# RELATION OF WATER TO THE GERMINATION OF CORN AND COTTON SEEDS

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(WITH SIX FIGURES)

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## Introduction

The relation of plants to climatic conditions constitutes an extremely intricate complex of simultaneous variables and, despite extensive studies, remains one of the most inaccurately documented fields of plant science. This is unfortunate, particularly in relating the results of laboratory studies to the problems of the field. In this realm of plant science, water relations are perhaps most accurately known, many studies such as those of BRIGGS and SHANTZ (**2**, **3**) having reported acceptable quantitative data. It is surprising that almost no studies have been reported on the environmental water relation of seeds and their significance. Ecologists have accepted classification of plants as hydrophytes, mesophytes, and xerophytes, but no one has shown whether or not seeds display comparable or related characteristics.

In the establishment of plants in their habitat, germination is an essential and active phase which is escaped only by those species which depend partly or completely upon vegetative production. It is obvious that hydrophytes, mesophytes, or xerophytes must produce seeds capable of germination in the habitat. Since the process of germination is of limited duration, the process may be accomplished during temporary periods of favorable water supply, or may take place under the less favorable condition average for the habitat. Such studies as have a bearing on the water relations have been concerned with the permeability of the seed coats, the gross absorption and water content, and the power with which the water is absorbed. Germination has been considered largely in relation to seed viability under conditions of favorable moisture and oxygen supply. While activities such as respiration and food transformation in seeds have been related to water content, the ultimate criterion of activity, namely, germination, has not been subject to quantitative studies.

A study was undertaken by the writer in 1941, and continued through 1942 and 1943, of the quantitative aspects of water absorption for germination. Seeds of widely different types of plants were selected for study to determine whether seeds actually differ in the total amount and rapidity of water intake for germination and to note the part played by the various anatomical structures in this process.

Seeds of sufficient size to permit quick dissection were selected from plants which represented hydrophytes, mesophytes, and xerophytes. These were exposed to various conditions of moisture and the water content determined at 24-hour intervals.

Seed structure, though widely different in the various plant groups, has not been correlated with behavior or ecesis. Yet the fact is obvious that the success of a species may be critically dependent upon a successful germination under the conditions of the habitat. It is also apparent that differences in germination-water requirements, structure, and rate of water absorption may be of applied interest. In those seasons, and in those regions characterized by dry spring conditions, the advantage of germination in soil with limited water content might mean earlier crops, as well as better and more regular stands. If strains could be found with low germination-water requirements, crops might be possible in many parts of the Southwest where their production is not now practicable.

A study of the gross structure of seeds from plants of various ecological types, and the relation of the structures and the whole to germination water thus seemed important. This paper is devoted to the studies of water intake in relation to the germination behavior of corn and cotton seeds.

## Water as a factor in germination

The necessity of water for the germination of seeds has long been taken for granted; but the amount of water necessary for germination, and the methods by which seeds absorb and distribute moisture have been given comparatively little notice.

Very little literature is available on the total amount of water necessary for germination. DETMER (**8**) found that the quantity of water absorbed by different kinds of seeds, when thoroughly soaked, was by no means the same; therefore, the capacity for absorbing water is different for different kinds of seeds. He found that the peas took up about 100% of their air dry weight, and wheat only 40 to 60%.

PETERS (**9**) worked on germination of seeds in a medium of low water content. He attempted to answer the question as to whether seeds can germinate when the amount of soil moisture is so low that plants growing in it will wilt and die. He found that seeds of peas, soybeans, and grains of corn and wheat germinated at or below the wilting coefficient of 1.31% moisture in quartz sand of 0.1-mm. size. Thus, his work substantiated the idea that seed can germinate in soil at or below the wilting coefficient of plants growing in soil of the same moisture content.

The rate of water absorption is so dependent upon temperature that the two factors, water and temperature, cannot be separated. BROWN and WORLEY (**7**) studied the effects of temperature upon the rate of water absorption by barley seeds, and claimed that the velocity of water absorption was almost an exponential function of the temperature. SHULL (**14**) attacked this same problem, using seeds of Xanthium and pea seed cotyledons, but could not find support for the BROWN-WORLEY theory in his data. The velocity of water intake at any given moment was found to be approximately an inverse exponential function of the amount of water previously absorbed.

A later study by SHULL and SHULL (**15**) on grains of corn, agreed satisfactorily with the earlier work on Xanthium and pea cotyledons. The rate of absorption at 55° was somewhat more than 8 times as great as at 5° C., whereas the chemical theory of water simplification by rising temperature would call for a rate thirty-two times as great at 55° as at 5°. The results with corn seeds were in complete agreement with the postulate that the rate of water intake depends upon the previous absorption, as an inverse exponential function.

Since one function of the seed coat is to serve as a vehicle for the conveyance of water, its structure and permeability are of importance. BROWN (**5**) reported semipermeability in barley (*Hordeum vulgare* var. *coerulescens*), and traced the semipermeability to the spermoderm of the grain, which resisted the action of 36% sulphuric acid. SCHRÖDER (**10**) found similar conditions in wheat and TJEBBES (**16**) obtained evidence of selective permeability in the seeds of sugar beets. SHULL (**11**) found that seeds of Xanthium have coats that are selectively permeable. In this case the middle and inner layers of the seed coat are mainly responsible for the observed phenomena. ATKINS (**1**) failed to find selective permeability in beans.

SHULL (**12**) made use of the almost perfect semipermeability of Xanthium seed coats toward the chlorides of sodium and lithium to measure the internal forces of seeds. Seeds were placed in solutions of these salts of varying concentrations and allowed to come to moisture equilibrium, which was indicated by constancy in the weight of the seeds. The osmotic concentration of the external solutions was known in each case from the vapor pressure of the solution. At equilibrium it was assumed that the internal forces and the external forces were equal. While the forces thus measured were by no means as large as those indicated for oven-dried material, still they were of considerable magnitude. In saturated solutions of sodium chloride, the seeds were able to crystallize salt out of solution by withdrawal of pure water from its hydration compounds. Air-dry seeds (moisture 7% above the absolute weight) had an initial imbibition pressure of little less than a thousand atmospheres (965), or more than 14,000 pounds per square inch. When the moisture content had been doubled (14% above absolute weight), the internal pressures had fallen to a little less than 400 atmospheres. He measured these forces across the entire range from air-dry to complete saturation.

Using seeds which had been calibrated in this manner SHULL (**13**) proceeded to measure the water-holding power of soils, and showed that air-dry soils and air-dry seeds were in equilibrium, at about 1000 atmospheres each. If the soil moisture were increased above air-dry, the seeds would absorb moisture until in equilibrium with the soil. For instance, at 3.5% above air-dry, the seeds and soil reached an equilibrium indicating about 375 atmospheres. When the soil moisture reached 6% above air-dry (Oswego silt loam subsoil) the moisture was held on the soil particles with about

130 atmospheres pressure. At 11%, soil moisture equilibrium indicated 22.4 atmospheres; and at the wilting coefficient (13.3%) the balance was equivalent to the action of 0.1 M sodium chloride solution, or about 4 atmospheres. Various soil types with differing wilting coefficients all gave similar results except the coarser sands. These studies have thrown much light upon the behavior of seeds with respect to the absorption of water, and have clarified the dynamics of water intake.

