fig. 25. Early Prolific Straightneck squash: P. A Cross Section of fruit produced by pollination, and KN(1) produced by hormone treatment. Empty seedcoats were present in the hormone-produced fruit.

Fig. 26. Dark Green Zucchini squash: H. A Cross section of fruit produced from hormone treatment, and P. fruit from open pollination. Normal seeds were present in the pollinated fruit but neither seed nor seedcoats were present in the hormone-produced fruit.

Fig. 27. Buttercup squash: A Blossom-end view of a hormone-treated fruit (NAc) and a pollinated fruit (Poll) showing the similarity in external appearance.

Fig. 28. Buttercup squash: A longitudinal section of a hormone treated fruit showing the absence of seeds and seed-coats. The placental region was more restricted and had a much thicker receptacle and pericarp than normal seed-bearing fruit.

Fig. 29. African Bell squash: A parthenocarpic fruit produced from hormone treatment.

Fig. 30. African Bell squash: P. A Cross section of a pollinated fruit and H, a hormone-treated fruit. Empty seed-coats of small size were present in H.

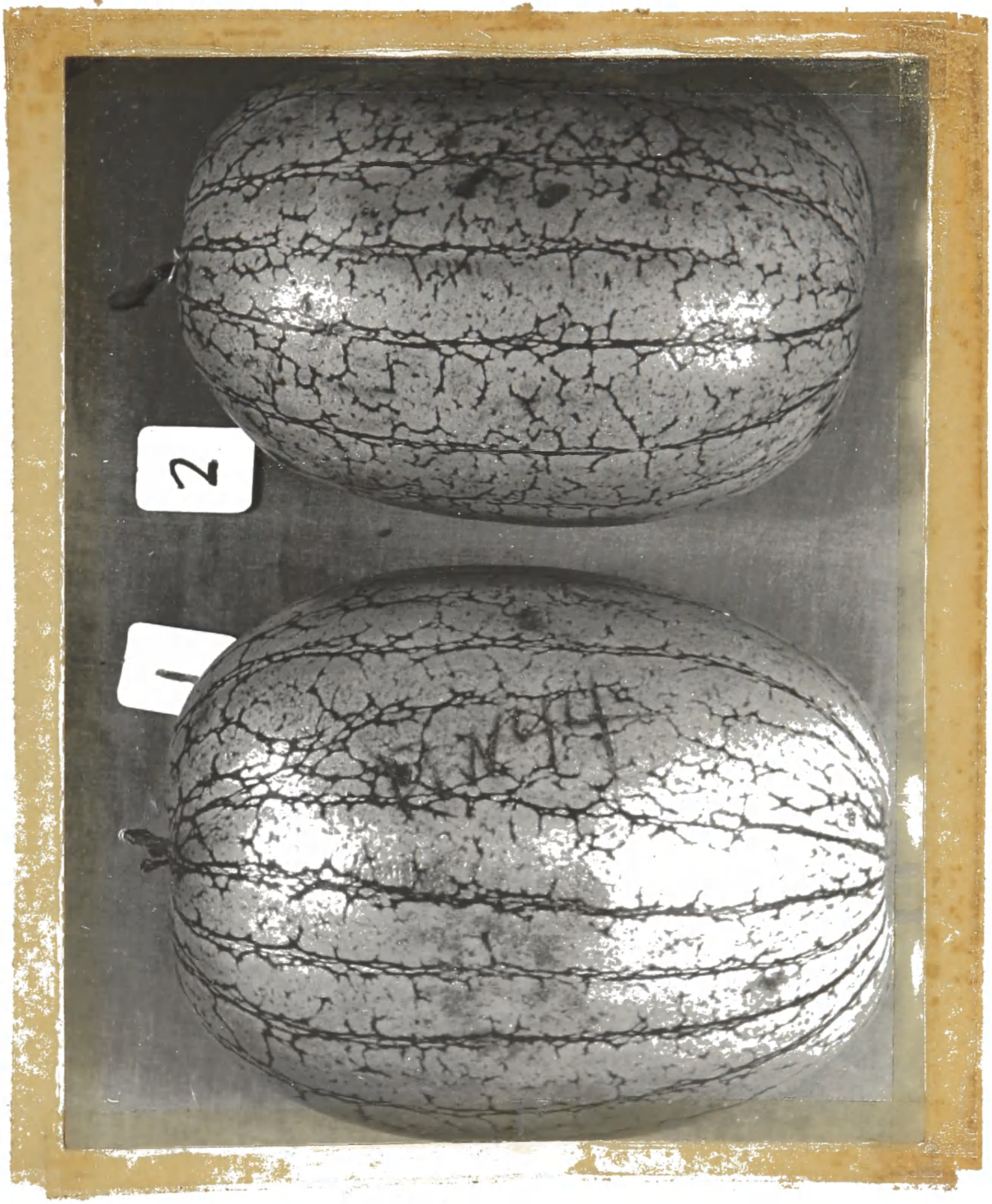
Fig. 31. Muskmelon: A pair of hormone-treated muskmelons. The large fruit was produced from a mixture of naphthalene

acetic acid and acenaphthene in lanolin, the small one was treated with naphthalene acetic acid alone. Both flowers were treated at the same time. The small fruit (N) ceased growing about 25 days after treatment, turned yellow, then soft. The large fruit (AN) continued to grow until maturity. No seeds of any sort were present.

Fig. 32. Harris Wonder pepper: A, from naphthalene acetic acid treated blossom; B, from self-pollinated blossom. No seeds were present in the hormone-produced fruit.

Fig. 33. New Hampshire Hybrid eggplant: A hormone-treated fruit (smaller one) and a self pollinated fruit.

Fig. 34. New Hampshire Hybrid eggplant: (1) A Cross section of a hormone-treated fruit and (2) a self-pollinated fruit. Note the presence of seeds in (2) but not in (1).



