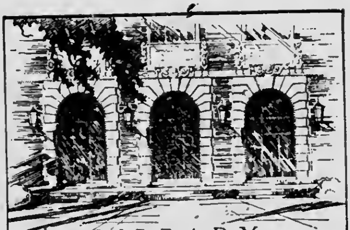

EXPERIMENTS IN

ARTIFICIAL DRYING OF SWEET CORN SEED

BY W. A. HUELSEN AND W. N. BROWN

BULLETIN 656

NIVERSITY OF ILLINOIS
GRICULTURAL EXPERIMENT STATION

CONTENTS

Urbana, Illinois April, 1960

Publications in the Bulletin series report the results of investigations made or sponsored by the Experiment Station

Artificial Drying of Sweet Corn Seed

By W. A. HUELSEN and W. N. BROWN[a]

ARTIFICIAL DRYING OF MANY CROPS is now recognized as the safest method for reducing moisture content to the point where prolonged storage is possible. Many available publications deal with both the physical and biological aspects of the problem. Hay, small grains, and field corn are dried in Illinois. Dryers for corn are probably the most numerous because every seed-corn grower regards artificial drying as an essential part of his operations.

Artificial drying of sweet-corn seed is absolutely necessary. After the roasting-ear stage, the rate of deterioration due to insects, birds, and microorganisms is much more severe than in field corn. During the early days of sweet-corn seed production in Connecticut, maturity was hastened in the field by breaking off the stalks above the ears and loosening the husks. If the ears were still too wet when harvested, they were placed in racks or trays in well-ventilated barns. Artificial heat was used to some extent, and occasionally fans circulated the air.

Because of high prices for sweet-corn seed, many Illinois canners raised their own seed until hybrids came into general use (1930-1940). Some canners left their crops in the field as long as possible, and then spread the ears to dry on the slatted floors of their husker sheds. Others placed the ears in racks hung in the warehouse. In some cases, stoves were used to provide heat. This system was slow and costly because the individual germination of each ear had to be tested in order to produce top-quality seed. Yields of finished shelled corn ready for planting seldom exceeded 400 pounds per acre.

The first dryer in Illinois capable of rapidly drying sweet-corn seed was designed by the senior author of this publication. This dryer, consisting of a well-constructed, long, narrow machine shed with wide doors at each end, was erected in 1924 at the Gibson Canning Company plant (now Stokely-Van Camp, Inc.) in Gibson City, Illinois. Steam coils were placed at one end of the shed, and several exhaust fans at the other end. The ears were placed in racks constructed from 3- by 3-inch, welded, concrete reinforcement mat nailed to 2×4 frames. This mat provided pigeon holes, each of which was sufficiently large for a single ear.

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Corn with moisture as high as 40 percent could be dried in as little as four days. Since the crop could be harvested earlier, deterioration was reduced, and yields were doubled or tripled. Even more important was the discovery that contamination from microorganisms was drastically reduced, and therefore individual ear testing was unnecessary. A second dryer of the same general type was constructed at Rochelle, Illinois, in 1927. This dryer is still in operation.

Between 1930 and 1940, sweet-corn hybrids came into wide use. Because of the highly favorable growing conditions in southwestern Idaho, about 90 percent of the seed production shifted to that area, where it still remains. The rainfall there totals 8 to 9 inches annually, and the growing season is practically free of all precipitation. All crops have to be irrigated. Many of the early maturing hybrids can be grown to full maturity in the field, but the midseason and late types require artificial drying.

At first, Idaho seedsmen believed that artificial drying was not necessary in their arid climate; but they discovered that the short growing season and the cool nights during late summer slowed down drying to such an extent that germination often suffered because of frost damage. By 1940 all of the Idaho producers had some kind of a corn dryer. Most of these dryers were inefficient; others were complete failures. In either event, the quality of the seed suffered. And since practically all of the fresh-market sweet-corn acreage and most of the canning acreage is planted with Idaho-grown seed, the problem is of primary importance to Illinois growers and canners. In addition, the Illinois Station is engaged in an extensive sweet-corn breeding project, and seed of all released inbreds and hybrids must be grown in Idaho.