Finally, there are hard seeded species whose seed coats are impervious to water. Among these are certain legumes, clover, sweet clover, Kentucky coffee bean, morning glory, asparagus, okra, rose mallows, etc. The causes of hardness are still obscure, and most probably concern the chemical nature of certain cell layers within the testa. In some cases the outer layer of cells can be removed, notably in the rose mallows, and the seeds still remain hard. Such seeds may lie in water for months without absorbing appreciable amounts of moisture.

## Materials and methods

A quantitative study of the course of water absorption by seeds during germination was made in order to determine (1) whether seeds actually differ in the total amount and rate of water intake; (2) to note the role played by the various parts of the seed; (3) to determine whether there exist seeds with "mesic," "hydric," or "xeric" germination modifications; and (4) to determine whether there are varietal differences in water absorption by seeds. Many types of seeds have been studied but, for the purposes of this report, the data are given only for the seeds of corn and cotton. The varieties of corn used are: Yellow Dent, "Sure Cropper," and Gehu Flint. Varieties of cotton used (*Gossypium hirsutum*) are Rogers Acala, 1940; Rogers Acala, 1941; and Drought Resistant #293.

For the experiments, seeds of each variety were selected for uniform size and appearance. Preparatory to germination they were sterilized by placing them in 0.01% $HgCl_2$ solution for 3 to 5 minutes and then rinsing twice in sterile distilled water. Forty seeds of each variety were then placed on filter paper in a sterilized Petri dish. Ten cc. of sterile distilled water were added to each dish and small quantities thereafter as needed. Practically no contamination occurred after this treatment. The seeds were allowed to germinate in the Petri dishes at room temperatures (25° to 30° C.). The cotton seeds were delinted by placing them in concentrated $H_2SO_4$ for 3 minutes to increase permeability of the seed coats.

At 24-hour intervals (0, 24, 48, 72, 96 hours) of germination, seeds were dissected into seed coats, cotyledons, "growing parts" of the embryo, and endosperm. The axis is hereafter referrred to as the "growing parts" of the embryo and as "embryo" in the tables and graphs because it is the part of the seed that develops into the mature plant. The percentage of water was determined on similar parts of 20 seeds of each kind and expressed on the absolute basis. The amount and percentage of water absorbed by the entire seed were determined by the same methods.

At each interval of germination time a new set of 20 seeds was selected. The amount of hygroscopic water present in the parts of air-dry seeds was determined by dissecting the seeds into their parts and determining the moisture content. The percentage of hygroscopic water was calculated on the absolute basis for each part and for the seed as a whole.

The Dent corn was dissected dry but, because of the difficulty encountered with it, the other varieties of corn and the cotton seeds were soaked in water long enough to make dissection possible. After dissection, the parts were air-dried to constant weight before the hygroscopic moisture determinations were made. It required about ten days of clear weather to return to air-dry condition after soaking and dissection. The period of soaking, before desiccation, was only three hours.

## Observations and results

### Corn

Pericarp and integuments.—The protective covering of the grain of corn, sometimes called the hull, consists of the pericarp and the testa. The

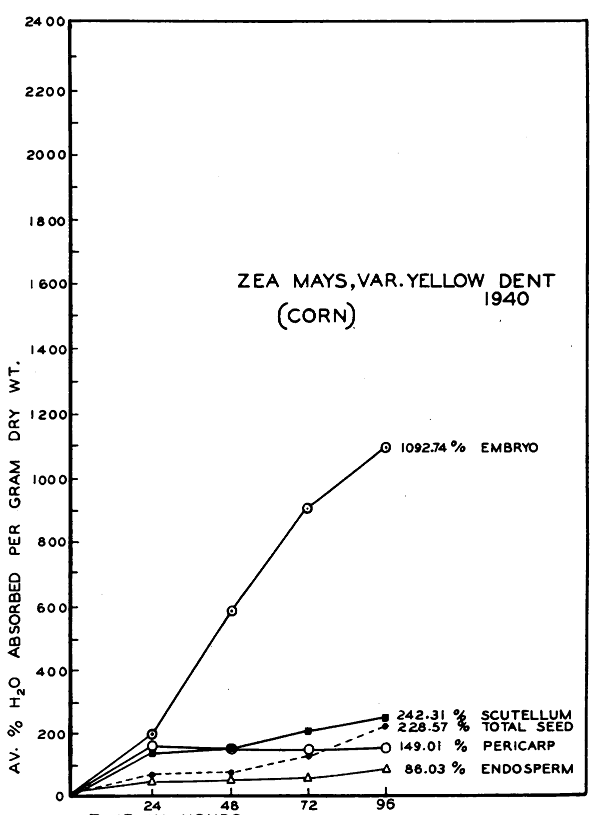


Fig. 1. Absorption of water by the various organs of *Zea mays*, var. Yellow Dent (1940), during early phases of germination.

cells of the pericarp continue to divide and increase in size and, as the fruit nears maturity, these cells cease to divide and the walls thicken. The subsequent increase in size of the pericarp is due to the stretching of tissues already formed. Its late development, at all stages, causes it to be in a constant state of tension and gives it a tough fibrous texture in the mature form. The translucent hull shows little or no starch but scattered traces of reducing sugar.

During germination the hull transfers water to the interior of the grain,

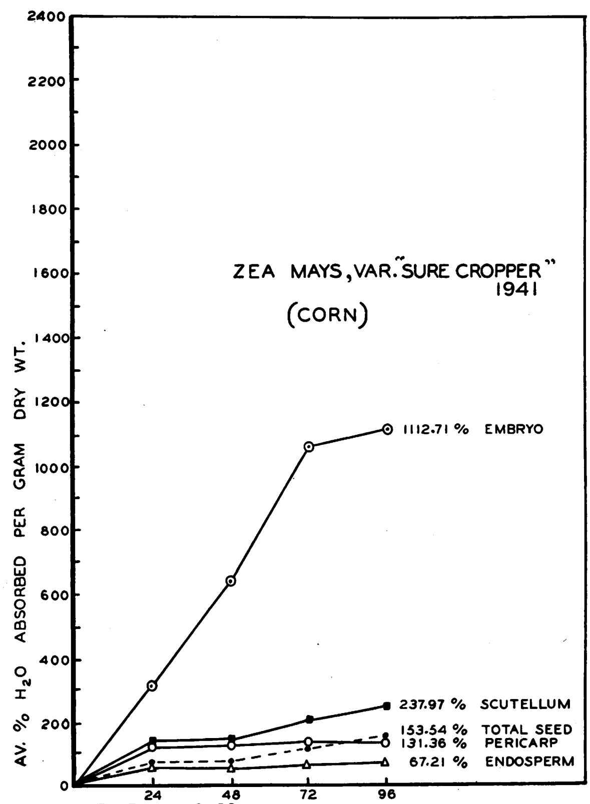


FIG. 2. Absorption of water by the various organs of *Zea mays*, var. "Sure Cropper" (1931), during early phases of germination.

and of course retains some water. Tables I and II give the weights and percentage relations of water in the hull of germinating grains and figure 1 shows the percentage of water absorbed by this structure in comparison with its own dry weight, as exemplified by Yellow Dent.