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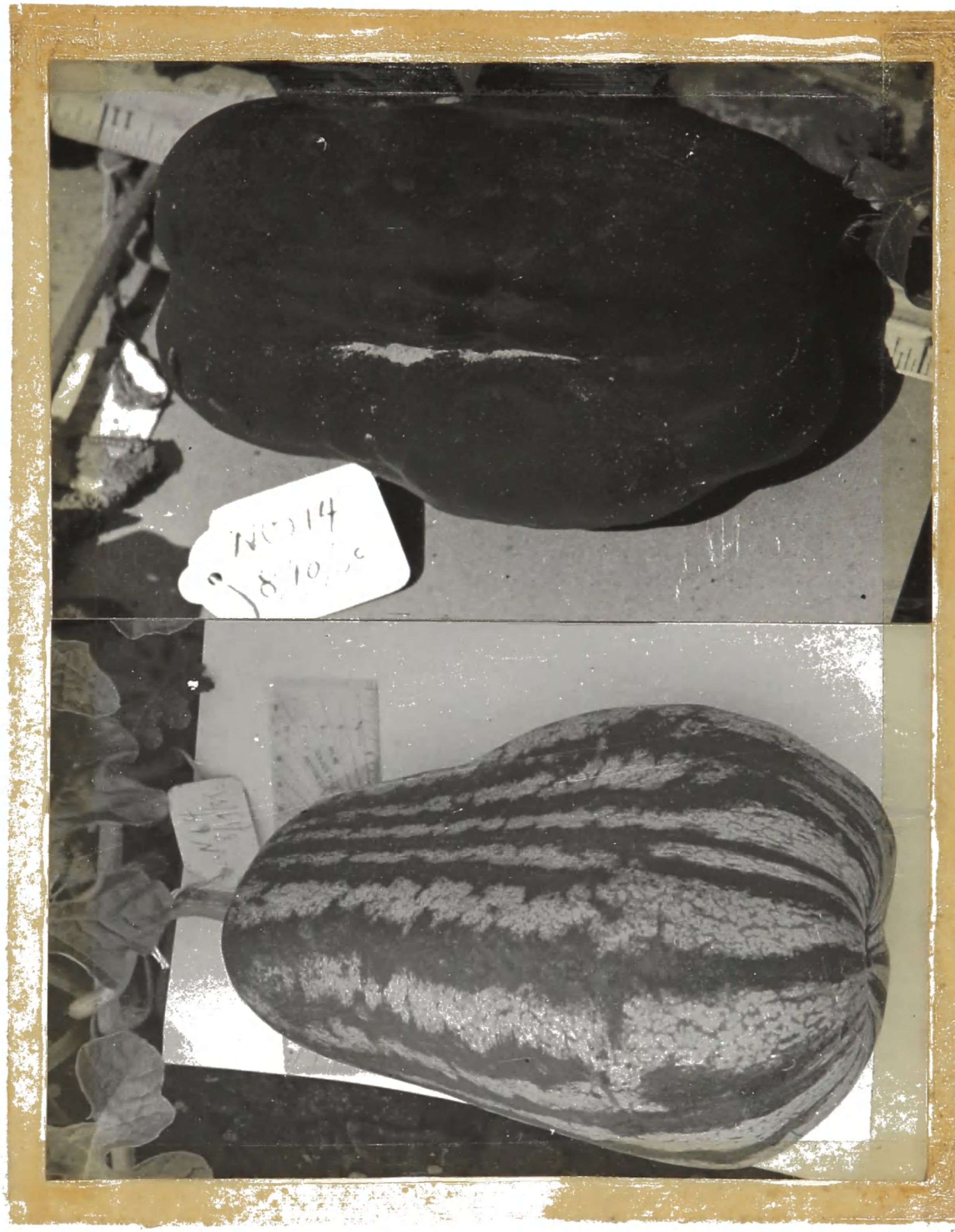

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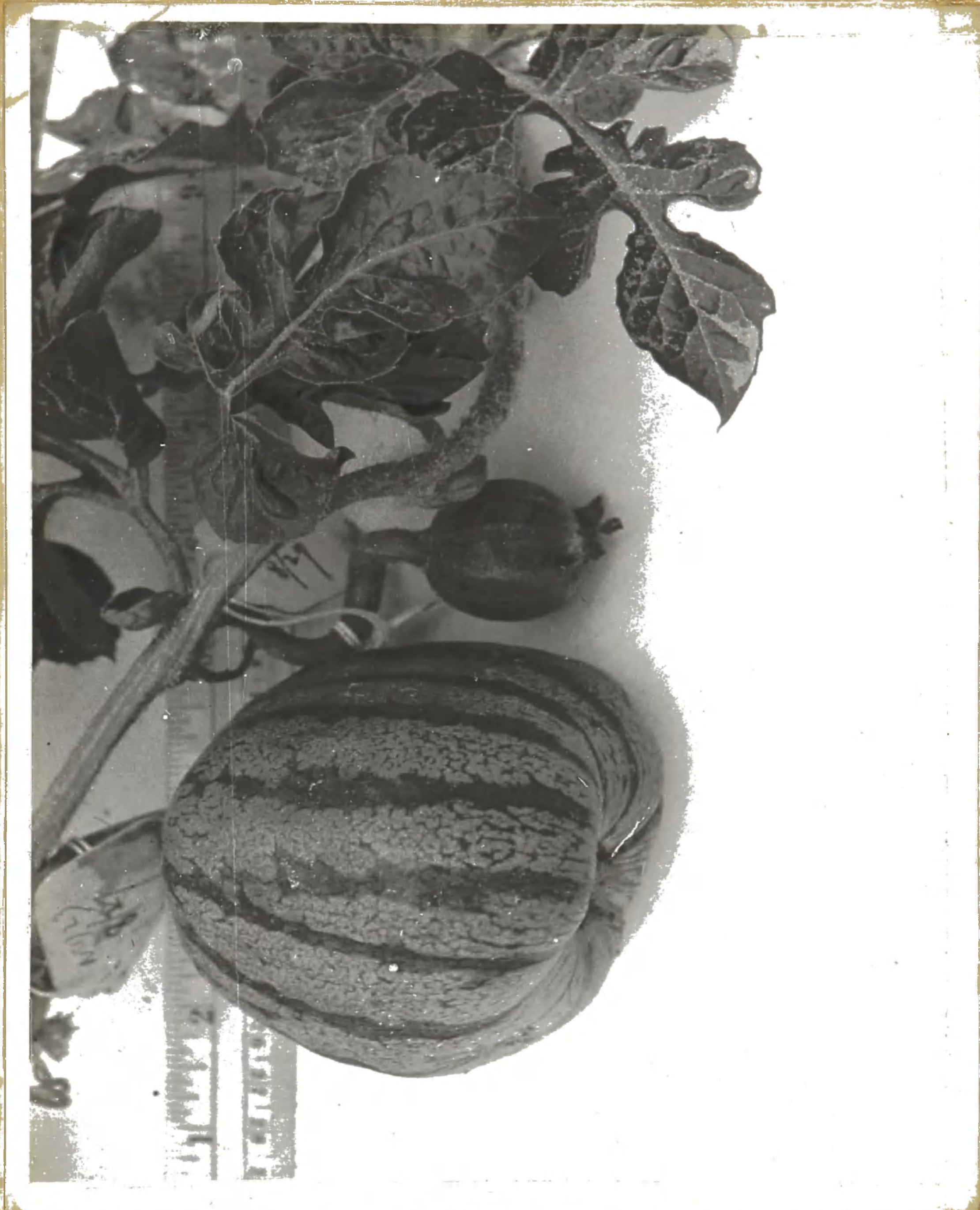