TYPES OF DRYERS AND THEIR EFFICIENCY

All of the early dryers were of the bin type or some modification of the bin type, similar to those used in Illinois for drying hybrid field corn. They were engineered according to the standards used for field corn, but it was soon found that the drying rate was slow and uneven. More fan and heat capacity were needed because sweet-corn hybrids are single crosses, and the seed to be dried consists of small inbred ears that pack much more closely in the bin than double-crossed field corn. In addition, sweet corn is more "trashy" than field corn. Silks, husks, and shelled corn packed the interstices between the ears, and considerable static pressure was needed to force the heated air through the usual 8-foot depth of ears in the bins.

Before the project was started, recording instruments were set up in 1944 in a typical drying bin of that period belonging to the Crookham Company, Caldwell, Idaho. (These bins were fully modernized later.) Careful records were kept throughout the 1944 drying season. The bin was usually filled to a depth of 8 feet. During the season, 11 runs were made with different hybrids having a wide range of initial moistures. A condensed summary of the data appears in Table 1.

The drying rates of all of the hybrids except one (#1650) were slower than desirable. An efficient dryer should dry sweet corn from 50-percent to 12-percent kernel moisture, wet basis, in 72 hours — a total loss of 0.864 parts of moisture, or 0.012 parts per hour, dry basis. The various lots were planted in flats filled with sterilized soil. Each flat was planted with two checks. The corn was germinated at 80° F., and the data on germination and seedling green weights in Table 1 are the averages of five replications. The controls were Country Gentleman 8×6 for the white hybrids and Golden Cross for the yellow hybrids. The Penicillium and Fusarium readings were taken on 100-kernel samples surface sterilized prior to testing.

The germinations of all but two lots were 90 percent or above, but the growth, as determined by green weights per seedling cut off at ground level, was below the checks. Penicillium infection was above 10 percent in all but two lots, indicating that the ears had become moldy during the drying run. The temperatures shown in Table 2, which are typical of the performance of the bin when the other lots were dried, indicate why the ears could become moldy. These temperatures were recorded by Foxboro recording thermographs. The three instruments located in the corn had extended bulbs 25 feet long; and since the ears were in contact with the bulbs, the temperature readings might be regarded as modified wet-bulb. Only the readings for every twelfth hour were abstracted from the continuous thermograph charts and entered in Table 2.

Since the heating system was overloaded, it was unable to maintain 100° F. at night. The ears in the center of the bin did not reach 80° F. until more than 70 hours had elapsed, and the ears at the top of the bin did not reach 80° F. until 94 hours had elapsed. This slow heating accounted for the long drying period, the relatively weak seedling growth, and the high percentage of Penicillium infection. Other lots listed in Table 1 dried at an even slower rate. Since the air direction was reversed during the run, however, it could not be determined how rapidly corn at the exhaust end of the bin would heat up.

Table 1. — Drying Data of Eleven Successive Runs of Various Sweet-Corn Hybrids in the Same Bin of a Commercial Dryer Located in Idaho, 1944[a]

Lot number	Variety	Percent moisture, wet basis		Hours in dryer	Percent moisture loss per hour, wet basis	Percent germination		Green weight per seedling (grams)		Percent kernels with internal infection		Growth in greenhouse
		When entering dryer	When removed from dryer			Variety	Check	Variety	Check	Penicillium	Fusarium	
1672	Evergreen (14×11)×13.	48.8	9.2	147	.27	99	96	.51	.69	24	0	fair
1674	Evergreen (14×11)×13.	46.4	13.2	151	.22	91	96	.47	.69	14	3	weak
1728	Country Gentleman.....	40.4	13.8	95.5	.28	91	93	.32	.67	28	1	very weak
1698	Early Evergreen.........	39.0	11.4	187	.15[b]	92	96	.58	.69	24	7	fair
1706	Stowell's Evergreen.....	38.0	12.4	95	.27	92	93	.50	.67	22	1	weak
1669	Evergreen (14×11)×13.	36.0	12.4	121	.20	90	96	.43	.69	17	0	very weak
1727	Country Gentleman.....	30.4	13.8	93	.18	95	93	.41	.67	5	0	very weak
1699	Early Evergreen.........	28.6	12.0	85	.20	88	93	.62	.67	34	4	good
1650	(14×13)×Evergreen 20.	28.4	13.8	38.5	.38	93	94	.51	.66	27	3	fair
1659	Evergreen 14×11.......	22.8	11.2	78.5	.15	88	94	.42	.66	25	3	weak
1433	Golden Cross...........	40.8	10.2	135.5	.23	90	92	.47	.44	10	2	good