It will be seen that a water content of 155.56% is reached in 24 hours, after which there is maintained a slightly lower but approximately stable water content throughout the period of observation. Computed as percentage of water in the germinating seeds (table II, column c) the hull at-

## TABLE I

WATER ABSORBED BY GERMINATING SEED OF CORN AND COTTON

| Plant | Time | Total | | | Parts of seed | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Embryo | | | Scutellum or cotyledon | | | Endosperm | | | Pericarp or seedcoat | | |
| | | a* | b† | c‡ | a | b | c | a | b | c | a | b | c | a | b | c |
| | hrs. | gm. | % | % | gm. | % | % | gm. | % | % | gm. | % | % | gm. | % | % |
| Corn, 1940 | 0 | 0.0575 | 12.98 | 100 | 0.0006 | 10.52 | 1.04 | 0.0041 | 9.27 | 7.13 | 0.0493 | 13.80 | 85.73 | 0.0034 | 9.67 | 5.91 |
| | 24 | 0.3185 | 64.36 | 100 | 0.0118 | 187.12 | 3.70 | 0.0747 | 143.88 | 23.45 | 0.1888 | 46.20 | 59.27 | 0.0432 | 155.43 | 13.56 |
| | 48 | 0.3577 | 76.76 | 100 | 0.0557 | 576.08 | 15.57 | 0.0705 | 148.39 | 19.70 | 0.1885 | 49.71 | 52.69 | 0.0430 | 145.09 | 12.02 |
| | 72 | 0.5608 | 132.54 | 100 | 0.2078 | 905.29 | 37.05 | 0.0917 | 205.45 | 16.35 | 0.2148 | 50.77 | 38.30 | 0.0465 | 142.34 | 8.29 |
| | 96 | 0.8383 | 228.57 | 100 | 0.4782 | 1092.74 | 57.04 | 0.1036 | 242.31 | 12.35 | 0.2203 | 86.03 | 26.27 | 0.0362 | 149.01 | 4.31 |
| Cotton, 1940 | 0 | 0.0075 | 6.91 | 100 | 0.0003 | 6.49 | 4.00 | 0.0033 | 5.29 | 44.00 | 0.0004 | 7.50 | 5.33 | 0.0036 | 9.54 | 48.00 |
| | 24 | 0.1240 | 119.87 | 100 | 0.0119 | 275.09 | 9.59 | 0.0770 | 126.12 | 62.09 | 0.0069 | 199.15 | 5.56 | 0.0299 | 83.15 | 24.11 |
| | 48 | 0.1947 | 198.55 | 100 | 0.0499 | 736.05 | 25.62 | 0.1111 | 208.83 | 57.06 | 0.0087 | 326.22 | 4.46 | 0.0299 | 82.87 | 15.35 |
| | 72 | 0.2864 | 286.88 | 100 | 0.0937 | 868.55 | 32.71 | 0.1543 | 301.37 | 53.87 | 0.0124 | 455.84 | 4.32 | 0.0286 | 80.47 | 9.98 |
| | 96 | 0.3108 | 301.14 | 100 | 0.1185 | 1067.95 | 38.12 | 0.1478 | 296.26 | 47.55 | 0.0149 | 389.66 | 4.79 | 0.0297 | 77.44 | 9.55 |
| Cotton, 1941 | 0 | 0.0123 | 12.55 | 100 | 0.0003 | 7.49 | 2.42 | 0.0080 | 15.62 | 65.04 | 0.0004 | 8.17 | 3.25 | 0.0035 | 9.48 | 28.45 |
| | 24 | 0.1226 | 115.9 | 100 | 0.0095 | 203.03 | 7.74 | 0.0726 | 124.86 | 59.21 | 0.0082 | 209.63 | 6.68 | 0.0324 | 82.92 | 26.42 |
| | 48 | 0.1561 | 147.36 | 100 | 0.0235 | 452.22 | 15.05 | 0.0939 | 160.82 | 60.15 | 0.0083 | 230.33 | 5.31 | 0.0304 | 78.79 | 19.47 |
| | 72 | 0.2669 | 256.21 | 100 | 0.0813 | 988.66 | 30.45 | 0.1428 | 276.98 | 53.50 | 0.0107 | 289.27 | 4.00 | 0.0320 | 83.24 | 11.98 |
| | 96 | 0.3323 | 320.53 | 100 | 0.1442 | 1198.64 | 43.39 | 0.1447 | 301.22 | 43.54 | 0.0136 | 308.34 | 4.09 | 0.0299 | 76.37 | 8.99 |

* a—Grams water per seed.
† b—Percentage water of part to its dry weight.
‡ c—Percentage water of part to total water in seed.