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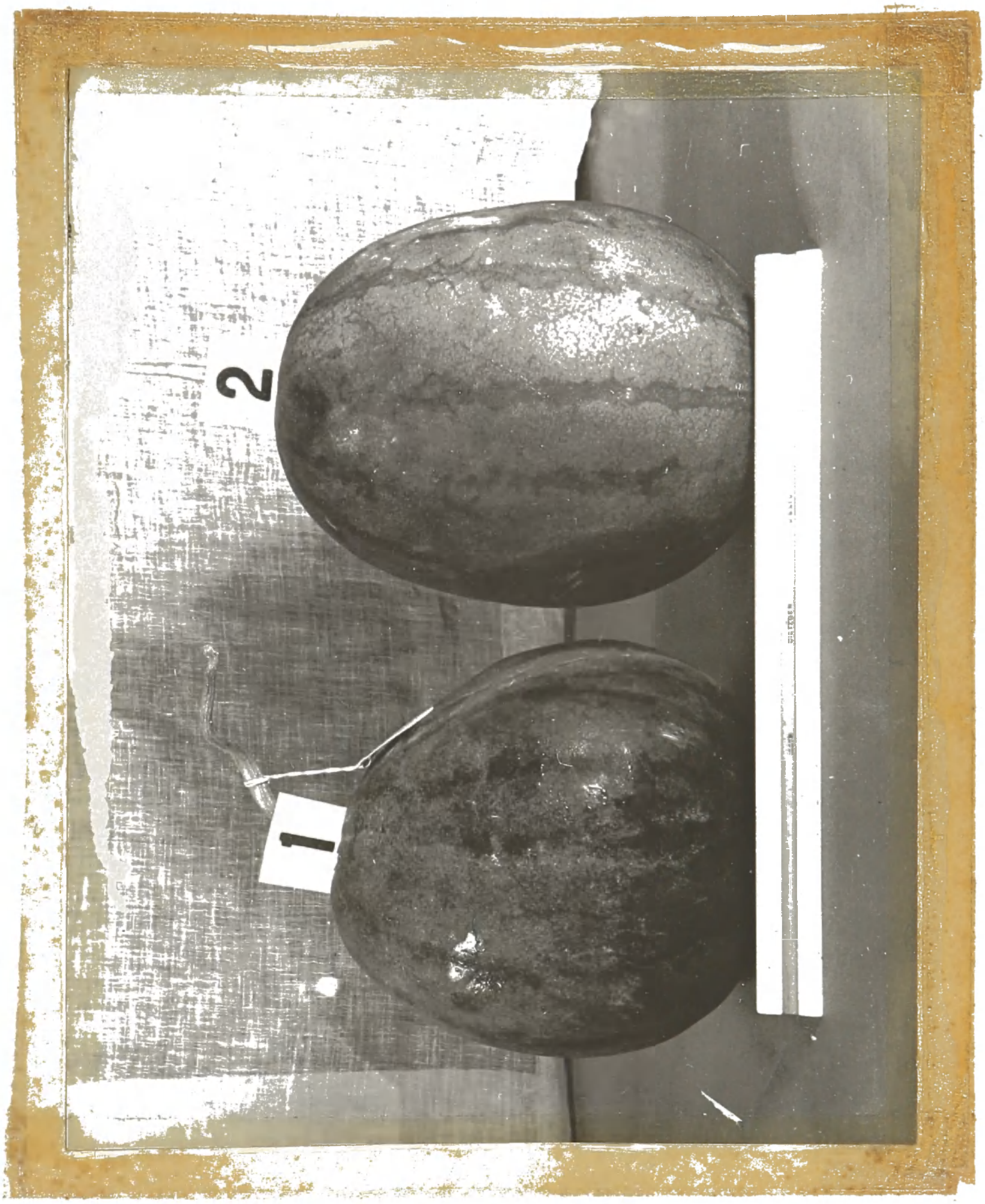

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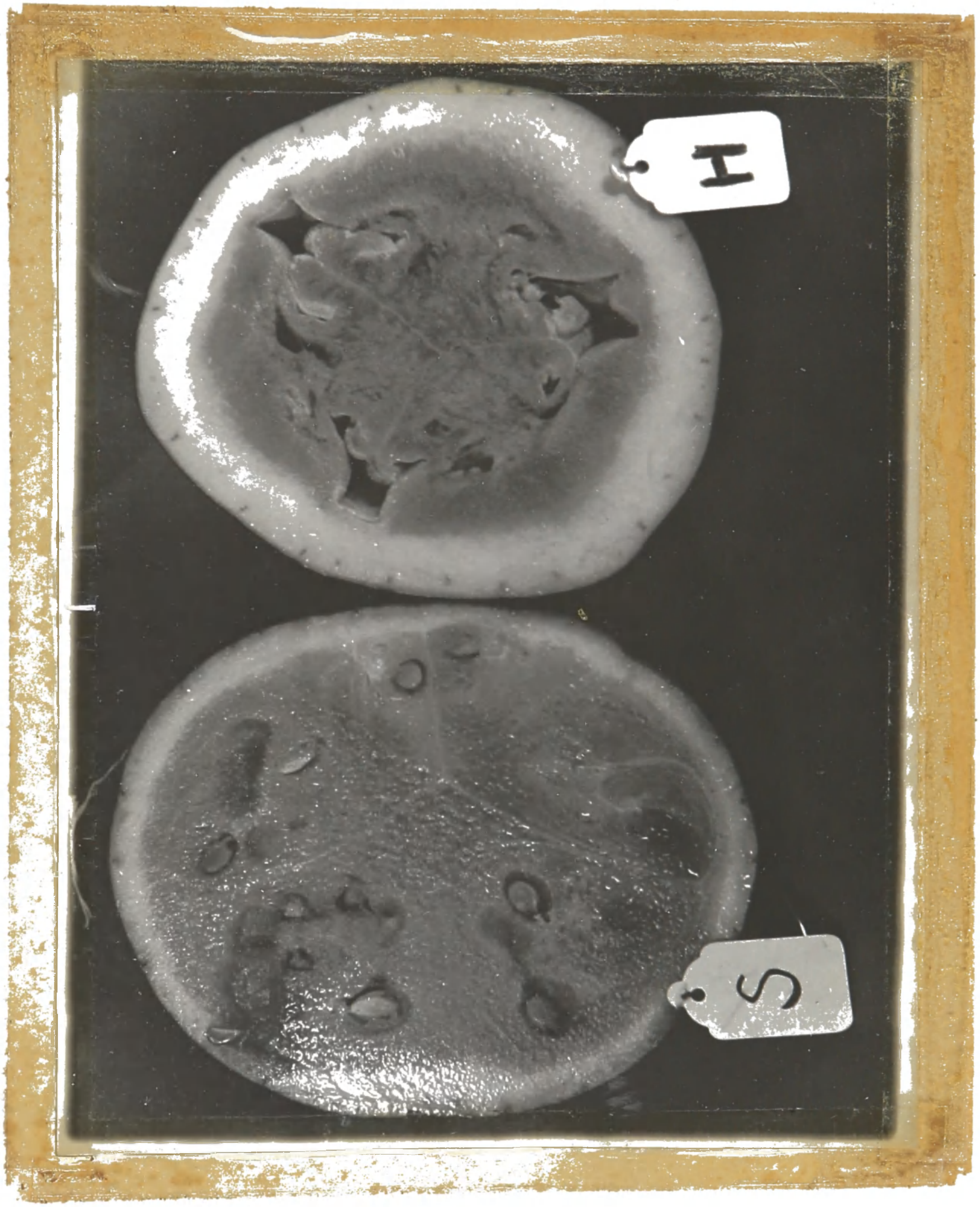