[a] Germination and growth tests are averages of 5 replications, and the controls were Country Gentleman 8×6 for white hybrids and Golden Cross for yellow hybrids. All tests were run in sterilized soil under a controlled temperature of 80° F.
[b] Additional corn added 20.5 hours after start of experiment.

Table 2. — Temperatures of Lot #1672 (Evergreen (14×11)×13) During Drying Run in a Commercial Dryer Located in Idaho
(Air flow maintained at continuous updraft)

Elapsed hours starting at 1:00 p.m.	Recorded temperatures (° F.)			
	Entering air	Part of bin		
		Bottom	Center	Top
0 (day)	100	66	53	56
12 (night)	93	76	69	65
24 (day)	102	80	73	67
36 (night)	97	76	70	66
48 (day)	102	82	76	69
60 (night)	96	82	78	72
72 (day)	102	86	82	75
84 (night)	99	86	84	79
96 (day)	100	87	86	81
108 (night)	96	86	85	82
120 (day)	101	89	89	87
132 (night)	96	86	86	86
144 (day)	100	90	84	84
147 (night)	100	90	85	80

These preliminary experiments indicated that it was necessary to increase the drying rate in order to improve germination. However, the possible effect of speeding up the drying rate was still to be determined. It was believed that if the drying rate were speeded up too much the kernels would "case harden," a phenomenon familiar to fruit dehydrators that occurs (2)[a] when the "surface evaporation from tissues exceeds the rate of moisture diffusion to the surface and the surface becomes dry and hard and seals in the moisture."

There was also little information about the optimum temperature of drying. Huelsen (3) dried sweet corn in a small dryer equipped with forced-air circulation at 98.6°, 109.4°, and 116.6° F. Corn with an initial moisture content of 69 percent germinated poorly; but in corn with 44.2 percent moisture, germination and seedling growth were generally equal to or better than the field-cured checks. Huelsen concluded that the factors affecting germination were initial moisture content of the kernels; drying temperature; and length of drying period. Increases in one or more of these factors with relation to the others had a progressively injurious effect on germination.

Wileman and Ullstrup (14) concluded that field corn with an initial moisture content above 25 percent should not be dried in air temperatures above 110° F. Below 25-percent moisture, a drying temperature of 120° F. was considered safe, although certain lots dried at 100° and 110° F. germinated poorly.

[a] This number and similar numbers in parentheses refer to "Literature Cited" on pages 47 and 48.

During World War II, there was tremendous activity in dehydration of food items, but the large number of publications that appeared on the subject were not applicable to seed drying. The general objectives of the experiments discussed in this bulletin were to find out how to dry sweet-corn seed with little or no injury by circulating heated air. The experiments were planned to study the effects of the following: (a) initial moistures (maturity); (b) length of drying period (drying rates); (c) drying temperatures; (d) kernel-cob moisture relationships; (e) variety of sweet corn; (f) air velocity; (g) phase drying — starting at one temperature and finishing at a lower temperature; (h) rates of moisture loss from kernels and cobs; and (i) actual kernel temperatures.

Except for increased heat and fan capacity, bin dryers have changed little in construction since they were first built. For this reason, the results of the experiments reported here, although conducted from 1945 to 1950, are still valid. The present trend in dryer construction seems to be equally divided between bin and tunnel dryers. The construction and operation of the tunnel dryer will be discussed later.

DRYING EQUIPMENT

Preliminary experiments in 1945 consisted of two drying runs with hybrid Country Gentleman Illinois 13. The bin dryer consisted of four bins, each equipped with six trays. Each tray held 2 bushels of ear corn spread 4 inches deep. The air flow was reversible, but only the temperature in the supply plenum could be controlled. Attempts were made to run each bin at a different temperature by introducing cold air through a trapdoor in the bin doors. This plan was unsatisfactory, and a small pilot dryer was built.