# TABLE II

WATER ABSORBED BY GERMINATING SEED OF 3 VARIETIES OF CORN

| PLANT | TIME | TOTAL | | | PARTS OF SEED | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | EMBRYO | | | SCUTELLUM OR COTYLEDON | | | ENDOSPERM | | | PERICARP OR SEEDCOAT | | |
| | | a* | b† | c‡ | a | b | c | a | b | c | a | b | c | a | b | c |
| | *hrs.* | *gm.* | % | % | *gm.* | % | % | *gm.* | % | % | *gm.* | % | % | *gm.* | % | % |
| Corn: Yellow Dent, 1940 | 0 | 0.0575 | 12.98 | 100 | 0.0006 | 10.52 | 1.04 | 0.0041 | 9.27 | 7.13 | 0.0493 | 13.80 | 85.73 | 0.0034 | 9.67 | 5.91 |
| | 24 | 0.3185 | 64.36 | 100 | 0.0118 | 187.12 | 3.70 | 0.0747 | 143.88 | 23.45 | 0.1888 | 46.20 | 59.27 | 0.0432 | 155.43 | 13.56 |
| | 48 | 0.3577 | 76.76 | 100 | 0.0557 | 576.08 | 15.57 | 0.0705 | 148.39 | 19.70 | 0.1885 | 49.71 | 52.69 | 0.0430 | 145.09 | 12.02 |
| | 72 | 0.5608 | 132.54 | 100 | 0.2078 | 905.29 | 37.05 | 0.0917 | 205.45 | 16.35 | 0.2148 | 50.77 | 38.30 | 0.0465 | 142.34 | 8.29 |
| | 96 | 0.8383 | 228.57 | 100 | 0.4782 | 1092.74 | 57.04 | 0.1036 | 242.31 | 12.35 | 0.2203 | 86.03 | 26.27 | 0.0362 | 149.01 | 4.31 |
| Corn: Sure Cropper, White Dent, 1941 | 0 | 0.0380 | 10.80 | 100 | 0.0003 | 8.51 | 0.78 | 0.0029 | 7.23 | 7.63 | 0.0333 | 11.69 | 87.63 | 0.0016 | 6.35 | 4.21 |
| | 24 | 0.3147 | 75.85 | 100 | 0.0145 | 318.57 | 4.60 | 0.0700 | 162.79 | 22.24 | 0.1981 | 58.11 | 62.94 | 0.0321 | 121.65 | 10.19 |
| | 48 | 0.3400 | 83.23 | 100 | 0.0481 | 645.21 | 14.14 | 0.0766 | 184.26 | 22.52 | 0.1837 | 55.08 | 54.02 | 0.0316 | 121.44 | 9.29 |
| | 72 | 0.4410 | 117.21 | 100 | 0.1378 | 1062.26 | 31.24 | 0.0847 | 242.21 | 19.20 | 0.1853 | 61.36 | 42.01 | 0.0333 | 126.25 | 7.55 |
| | 96 | 0.6554 | 153.54 | 100 | 0.2969 | 1112.71 | 45.30 | 0.1002 | 237.97 | 15.28 | 0.2220 | 67.21 | 33.87 | 0.0362 | 131.36 | 5.52 |
| Corn, Gehu Flint, 1941 | 0 | 0.0299 | 10.38 | 100 | 0.0002 | 5.67 | 0.66 | 0.0024 | 7.30 | 8.02 | 0.0262 | 11.29 | 86.62 | 0.0012 | 5.62 | 4.01 |
| | 24 | 0.2272 | 71.21 | 100 | 0.0165 | 374.03 | 7.26 | 0.0473 | 143.33 | 20.81 | 0.1399 | 53.34 | 61.57 | 0.0235 | 121.11 | 10.34 |
| | 48 | 0.2677 | 83.43 | 100 | 0.0529 | 717.75 | 19.76 | 0.0518 | 162.84 | 19.35 | 0.1423 | 54.07 | 53.15 | 0.0207 | 112.26 | 7.73 |
| | 72 | 0.3996 | 132.48 | 100 | 0.1691 | 1055.68 | 42.31 | 0.0610 | 182.56 | 15.26 | 0.1440 | 62.05 | 36.03 | 0.0255 | 127.22 | 6.38 |
| | 96 | 0.5366 | 178.00 | 100 | 0.2939 | 1102.80 | 54.77 | 0.0631 | 187.61 | 11.75 | 0.1560 | 70.03 | 29.07 | 0.0236 | 127.97 | 4.39 |

* a—Grams water per seed.
† b—Percentage water of part to its dry weight.
‡ c—Percentage water of part to total water in seed.

tained a maximum of 13.5%. This percentage of total seed water in the hull decreases after 24 to 48 hours, as hydration of the grain continues. The above observations apply to all varieties of corn used (table II).

The varieties of corn used show different maximum water content at saturation. In order of decreasing water content at the saturation point the varieties are Yellow Dent, "Sure Cropper," and Gehu Flint (table II, and figs. 1, 2, and 3). The dry weight of the pericarp decreased in the same order; therefore the percentage of water content is comparatively constant.

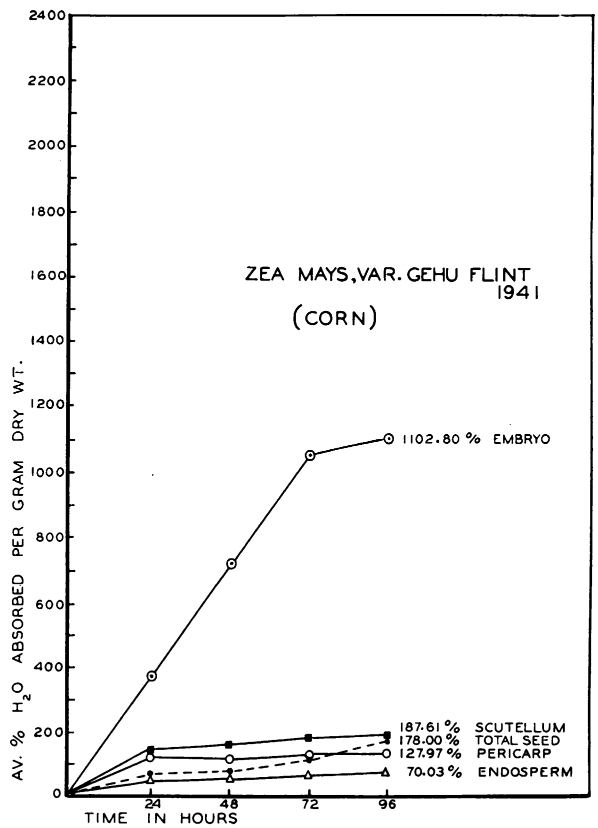


FIG. 3. Absorption of water by the various organs of *Zea mays*, var. Gehu Flint (1941), during early phases of germination.

The hull absorbs water imbibitionally to maximum hydration in 24 hours. After that, it permits the passage of water to the rest of the grain. SHULLS's measurements of the rate of water absorption (**14**) were probably made while the seed coat was becoming hydrated. His curves (fig. 1) indicate that Xanthium seeds reached the relatively stable stage after 12–18 hours. That the Gramineae behave in an essentially different manner as suggested by SHULL (**11**) in reference to the work of BROWN (**6**) is not borne out by the writer's results; however, his statement bears out the report of BROWN for the one variety *coerulescens,* of *Hordeum vulgare.*

The three varieties of corn used show very similar behavior of the hull in relation to water, the chief difference being that "Sure Cropper" and Gehu Flint reached the maximum water content at lower percentages than Yellow Dent.

It may be noted in table II that the stable water content of the hull of Yellow Dent tended to decrease after the 24-hour maximum, while that of "Sure Cropper" and Gehu Flint tended to increase slightly throughout the period of observation.

ENDOSPERM AND SCUTELLUM.—Tables I and II present data on water relations of the endosperm and scutellum during germination and figures 1, 2, and 3 show the hydration curves of the two structures.

From the data it is obvious that moderately rapid hydration of endosperm occurs in the first 24 hours, which is followed by continuous slow increase in water absorption throughout the period of observation. Maximum amount and percentage of water content were reached at the final 96-hour period for all varieties of corn. The maximum percentage of moisture was about the same as that occurring in the hull, the comparative percentages being 57, 51, and 50 for Yellow Dent, "Sure Cropper," and Gehu Flint, respectively.

The percentage of water based on the total water absorbed by the grains of corn decreased after 24 hours, owing to the absorption of the "growing parts" of the embryo.

Different varieties of corn showed different maximum percentages of water content in the endosperm at the final 96-hour period (table II, column b, and figs. 1, 2, 3). Of the three varieties tested, Yellow Dent absorbed the highest percentage of water with Gehu Flint second and "Sure Cropper" the lowest (table II, column b); but the percentage of water to the total water absorbed by the seed (table II, column c) was highest in "Sure Cropper," second in Gehu Flint, and lowest in Yellow Dent. The endosperm is a non-active mass of food materials and contains 85% or more of the total seed water in the air-dry state. This percentage decreased throughout the period of observation to 26 to 34% with the growth of the embryo. Since column a, table II, shows a slow increase in the actual amount of water present in grams in the endosperm, this decreasing relative percentage resulted from the much greater absorptive activity of the growing embryo and scutellum.