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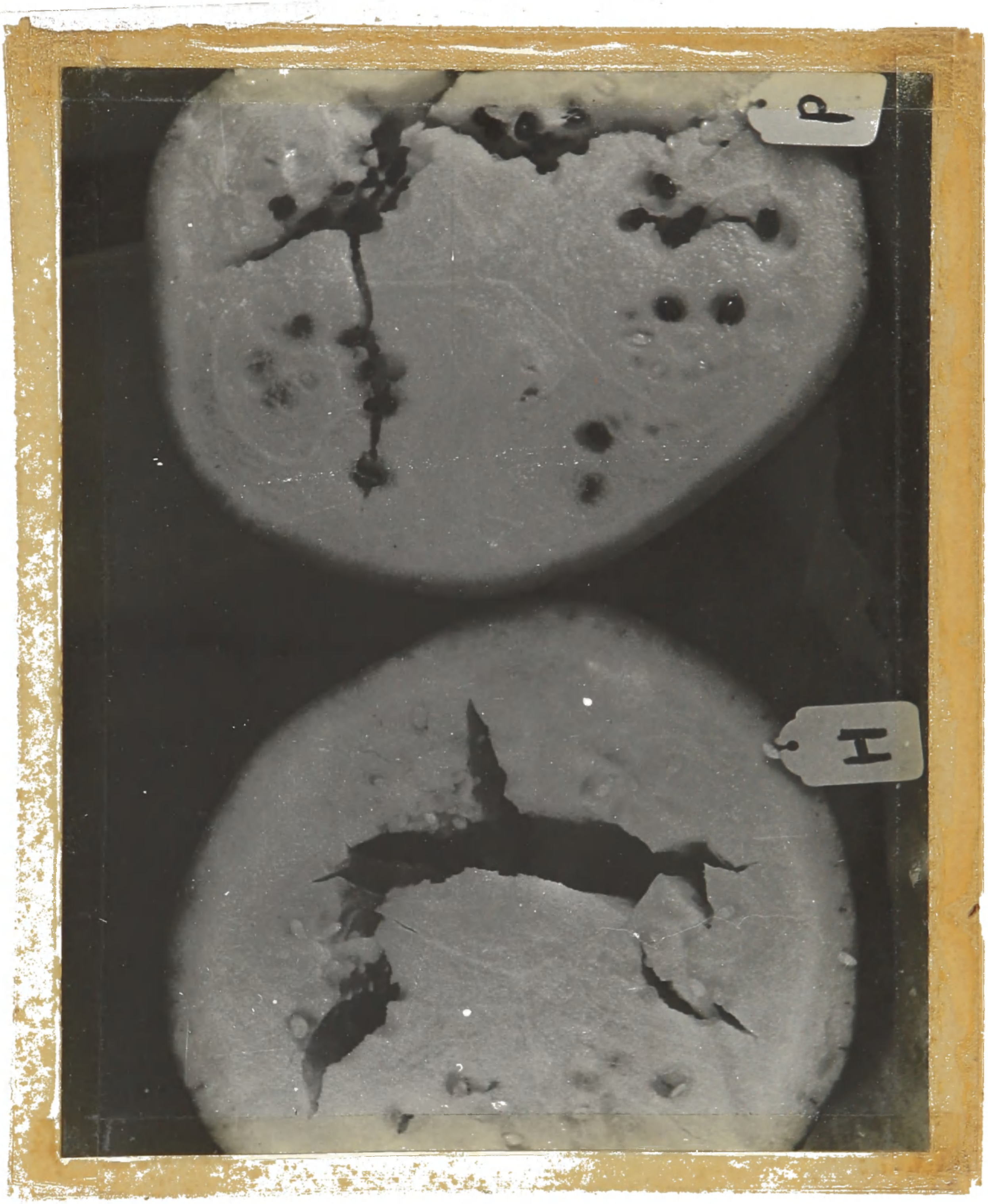

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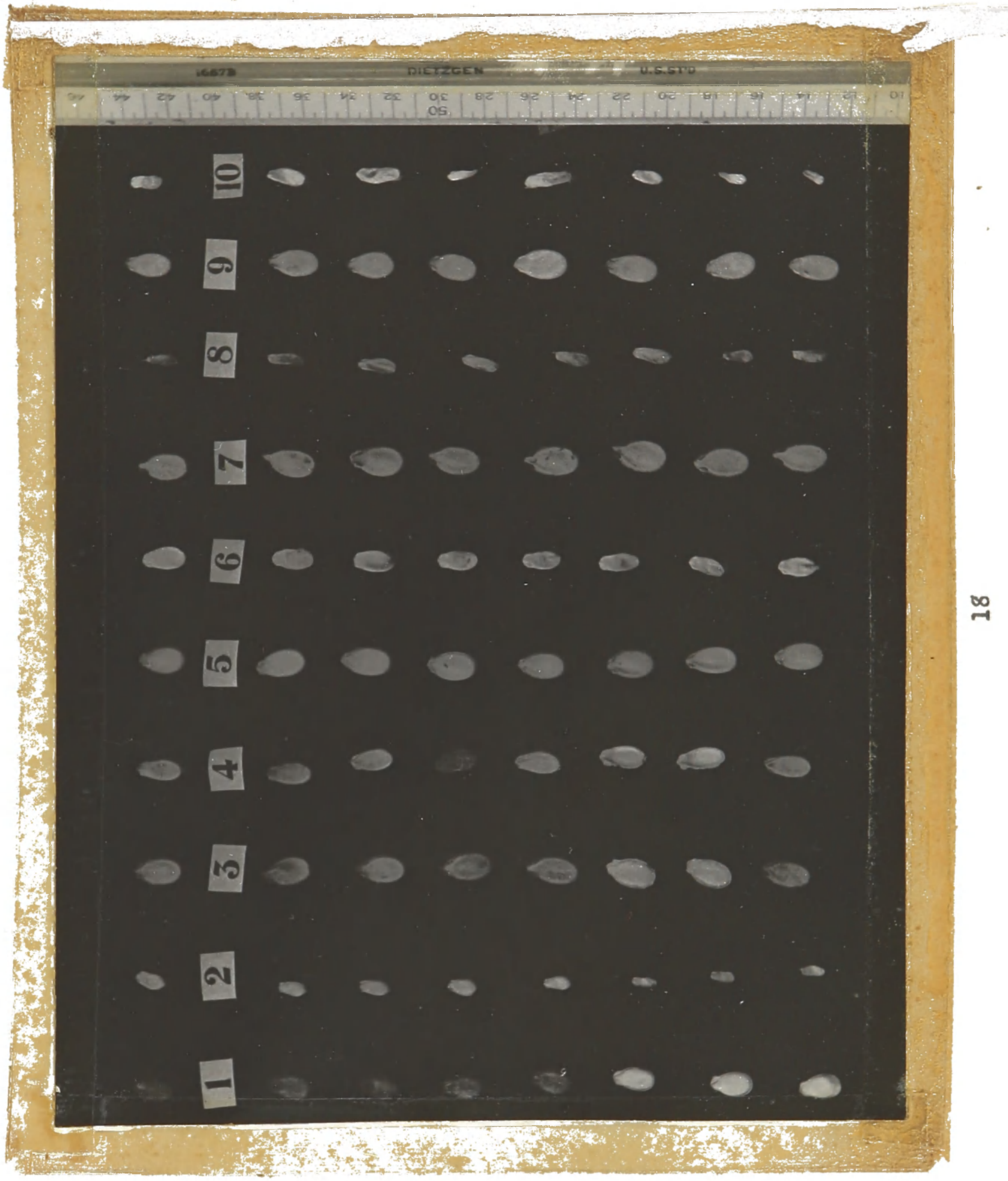