The pilot dryer consisted of four bins constructed as a single unit. Each bin was complete in itself, with its own heating unit, fan, and controls, so that it could be operated independently of any of the other bins. The bins were built in the basement of a laboratory building where the ambient temperatures ranged from 70° to 85° F. Under these conditions, the dryer could be operated at temperatures as high as 140° F. at maximum air velocity.

The heating unit for each bin consisted of an Aerofin Flexitube booster coil with a nominal tube length of 18 inches and a face area of 1.06 square feet. Heat was supplied by a special 7.5-hp. steam boiler with sufficient capacity to operate all four bins simultaneously at 140° F. when the boiler pressure was 2.5 p.s.i. All of the controls were the modulated type manufactured by Minneapolis-Honeywell. The boiler was equipped with a pressure control, and the bin temperatures were controlled by a modulated system consisting of a potentiometer-type temperature control that operated a motorized valve on the steam intake to the heating coils. Thus temperatures could be controlled independently of the ventilating system (Fig. 1).

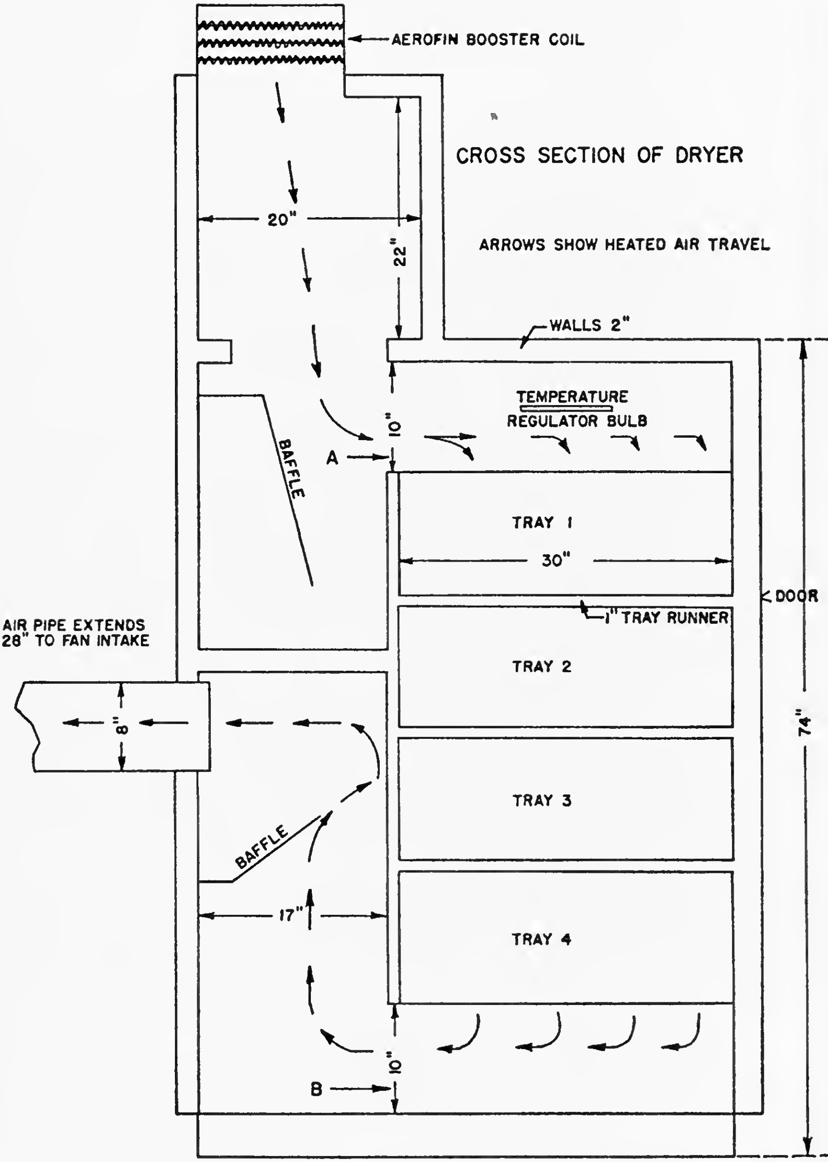
Ventilation was provided by a Buffalo direct-connected "baby vent" set, size E, with a 7¾-inch wheel and a ¼-h.p., 1,750 r.p.m. motor. The fan had a nominal rating of 690 c.f.m. against ¾-inch static pressure. This was a suction system — the fans created a slight vacuum (Fig. 1) that promoted drying. Conversely, a blower system that creates static pressure within a dryer tends to inhibit drying. Drying depends on the vapor concentration at the surface of the material to be dried; and heat, air velocity, and a vacuum, singly or in combination, promote the rate of moisture loss (9).