The amount of water in Gehu Flint was the lowest observed (table II, column a), and the total percentage of germination water was least in the endosperm of Yellow Dent, because of the high values of the embryo, including the scutellum. The Flint differed from the varieties of Dent studied by its lower percentage of water in the hull and endosperm.

In order to determine the storage functions of the cotyledons as compared to that of the endosperm, the data were tabulated in table IV, which shows the percentage proportions of the dry weights of the endosperm and cotyledons. The dry weights of the seed coats remained approximately constant; those of the embryos increased with growth (table IV).

# TABLE III

WATER ABSORBED BY GERMINATING SEED. COTTON: ROGERS ACALA, 1941 AND DROUGHT RESISTANT #293, 1941

| PLANT | TIME | TOTAL | | | PARTS OF SEED | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | EMBRYO | | | COTYLEDON | | | ENDOSPERM | | | SEEDCOAT | | |
| | | a* | b† | c‡ | a | b | c | a | b | c | a | b | c | a | b | c |
| | *hrs.* | *gm.* | % | % | *gm.* | % | % | *gm.* | % | % | *gm.* | % | % | *gm.* | % | % |
| Cotton: | 0 | 0.0123 | 12.55 | 100 | 0.0003 | 7.49 | 2.42 | 0.0080 | 15.62 | 65.04 | 0.0004 | 8.17 | 3.25 | 0.0035 | 9.48 | 28.45 |
| *Gossypium* | 24 | 0.1226 | 115.90 | 100 | 0.0095 | 203.03 | 7.74 | 0.0726 | 124.86 | 59.21 | 0.0082 | 209.63 | 6.68 | 0.0324 | 82.92 | 26.42 |
| *hirsutum*, | 48 | 0.1561 | 147.36 | 100 | 0.0235 | 452.22 | 15.05 | 0.0939 | 160.82 | 60.15 | 0.0083 | 230.33 | 5.31 | 0.0304 | 78.79 | 19.47 |
| var. Rogers | 72 | 0.2669 | 258.21 | 100 | 0.0813 | 988.66 | 30.45 | 0.1428 | 276.98 | 53.50 | 0.0107 | 289.27 | 4.00 | 0.0320 | 83.24 | 11.98 |
| Acala, 1941 | 96 | 0.3323 | 320.53 | 100 | 0.1442 | 1198.64 | 43.39 | 0.1447 | 301.22 | 43.54 | 0.0136 | 308.34 | 4.09 | 0.0299 | 76.37 | 8.99 |
| Cotton: | 0 | 0.0084 | 7.60 | 100 | 0.0003 | 7.59 | 3.57 | 0.0037 | 6.21 | 44.04 | 0.0003 | 5.46 | 3.57 | 0.0041 | 9.84 | 48.80 |
| *Gossypium* | 24 | 0.1193 | 108.98 | 100 | 0.0082 | 174.83 | 6.87 | 0.0724 | 118.16 | 60.68 | 0.0089 | 256.63 | 7.46 | 0.0298 | 74.42 | 24.97 |
| *hirsutum*, | 48 | 0.1382 | 131.38 | 100 | 0.0111 | 233.91 | 8.03 | 0.0831 | 144.89 | 60.13 | 0.0118 | 270.18 | 8.53 | 0.0321 | 63.12 | 23.22 |
| var. Drought | 72 | 0.1540 | 141.61 | 100 | 0.0161 | 345.03 | 10.45 | 0.0949 | 158.53 | 61.62 | 0.0121 | 294.04 | 7.85 | 0.0310 | 78.91 | 20.12 |
| Resistant (#293) 1941 | 96 | 0.1863 | 169.04 | 100 | 0.0295 | 557.49 | 15.83 | 0.1109 | 181.66 | 59.52 | 0.0125 | 302.49 | 6.70 | 0.0334 | 84.05 | 17.92 |

* a—Grams water per seed.
† b—Percentage water of part to its dry weight.
‡ c—Percentage water of part to total water in seed.

## TABLE IV

RELATION OF SEED ORGANS TO TOTAL DRY SEED

| NAME | TOTAL DRY WEIGHT OF SEED | EMBRYO | | | COTYLEDONS OR SCUTELLUM | | | ENDOSPERM | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | DRY WT. | % OF TOTAL DRY SEED | % OF GAIN IN DRY WT. AT 96 HRS. | DRY WT. | % OF TOTAL DRY SEED | % LOSS IN DRY WT. AT 96 HRS. | DRY WT. | % OF TOTAL DRY SEED | % LOSS IN AIR DRY SEED AT 96 HRS. |
| | *gm.* | *gm.* | % | % | *gm.* | % | % | *gm.* | % | % |
| Yellow Dent Corn | 8.8516 | 0.1160 | 1.31 | 654.40 | 0.8893 | 10.04 | 3.83 | 7.1491 | 80.77 | 28.38 |
| Sure Cropper Corn | 7.0298 | 0.0669 | 0.95 | 697.40 | 0.7896 | 11.23 | 0.00 | 5.1973 | 73.93 | 0.00 |
| Gehu Flint Corn | 5.7568 | 0.0605 | 1.06 | 766.60 | 0.6464 | 11.22 | 0.00 | 4.6450 | 80.68 | 3.99 |
| Rogers Acala Cotton, 1940 | 2.1622 | 0.0885 | 4.09 | 150.60 | 1.2295 | 56.80 | 18.77 | 0.0946 | 4.37 | 29.50 |
| Rogers Acala Cotton, 1941 | 1.9532 | 0.0874 | 4.50 | 170.90 | 1.0253 | 52.49 | 6.02 | 0.1027 | 5.25 | 28.20 |
| Drought Resistant cotton, 1941 | 2.2048 | 0.0855 | 3.80 | 22.30 | 1.1791 | 53.47 | 0.00 | 0.1037 | 4.70 | 20.04 |

The endosperm decreased in dry weight during the observation period; 28% in Yellow Dent and 4% in Gehu Flint. No reduction was found in "Sure Cropper," probably because the loss in weight was small and obscured by variation due to the method used.