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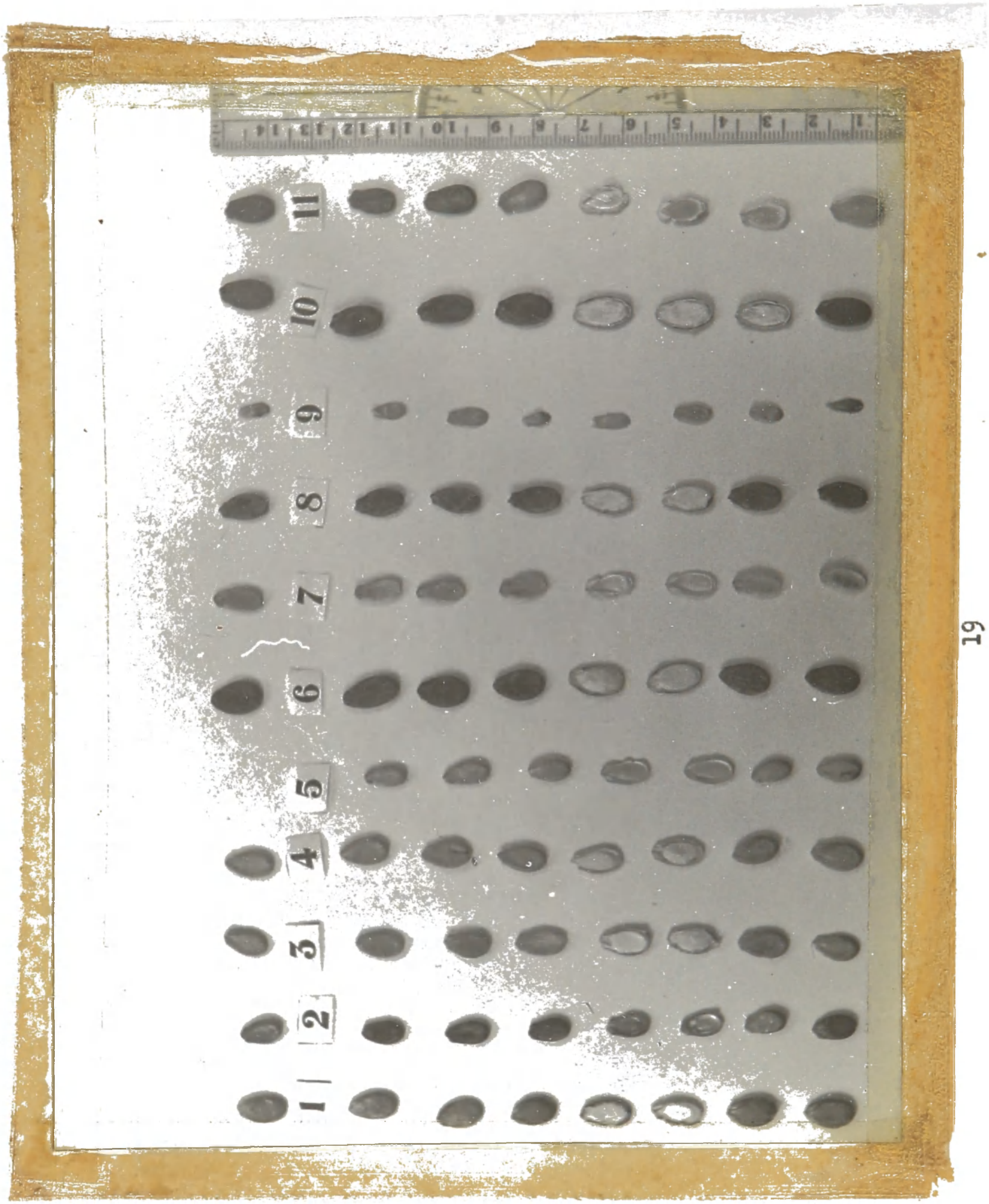

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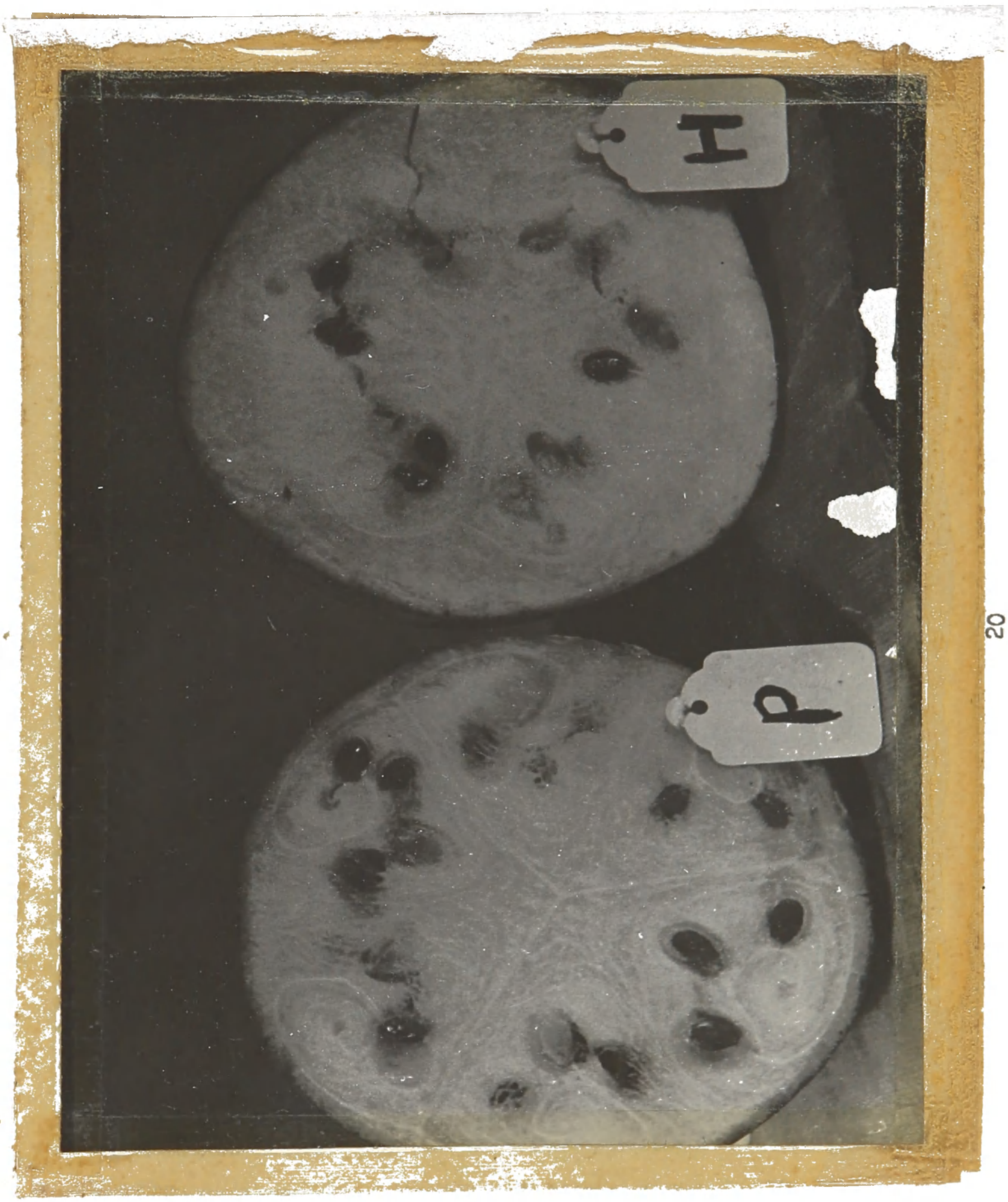