The air flow was regulated by means of a check damper located between the dryer and the exhaust fan. In addition, shut-off dampers were installed in each of the four exhaust stacks on the discharge side of the fans.

Each bin was equipped with four trays 9½ inches deep (Fig. 2). These trays were loaded to capacity at the start of each run. Thus the bin contained 38 inches of ear corn when first loaded. Although solid loading would have been preferable, it was impractical because of the numerous moisture samples taken during each run.

Temperatures were recorded by means of a 12-station Brown strip-chart recording potentiometer connected to a special rotary drum switch by means of 16-gauge iron-constantan wires. The drum switch was directly connected to a furnace check-draft motor that rotated exactly 180 degrees each time electrical contact was made. This motor was controlled by a General Electric time switch that changed from one set of 12 thermocouples to a second set every 30 minutes.

The thermocouples were made of 30-gauge duplex extruded nylon insulated iron-constantan wire that was just long enough to reach from the couple to the rotary switch. Pflug, Nicholas, and Butchbaker (10) have shown that this type of insulation is not waterproof, and that long leads of No. 24 duplex copper-constantan wire immersed in water will lead to gross errors in thermocouple readings. It is doubtful whether such errors occurred in these experiments. The vapor pressure of the air never reached 100 percent, and the longest lead of 30-gauge wire measured only 10 feet to the rotary switch. Beyond the rotary switch, 16-gauge rubber insulated wire was used, and the vapor pressures to which it was exposed were always low.



Cross-section of one of the four dryers used in drying sweet-corn seed. In a commercial installation, probably no trays would be used. (Fig. 1)