In summary, the results obtained in these experiments show that the endosperm of "Sure Cropper" and Gehu Flint exhibit a small decrease in dry weight during the period of observation, Yellow Dent showing the greater decrease. In comparison to this, the decrease in dry weight of the scutellum appears low; it is obviously only a secondary storage organ. No

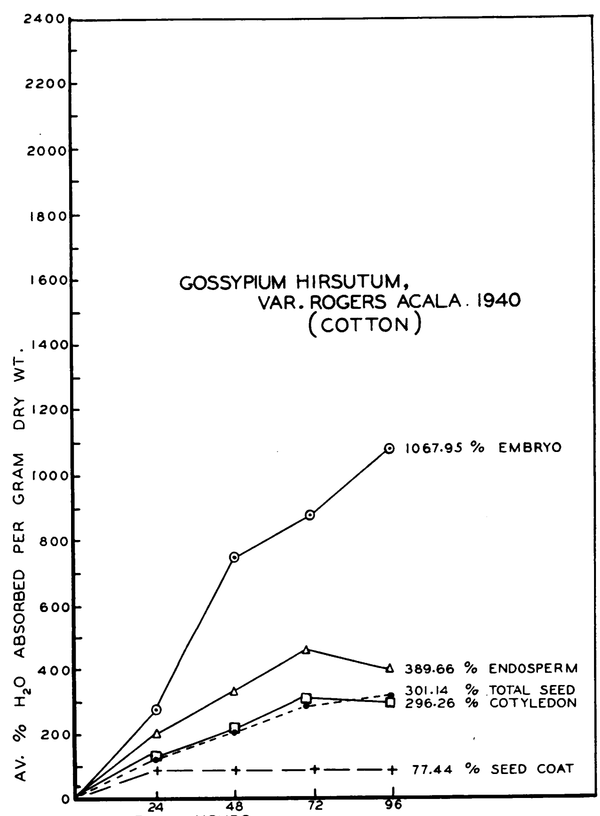


FIG. 4. Absorption of water by the various organs of the seed of *Gossypium hirsutum* var. Rogers Acala (1940), during the early phases of germination.

varietal differences in the corn used are obvious, other than that to be expected from the greater rate of activity of the embryo of Yellow Dent.

The large endosperm acts not only as a food supply but also as a reservoir for absorbed water; the scutellum also contains a considerable amount of water, approximating that found in other parts of the embryo.

THE EMBRYO.—For the study of the "growing parts" of the embryo behavior in relation to germination water, the same varieties of corn and cotton were used as for the study of seed and fruit coats, and "food storage" organs. The results are recorded in tables I, II, and III, and in the curves of figures 1 to 6. Tables I and II give the weights and percentage relations of water in the "growing parts" of the embryo of germinating kernels of corn, and the curve in figure 1 shows the percentage of germination water absorbed by this structure, as exemplified by the variety Yellow Dent.

It will be seen that a high percentage of water is absorbed in the first 24 hours, after which there is maintained a continuous high rate of absorption throughout the period of observation (table I, column b, and fig. 1). This percentage of moisture content is higher than that of any other part of the kernel. The percentage of total seed water in the "growing parts" of the embryo increases throughout germination, until a maximum is reached at the final reading (table II, column c). The amount of water in the grains also increases throughout germination (table II, column a).

The dry weight of the embryo is less than 2% of the total dry weight of the seed. This increased during germination.

The observations here recorded are true for all varieties of corn tested (table II).

The varieties of corn do differ, however, in their capacity for early absorption of water. This is shown by the fact that "Sure Cropper" absorbed the highest percentage, Gehu Flint second, and Yellow Dent the lowest in the first 24 hours (table II, column b, and figs. 1, 2, 3). The final reading shows less difference in the maximum percentage of water content for the three varieties; all three are very high.

The rate of absorption and percentage of total seed water in the "growing parts" of the embryo were different for the different varieties (table II, column c), the maximum being reached at the final reading. Of the three varieties tested, Yellow Dent absorbed the highest percentage of the total-germination water, Gehu Flint second highest, and "Sure Cropper" least.

The "growing parts" of the embryo is of course the growing part of the grain. This is evidenced by the consistent increase in the dry weight of the embryo during germination, and the increase in size and rapid increase in amount and percentage of water in proportion to other parts of the seed. Although the growth of the embryo is partly due to an increase of absorbed materials at the expense of stored food, much of the increase in size is due to hydration, as shown by the data (tables I and II, columns a, b, c).

The growing part of the embryos of all varieties reached similar water content at the final 96-hour reading. In the air-dry grains, this organ of all varieties contained a very small proportion of the seed moisture (1% or less), compared to that of the endosperm (85% or more), as shown in table II, column c.

Varietal differences appear in the air-dry water content, which was high (10.52%) in Yellow Dent, and low (5.67%) in Gehu Flint. In rate of water absorption, the "growing parts" of the embryo of Gehu Flint reached a water content of 374.4% in 24 hours, while in Yellow Dent the water content was 187.12%. "Sure Cropper" White Dent showed intermediate values.

While the "growing parts" of the embryo reached a final water content which was similar in all varieties tested, that of Gehu Flint may be considered to show a comparative adaptation to germination in dry land conditions. This was shown by its rapid initial absorption of water.

## Cotton

Seed coat.—Tables I and III give weights and percentage relations of water in the seed coats of cotton and figure 4 shows the typical hydration curves as found in the seed coats of Rogers Acala cotton seeds.

These data show that, as in corn, maximum hydration occurs in 24 hours and approximate stability is thereafter retained. It is striking that complete hydration is reached in the seed coats of cotton at about 80% water content, compared with 155% in corn. Column c, tables I and III, shows that the percentage of the total seed water contained in the seed coats is greater in the air-dry condition than at any succeeding period in germination. This was not true in corn. The seed coats of cotton are obviously more hygroscopic than the hull of corn, or than any organ in either corn or cotton except the food supply. Air-dry seeds of cotton thus contain a considerable portion of their water content in the seed coat. Progressive decrease in percentage of germination water in the seed coat in the course of the hydration of the inner seed, appears as in corn.

All varieties used behaved similarly (table III), but small varietal differences appear in Drought Resistant #293, in which the seed coat reached its maximum hydration only at 96 hours, and thus maintained a higher percentage of germination-water (table III, column c, and fig. 6). The seed coats in this variety are obviously more hygroscopic than is the case in Rogers Acala.

A year of storage under laboratory conditions showed mainly the progressive drying of the "growing parts" of the embryo. The higher proportional percentage of water in seed coats of air-dry seeds of the 1940 cotton (table I, column c and curves of fig. 4), obviously resulted from this slight drying out of the endosperm and of the "growing parts" of the embryo during storage and from the marked desiccation of the cotyledons as compared to the constant water content exhibited by the seed coats. Thus, table I shows that during a year's storage the endosperm and "growing parts" of the embryo decrease in water content 1% or less, while the cotyledons decreased from 15.62 to 6.29%

Cotyledons and endosperm.—Tables I and III give the data on the behavior of the food storage tissues of cotton seeds and figure 5 shows the curves for percentage of water content for variety Rogers Acala, 1941. This food is stored in the cotyledons and small portions of the endosperm. The plotted data for Rogers Acala and Drought Resistant #293 are shown in figures 5 and 6.

The amount of water absorbed, expressed as percentage of water content, (table III, column b) was large the first 24 hours in both cotyledons and endosperm, and in both cases continued to increase rapidly throughout the period of observation.

As in the endosperm of corn, the final amount (column a) and percentage value (column b) was highest at the final 96-hour reading; although the absolute amount of water per seed was considerably less than that observed in the endosperm of corn, the percentage was very much greater (column b).