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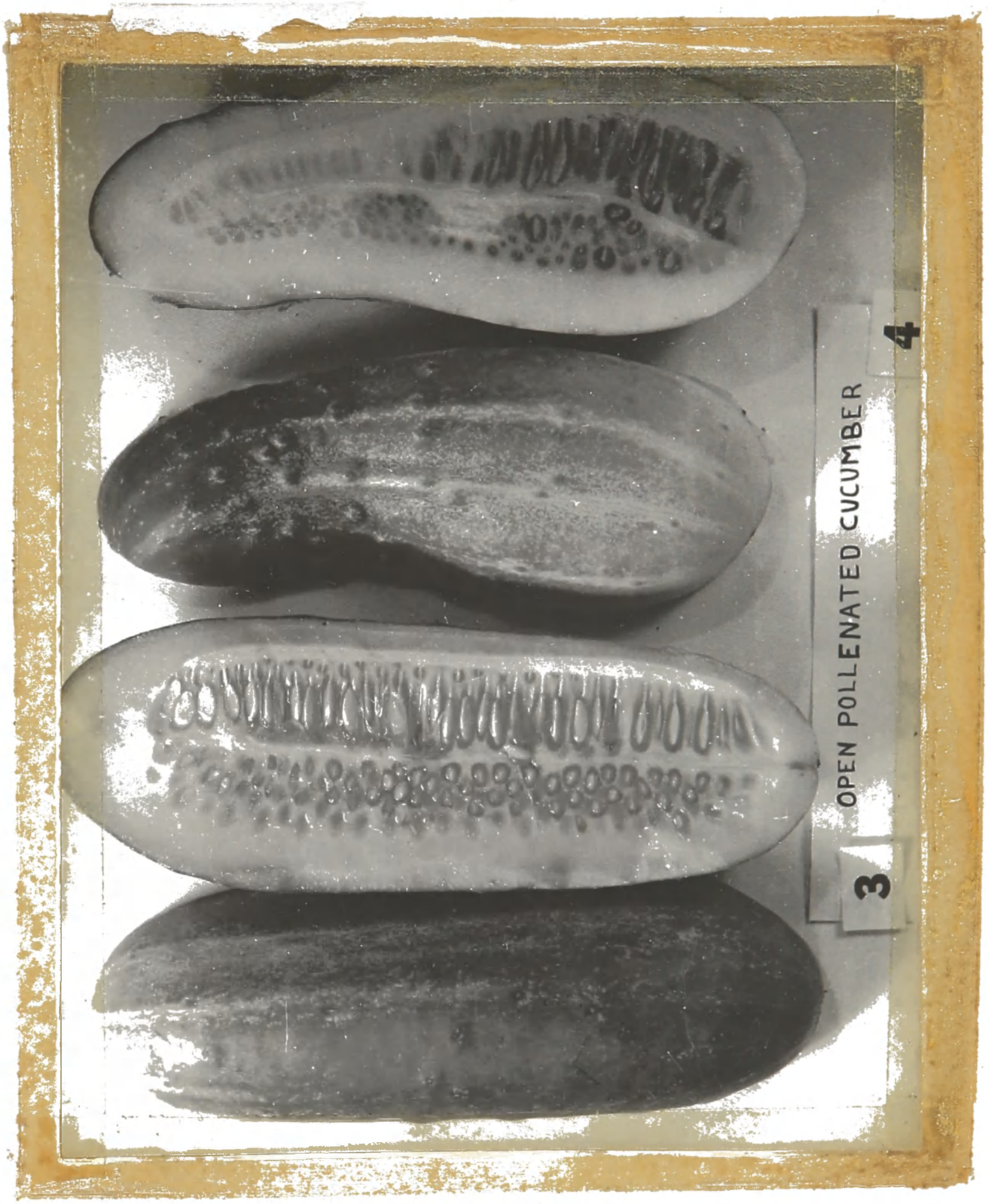

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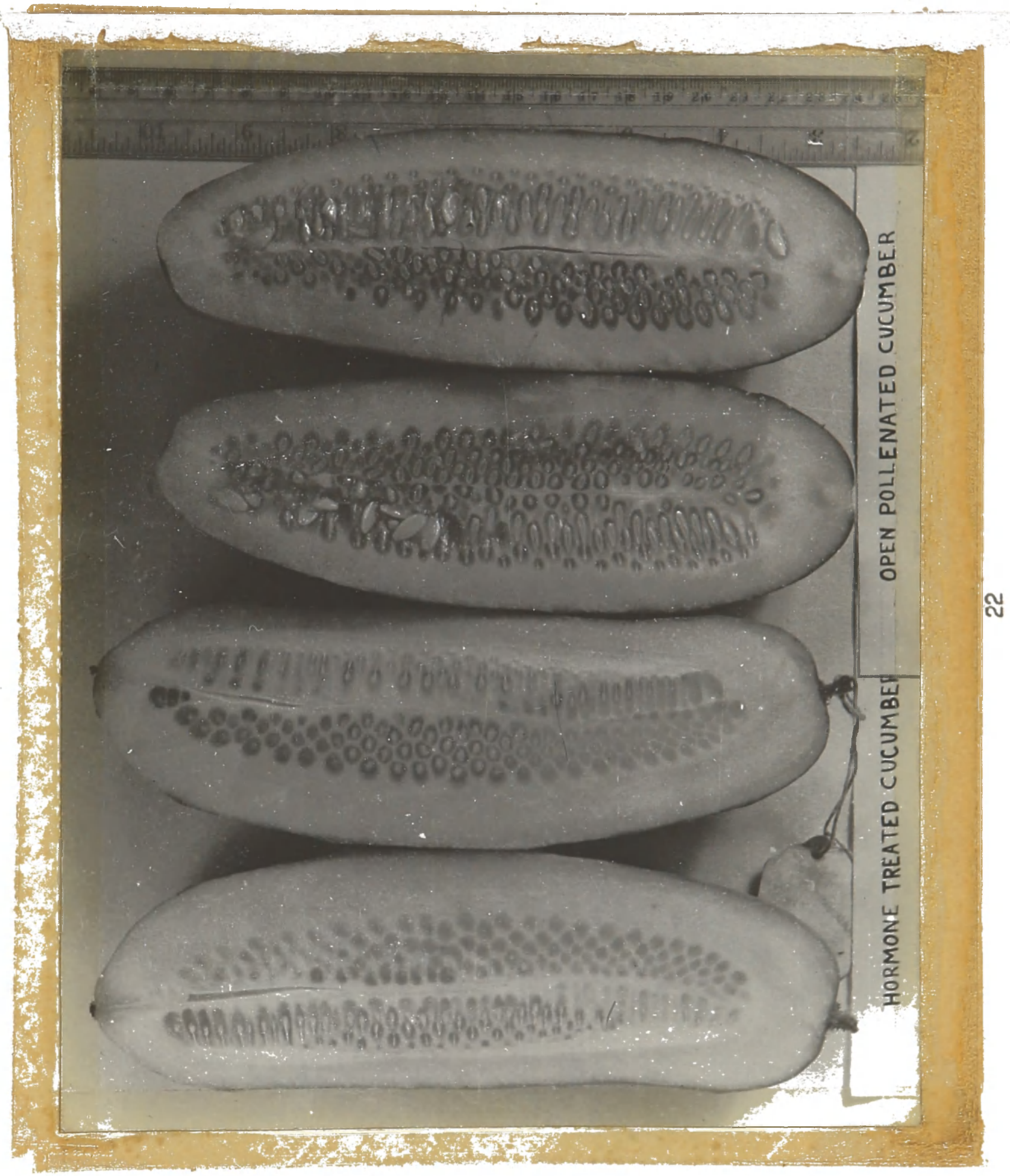