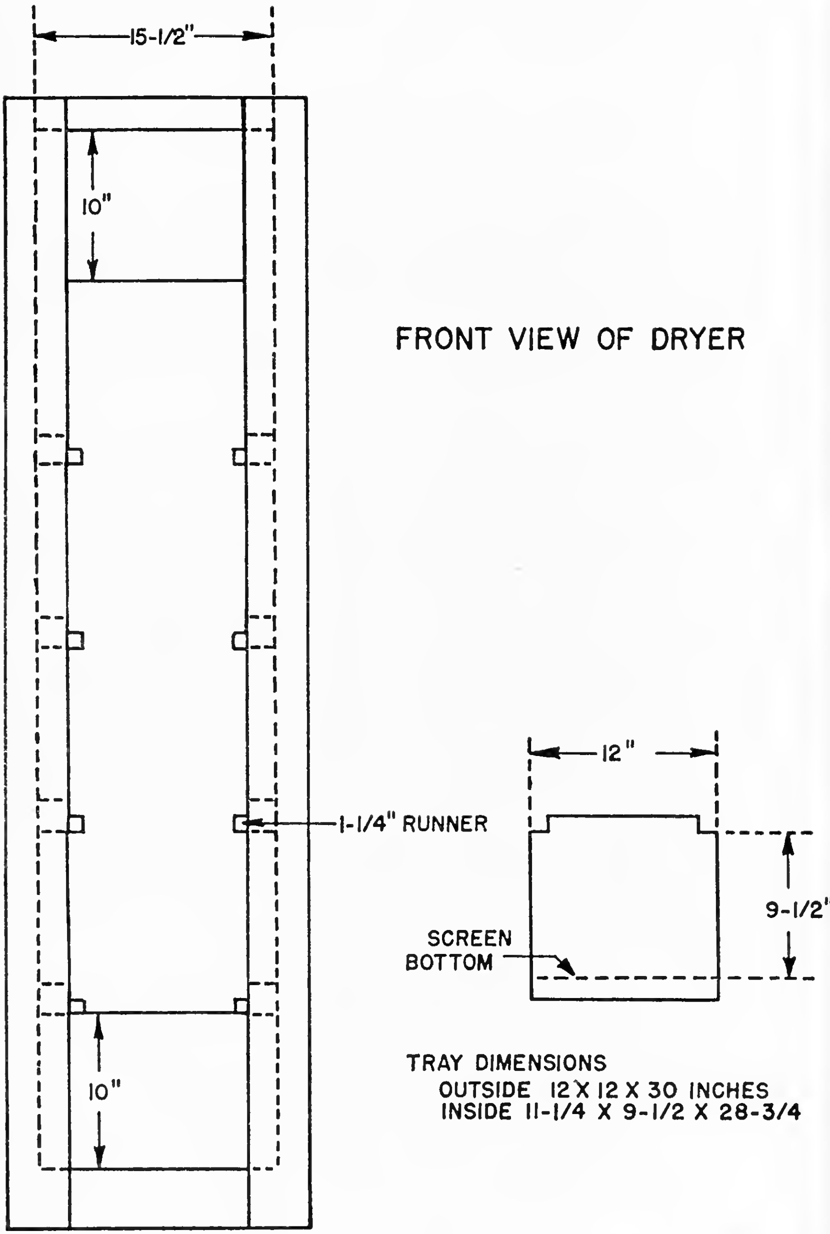
The couples were electro-welded and then coated with a special dielectric varnish that was renewed after each run. The couples had no other covering except when they were used for wet-bulb readings. These readings were taken in the exhaust plenum of each bin (position B, Fig. 1). The wet-bulb couples were sealed in thin glass tubing, and the cotton sock was immersed in a jar of distilled water. The wet-bulb thermocouples were checked frequently by means of both wet- and dry-bulb glass stem thermometers inserted in the air pipe (Fig. 1) leading to the fan intake.

The arrangement of the six thermocouples in each bin varied slightly. Two thermocouples — one wet and one dry — were always located in the exhaust plenum. Each of the four remaining couples was inserted in a single corn kernel of a representative ear in the center of a tray, thus enabling kernel temperatures to be recorded in four positions in the bin. In 1947 and 1948, the arrangement was changed so that a couple could be inserted in the cob as well as in a kernel of an ear in trays 1 and 4 of each bin. This use of two couples per bin prevented the recording of dry- and wet-bulb readings in the exhaust plenum, so Foxboro recording combination thermograph-hygrometers were used in the exhaust plenum.

The condition of the air entering the bins was recorded by means of a Foxboro thermograph and separate recording hygrometer. The temperature of the heated air entering each bin was also recorded on Foxboro extended bulb thermographs. The thermograph bulb was fastened to the temperature regulator bulb (Fig. 1) in each bin.

Air velocities were checked periodically by means of an anemometer placed in the center of the 8-inch air pipe extending to the fan intake (Fig. 1). Each anemometer reading represented a 10-minute run. Velometer readings were also taken, but the results were so variable that reliance was placed entirely on the anemometer. The anemometer readings were converted into changes of air per minute by means of suitable calculations.

Air velocities were recorded at the start of each run, and, where the experiment called for differences in temperature only, every effort was made to adjust the dampers in the discharge pipes so that the initial air velocities were equal in each of the four bins. Owing to the differences in drying rates at each temperature, this equality could not be maintained as the run proceeded. Air velocity always speeded up, regardless of temperature, since ears lost moisture because of shrinkage. This shrinkage in size reduced the total load in the bin. In addition, the shrinkage tended to open small air passages, permitting a freer movement of air. The greatest ear shrinkage coincided with the highest initial moisture content.