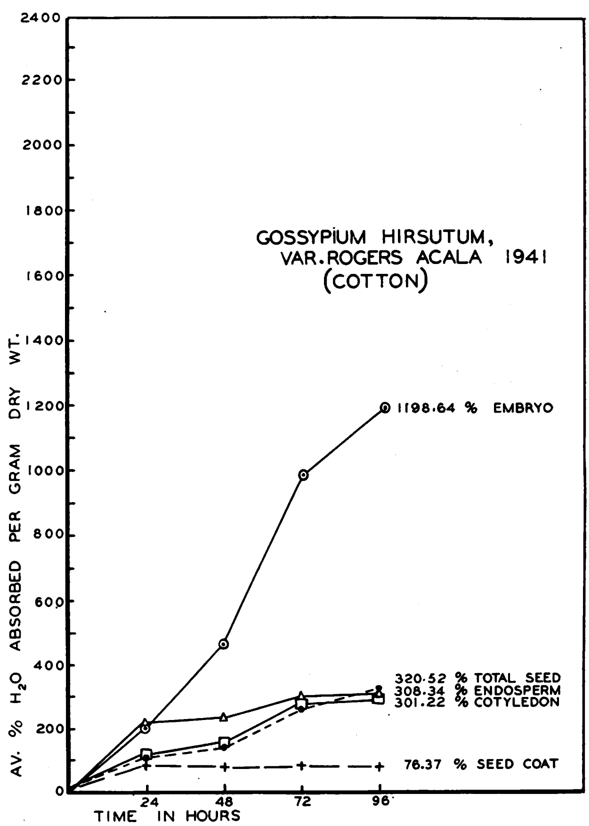


FIG. 5. Absorption of water by the various organs of the seed of *G. hirsutum* var. Rogers Acala (1941), during the early phases of germination.

The proportion of total-germination water held in the cotyledons of cotton was similar to that held in the endosperm of corn, but less variable. The proportion of the total germination water, as in other parts not actively growing, reached a maximum at the 24-hour period, and decreased slightly thereafter. The data show that in Rogers Acala the stored food supply in the cotyledons absorbed a larger quantity and a greater percentage of their own dry weight, and of the total amount of germination-water, than in variety Drought Resistant #293.

The stored food in cotton seeds, although contained chiefly in the cotyledons instead of in the endosperm as in corn, behaved similarly in showing continuous hydration in 96 hours. These cotyledons differ from the endosperm of corn in absorbing larger amounts of water. Tables I and III, and figures 4, 5, and 6 show that the endosperm of cotton absorbs water very rapidly in the first 24 hours, 300 and 257% respectively, for Rogers Acala, and Drought Resistant #293, as compared to corn 48, 199, and 209% in Yellow Dent, "Sure Cropper," and Gehu Flint, respectively. It continues to absorb water slowly throughout the observation period, reaching a maximum of 308% in Rogers Acala and 302% in Drought Resistant #293 at the final reading.

The percentage proportions of water in the seed increased at first and then decreased (column c), due to growth of the embryo. The dry weight of endosperm of cotton is about 5% of the total dry weight of the seed, while that of corn is about 80% (table IV). In spite of its small size in comparison to corn, this substance is initially more rapid in its absorption of water than is the endosperm of corn. The dry weight of the endosperm decreases very slightly throughout germination because of the rapid initial and slow continuous water absorption of the endosperm. In spite of its very small mass in comparison with other seeds used, it is obvious that cotton endosperm is an effective water absorbing and distributing agency; chemical tests and slight decrease in the weight of this structure during germination indicate that it serves only secondarily as a food storage organ.

From the results obtained it is obvious that the cotyledons of cotton are primarily food storage organs, and the scant endosperm is primarily a water absorbing substance.

THE EMBRYO.—Data on the "growing parts" of the embryo of cotton in relation to germination water are tabulated in tables I and III, and the percentage of water content absorbed is shown in figure 5 for Rogers Acala, 1941.

It is obvious that a high percentage of water is absorbed in the first 24-hour period of germination, after which there is a continuous high rate of absorption throughout germination (table I, column b). The percentage water content of the embryo was higher than that of any other part of the seed.

The percentage of total seed water absorbed by the "growing parts" of the embryo increased throughout germination until a maximum was reached at the final 96-hour period of observation (table I, column c). The amount of water in grams also increased throughout the period of observation (column a).

The dry weight of the "growing parts" of the embryo was between 3 and 5% of the total dry weight of the seed, that of the corn being less than than 2%. The dry weight of this growing part of the cotton seed increased during germination.

These observations hold for both varieties of cotton tested (Rogers Acala, and Drought Resistant #293), as shown in table I and III, columns a, b, and c, and figures 4, 5, and 6.

The two varieties, however, showed different capacities for absorption of water during the first 24 hours (table III), the percentage of water content being more comparable to that of Yellow Dent corn than to the other varieties of corn tested. Rogers Acala absorbed a higher percentage than Drought Resistant (table III, column b). The final observation showed a great difference in the maximum percentage of water content for the two

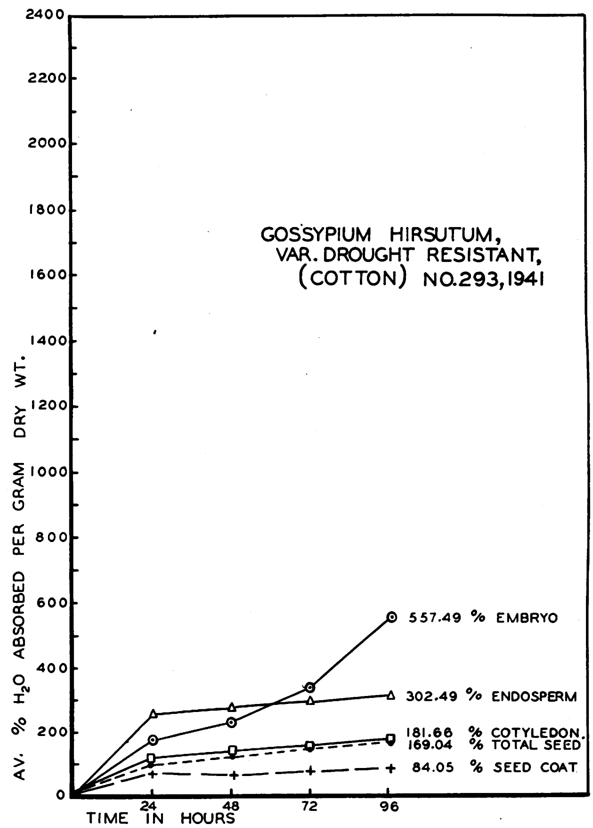


FIG. 6. Absorption of water by the various organs of the seed of *G. hirsutum* var. Drought Resistant #293 (1941), during the early phases of germination.

varieties, but both reached a high level in proportion to other parts of the seed. This high percentage of water content absorbed by Rogers Acala is similar to that of all varieties of corn.

The rate and percentage of total seed water in the "growing parts" of the embryo were different for the two varieties used (table III, column c), their highest values being reached at the final reading. Rogers Acala absorbed the higher percentage of total germination water, this final high percentage being more like that of the varieties of corn studied.