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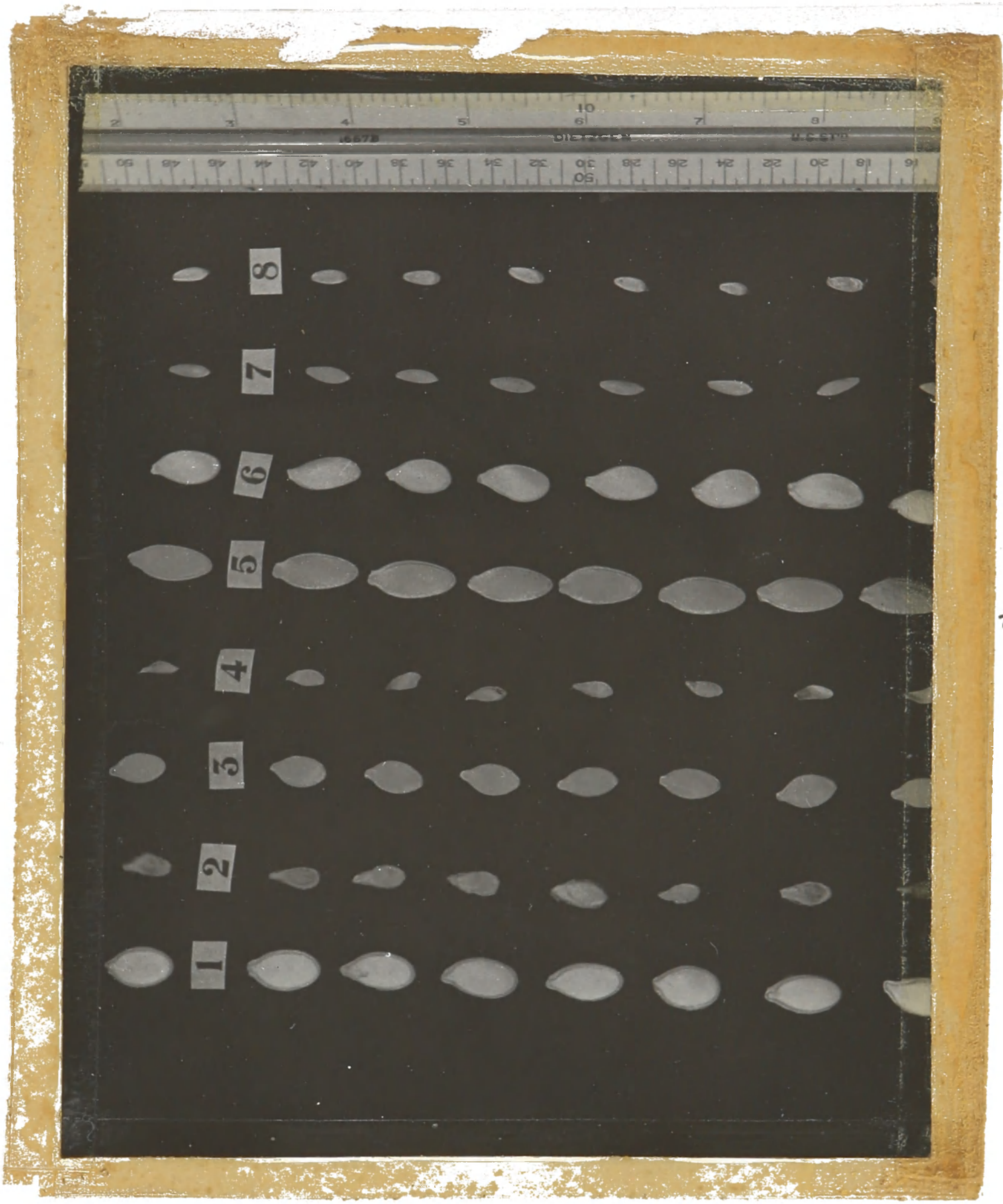

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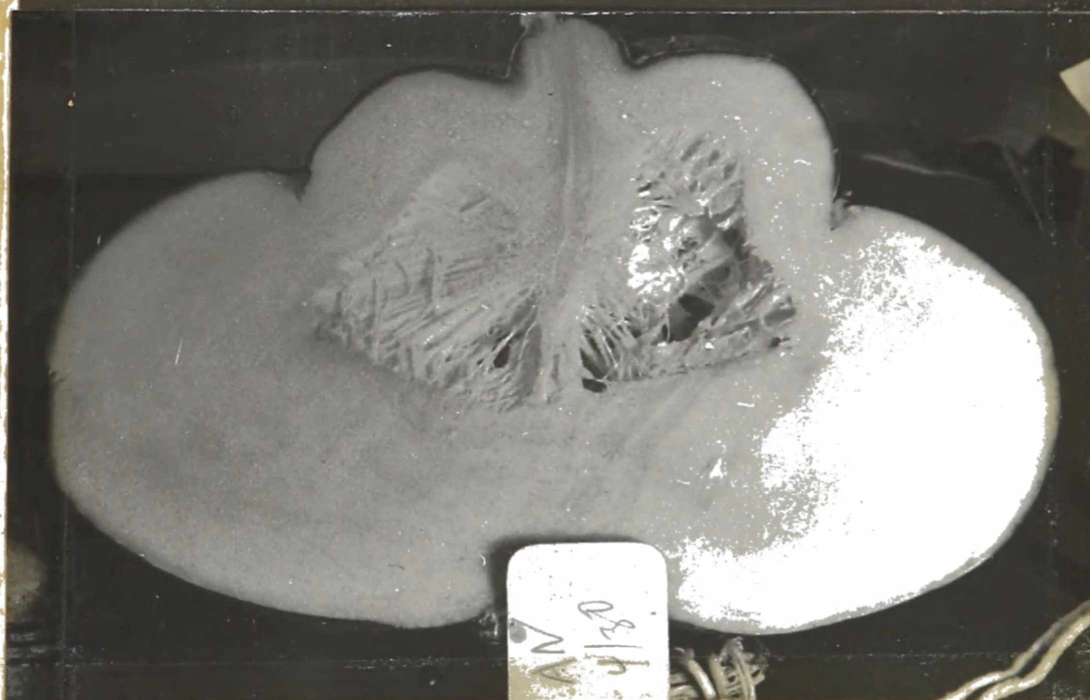