Front view of one of the four dryers used in drying sweet-corn seed. End section of one of the trays is shown. (Fig. 2)

MOISTURE TESTS

Moisture tests of the kernels and cobs were taken at the start of each run, and as nearly as possible, every four hours thereafter. In some runs, moisture tests were taken every four hours around the clock, but in others the night readings were omitted. Two ears were removed from each tray. In most of the runs, the four ears from the two upper trays and the two lower trays were bulked separately. Obviously, two ears from each tray did not constitute a representative sample; but removal of more ears would have reduced the bin load too much, thus introducing another source of error. Each tray had an initial load of 110 to 135 ears weighing 30 to 60 pounds. During an extended drying run with high-moisture corn, 14 or 15 samplings were taken and 28 to 30 ears were removed.

Readings were also taken with a Steinlite moisture tester at each sampling to use as a guide showing the progress of each run, but this instrument was not sufficiently accurate for experimental purposes. Therefore, all moisture samples were dried for 168 hours at 176° F. in a large Despatch oven equipped with a fan for forced air circulation. The oven dampers were wide open to permit maximum circulation. The test results were the averages of two 100-gram samples of kernels dried in 307×306 open cans.

The moisture samples consisted of a 2-inch section cut from the center of each ear. These ear sections were shelled to provide 200 grams of kernels. The cob sections were also placed in 307×306 cans and dried in the same manner as the kernels.

The butt and tip sections were used for germination tests. If the moisture was above 15 percent, the sections were placed in another dryer, finish-dried at 100° F., and then shelled.

GERMINATION TESTS

The viability of all samples was tested by means of cold tests similar to the one used by Tatum and Zuber (12). No seed disinfectant was used. Each sample was divided into five lots of 20 kernels each. These lots were planted with other lots in five greenhouse flats distributed at random. The flats were filled with soil from a corn field, and each flat was planted with seven rows of kernels, 2 inches apart, 20 kernels per row. The center row of each flat was planted with a check usually consisting of a dozen or more ears selected at random at the beginning of each run. These ears were then dried in another dryer at 100° F. The flats were covered with burlap, watered, and allowed to drain for several hours. They were then placed in cold storage at 50° F. After remaining in cold storage for seven days, they were removed to greenhouse benches and allowed to grow for about two weeks.

Germination readings were taken every other day in an attempt to combine time of emergence with number emerged. This method proved unsatisfactory, and therefore vigor is reported as the average green weight per seedling at the time the final germination reading was taken. The average green weight per seedling was obtained by cutting off the seedlings at ground level and weighing and dividing by the actual number germinating rather than by 20, the number planted.

METHODS OF EXPRESSING DRYING RATES

Since any lot of sweet-corn seed should be dried to a final kernel-moisture content of about 12 percent, it follows that moisture content taken periodically is an excellent index of the drying rate, provided it is expressed on the dry rather than the wet basis. Unfortunately, it is difficult to determine the correct moisture of a large volume of ear corn: first, because of the difficulty of selecting a representative sample; and second, because "quick" moisture tests are not very accurate.

Drying consists of two functions — the movement of moisture to exposed surfaces, and evaporation of water from these surfaces. Heated air, in turn, performs two functions: it supplies the heat energy absorbed during evaporation, and it carries away the vapor that is formed (2). If the air is stagnant or its movement is too slow, drying is either retarded or stops entirely. Under these conditions, germination is injured (Huelsen, 3).

The rate of drying can be effectively measured by means of wet-bulb temperature readings taken at the exhaust end of the dryer. These readings, combined with the dry-bulb readings, give the vapor pressure of the exhaust air. For the purposes of this work, the authors sought a single term that would express the drying rate of the corn in the bin. The derivation and use of the term chosen is shown by example.

At 2 a.m., after three hours of drying (Run 1, 1949), the temperature of the intake air before heating was 82° F. and the relative humidity was 32 percent. The air was heated to 110° F. before entering the top tray of corn. The dry-exhaust temperature was 85° F., and the wet-bulb reading was 77.5° F. The calculations follow, using the table compiled by Sawdon (11).

1. Entering air at 82° F. had a saturation pressure of 1.1013 inches of mercury at a barometric pressure of 29.921 inches of mercury. Since the relative humidity recorded by the hygrometer was 32 percent, the vapor pressure was 0.3524 inches (1.1013 times 32).