The "growing parts" of the embryo of cotton seed, like that of corn, are the growing portion of the seed. This is evidenced by the consistent increase in the dry weight during germination, as well as by the increase in size and rapid increase in amount and percentage of water as compared with other parts of the seed. Also, like that of corn, the growth of the "growing parts" of the embryo is partly an increase in materials at the expense of the stored food, even though much of the increase in size is due to hydration, as shown by data in tables I and III, columns a, b, and c. The "growing parts" of the embryo of both varieties of cotton increased in size noticeably through hydration.

Even though the "growing parts" of the embryo of both varieties reached a high percentage of water content at the final reading in proportion to that of other parts of the seed, that of Rogers Acala absorbed more than twice as much as did that of Drought Resistant #293. This high maximum was preceded by a higher rate of water absorption in Rogers Acala than in Drought Resistant. In the air-dry seed, the "growing parts" of the embryo of both varieties contained a small proportion of the seed moisture (less than 4%) which was similar to that of the endosperm. The cotyledons and seed coats contained a much higher percentage in both the varieties. The percentage of moisture in the air-dry embryo of corn is less than 1% (table II, column c).

The percentage of water content in the embryos of the air-dry seed is almost the same for the two verieties of cotton (table II, column b) and most comparable to that of "Sure Cropper" corn. In Rogers Acala, the "growing parts" of the embryo reached 203.03% water content in the first 24 hours, compared to 174.83% for the same tissues of Drought Resistant. These values are most similar to that of the "growing parts" of the embryo of Yellow Dent corn (table II, column b).

While the growing embryo has reached a final percentage of water content which was different in the two varieties, Rogers Acala shows adaptation to dry land conditions by absorbing water rapidly the first 24 hours, and by continuing this rapid rate of absorption during germination; and Drought Resistant #293 shows adaptation by not requiring as great a quantity of water for germination. The comparatively low percentage of initial water absorption by Drought Resistant #293 may be due to a low capacity for absorbing water; the comparatively low maximum percentage of water content reached at the final reading may be due either to low absorbing power, or to a slow rate of absorption which causes the embryo to fail to reach its maximum equilibrium value at the final reading.

## Summary and conclusions

This is a report on the germination water relations of three varieties of corn (Yellow Dent, Sure Cropper White Dent, and Gehu Flint), and two varieties of cotton, *Gossypium hirsutum* var. Rogers Acala, for 1940 and 1941; and var. Drought Resistant #293. The conclusions reached are as follows:

1. The seeds tested differ in percentage of initial 24-hour water intake and in percentage of final 96-hour water absorption. Rogers Acala cotton, 1940, absorbed 119.87% in the first 24 hours; same var., 1941, 115.90%; and var. Drought Resistant #293, 108.98%; Sure Cropper corn, 75.85%; Gehu Flint corn, 71.21%; and Yellow Dent corn, 64.36%. They are listed in a descending order of absorption rate, for the first 24 hours.

The total water absorption at the final 96-hour period of observation is for Rogers Acala cotton, 1941, 320.53%; same var., 1940, 301.14%; Yellow Dent corn, 228.57%; Gehu Flint corn, 178%; Drought Resistant #293 cotton, 169.04%; and Sure Cropper corn, 153.54%. It is obvious from these figures that not all seeds require the same percentage of water for germination.

2. Each part of the seed plays one or more roles in seed germination:

(a) The seed coats of all seeds behave similarly in that they absorb water quickly until an approximate saturation level is reached, and this saturation level is approximately maintained thereafter. The percentage of total seed moisture in these organs decreases after the saturation level is reached to the final 96-hour period of observation. This indicates that the seed coats serve as transporting agents for water from the external water supply to the internal parts of the seed. The seed coats absorb water passively by hygroscopic and imbibitional processes. Seed coats of different seeds have different hygroscopic and imbibitional absorption capacities throughout germination. These capacities are partly due to morphological differences of the seed coats, and partly to the activity of internal seed parts in rate and percentage of water absorption.

(b) The endosperm of the seeds of the three varieties of corn serves as a reservoir of primary importance for both food and water. The endosperm of the seeds of *Gossypium hirsutum* serves primarily as a water reservoir and only secondarily for food storage, the great power of absorption and storage of water in these seeds being due to the hydrophilic colloidal nature of the endosperm in comparison to that of other seeds.

(c) Not all cotyledons perform the same function. The scutellum (cotyledon) of the three varieties of corn digests starch into sugar and transports it and water from the endosperm to the "growing parts" of the embryo. The cotyledons of the seeds of *Gossypium hirsutum* var. Rogers Acala (both 1940 and 1941 crops), and of *G. hirsutum* var. Drought Resistant, are reservoirs of primary importance for both soluble food and water, and they transport both to the "growing parts" of the embryo to be used in growth.

(d) The axis of all seed used is the "growing parts" of the seed. This is evidenced by the consistent increase in the dry weight of the growing portion of the embryo, the amount of water absorbed, and the increase in total percentage of seed moisture throughout germination. It is further evidenced by the fact that the embryos of all seeds tested attained the highest maximum percentage of any seed organ at the final 96-hour period of observation.

3. Apparently seeds exist with mesic, hydric, or xeric germination adaptations or tendencies thereto.

Seeds of Rogers Acala cotton (both 1940 and 1941 crops), of Yellow Dent and "Sure Cropper" corn are adjusted to germination in mesic habitat.

Seeds of Drought Resistant cotton are adapted to germination in very dry land, or xeric habitat of temporary water after a rain.

Seeds of Gehu Flint corn are adapted to germination in dry-land conditions, tending toward xeric conditions.

4. Such adaptations of seeds for germination in mesic, hydric, or xeric conditions are evident in germination in the water requirements of the "growing parts" of the embryo, and in the imbibitional capacity of the cotyledons and endosperm to absorb and store water for use by the "growing parts" of the embryo as needed.

5. Varietal differences appear in the germination-water requirements of seeds of the three varieties of *Zea mays* and the two varieties of *Gossypium hirsutum*.

(a) The chief varietal difference in kernels of *Zea mays* lies in the different capacities of the embryos for early absorption of water. The embryo of Gehu Flint corn absorbs the highest percentage (374.03), that of "Sure Cropper" the second highest (318.57), and that of Yellow Dent the lowest (187.12) during the initial 24-hour period of germination. The final percentage of germination-water shows less difference.

(b) The chief varietal differences in the two varieties of cotton seed used apparently lie in the germination-water requirement of the embryo, the capacity rate of water absorption by the endosperm, the hygroscopicity of the seed coats, and the percentage of final germination-water absorbed by the seeds.

The embryo and seed of Drought Resistant cotton require about half the percentage of water required by Rogers Acala, 1941. Thus, a low percentage of water in the embryo of Drought Resistant cotton, the rapid initial and extended absorption of water, and the high percentage of water in the endosperm of this variety of cotton adapt this seed to germination in dry-land conditions; the seed of Rogers Acala, requiring twice as much water, is adapted to germination under more mesic conditions.

This investigation further indicates that various seeds do differ in the total amount of water absorption and the rate of its absorption; that different organs of the seed play different roles in the process of germination; that seeds apparently possess degrees of mesic, hydric, and xeric adaptations in germination; and that varietal differences appear in water absorbing capacity of seeds of the several varieties of corn and cotton tested.

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