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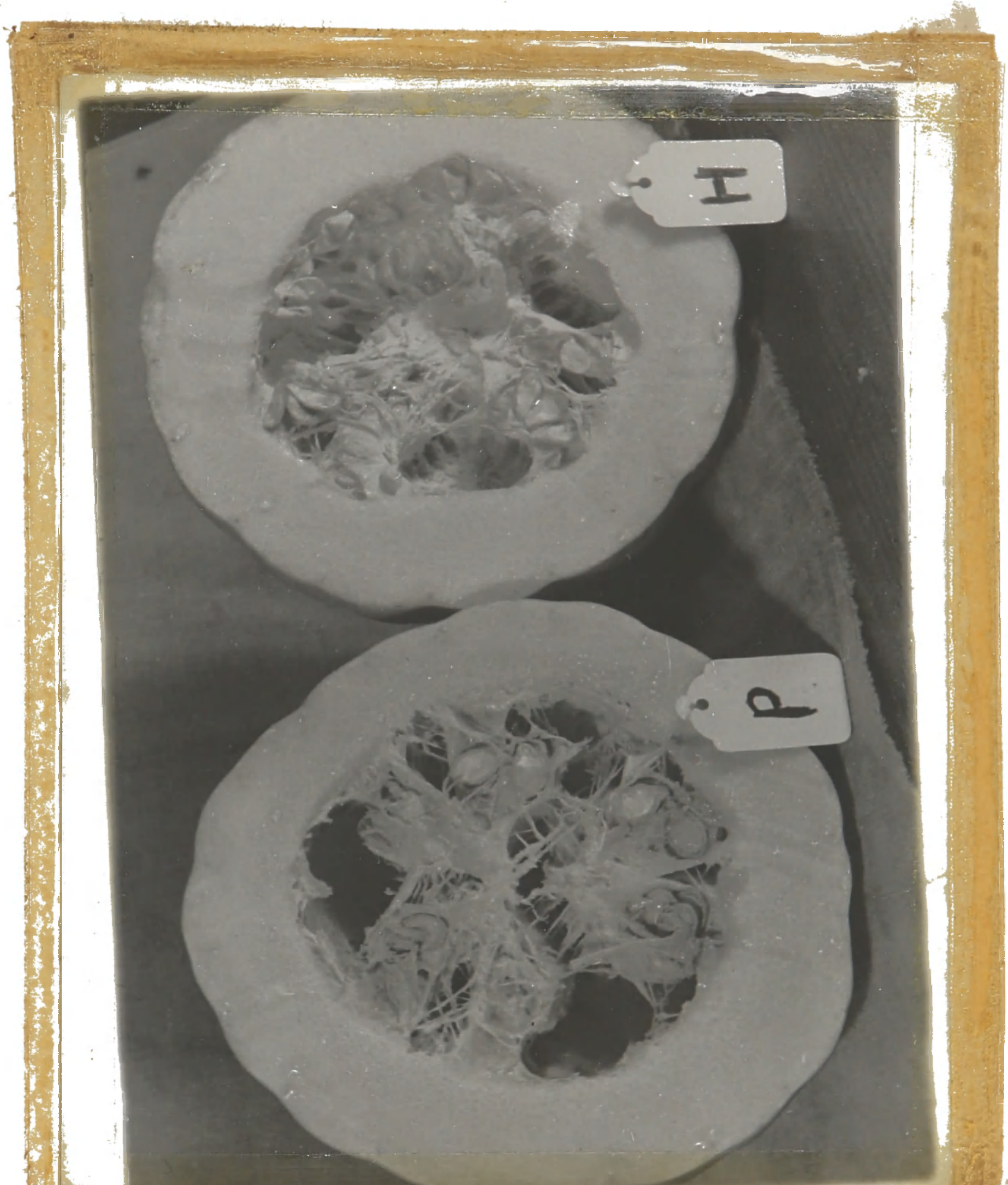

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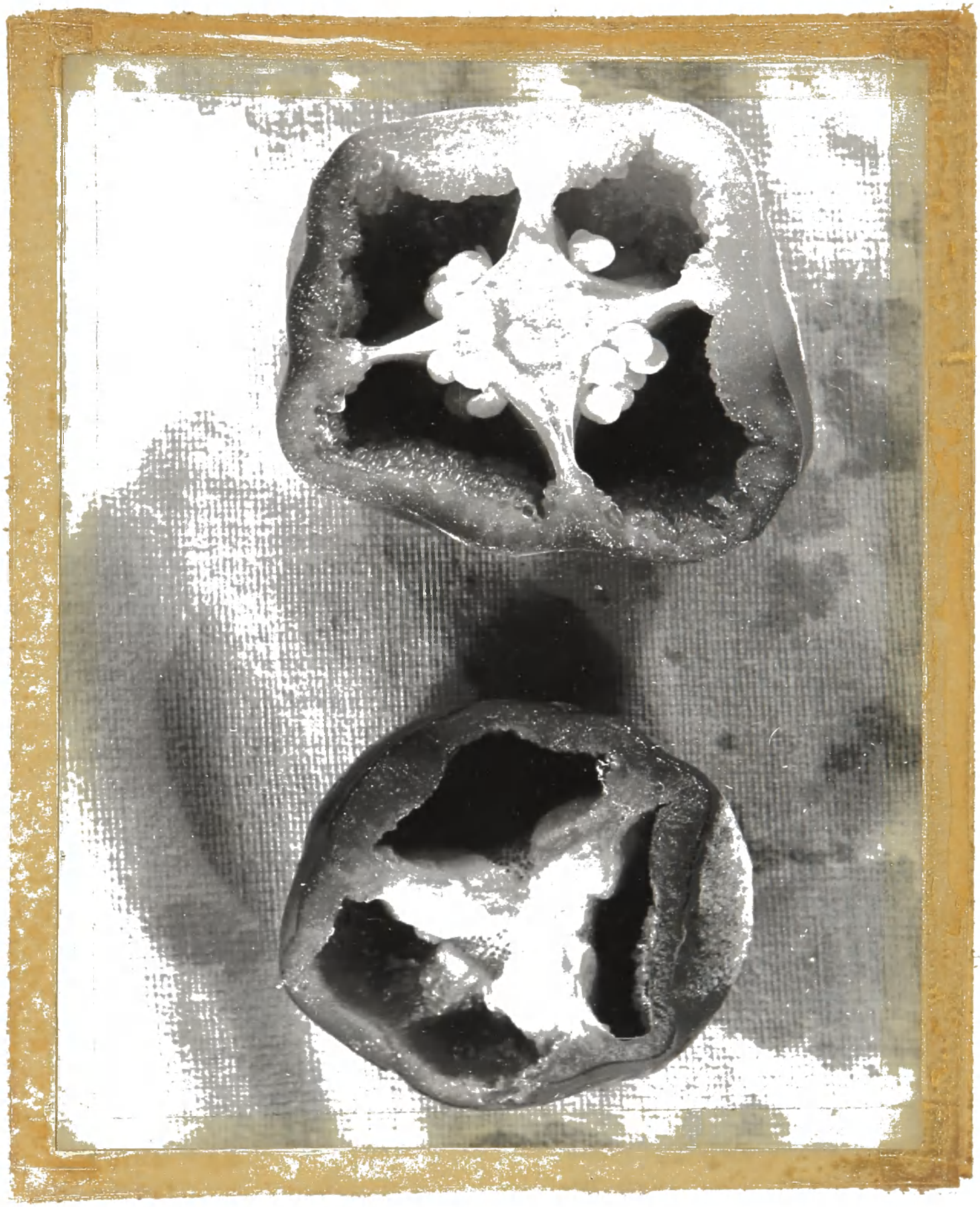

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