2. The vapor-pressure deficiency of the entering air was 0.7489 inches (1.1013 minus 0.3524). This was the theoretical drying power of the unheated air.

3. The saturation pressure of air heated to 110° F. is 2.5939 inches. Therefore, the vapor-pressure deficiency of entering air heated to 110° F. equaled 2.5939 minus 0.3524 (the vapor pressure of entering air) or 2.2415 inches.

4. The dry-bulb exhaust temperature was 85° F. with a saturation pressure of 1.2135 inches at 85° F.; the wet-bulb reading was 77.5° F., a depression of 7.5° F. According to Weather Bureau tables, the relative humidity was 71 percent. Therefore, the vapor pressure of the exhaust air equaled 1.2135 times 71 percent or 0.8616.

5. The vapor-pressure deficiency of the exhaust air equaled 1.2135 minus 0.8616 or 0.3519.

6. The moisture pickup equaled 1.8896, the vapor-pressure deficiency of the heated entering air minus the vapor-pressure deficiency of the exhaust air (2.2415 minus 0.3519).

As shown by the high moisture pickup (exhaust air having 71 percent relative humidity at 85° F.), the efficiency of the dryer was very high during the early stages of a drying run. As each drying run progressed, the moisture pickup decreased and, as will be shown later, approached zero when the kernel moisture reached 12 percent.

DRYING RUNS

The experimental evidence is based on two preliminary runs in 1945, and 23 additional runs during the 5-year period 1946-1950. In each instance, except in 1945, a run consisted of four bins (Figs. 1 and 2) loaded to capacity with husked ears harvested the same day. The harvest moisture of the ears was varied intentionally each year, since one of the principal objectives of the experiments was to determine the relationship between initial moisture, drying temperatures, germination, and seedling growth.

All of the results are based on the performance of the ears of F_1 hybrids (F_2 seed). The authors were aware that in commercial practice the female inbred parent is dried rather than the hybrid ear because the commercial sweet-corn hybrid is an F_1 cross. The growing of inbreds at Urbana on the scale required by these experiments proved impractical because of low productivity. In addition, there was no reason for believing that F_1 and F_2 seed would respond differently to drying, and four yellow hybrids (Golden Cross, Illinois 10, Illinois 17, and an experimental cross, 73c×104b) and two white hybrids (Illinois Country Gentleman 13 and Illinois 14×13) were used.

The drying bins were constructed so that the effect of the two variables, air temperature and air velocity, could be studied separately or in various combinations. In 18 runs, sweet corn was dried on the ear at 100°, 110°, 120°, and 130° F., while the air velocity was held as constant as possible. In five additional runs, the temperature in the four bins was held at 100° F., and the velocities were varied.

The four bins were always loaded to capacity with the same harvest of ear corn. Since corn with a high initial moisture content is subject to the greatest damage during drying, the runs were planned so that in most of them the ears had a relatively high initial moisture content.

The efficiency of the four bins far exceeded that of any commercial sweet-corn dryer. Both the heating units and the fans were oversize, and corn could be dried at a very rapid rate. The corn was dried rapidly because some seedsmen believe that slow drying is necessary to prevent injury to germination.

PHYSICAL AND BIOLOGICAL FACTORS INVOLVED IN DRYING AT DIFFERENT TEMPERATURES

Air temperature and air velocity are the two physical factors that determine the success of any drying installation. If either one is too low, drying time will be extended, often leading to the injury of seed corn. Injury may also result if the temperature is too high, although increasing the air velocity can be beneficial.

The biological factors to be considered are the effects on germination and growth of drying temperature, length of exposure to heat, and the initial moisture of the corn when it enters the dryer. Huelsen (3) has shown that all three of these factors are closely related in their ability to injure sweet corn. Wileman and Ullstrup (14) have shown that the initial moisture content of dent corn is the important factor governing a safe drying temperature. McFarlane *et al.* (7) found that the resistance of paddy rice to impairment of its viability varied inversely with its moisture content.

Out of the total of 23 runs, three typical runs were selected for critical analysis. These runs had an initial moisture content of 53.0, 41.0 and 24.4 percent. Several runs had a much lower initial moisture content, but the corn dried too quickly for an extended analysis.

Physical Factors

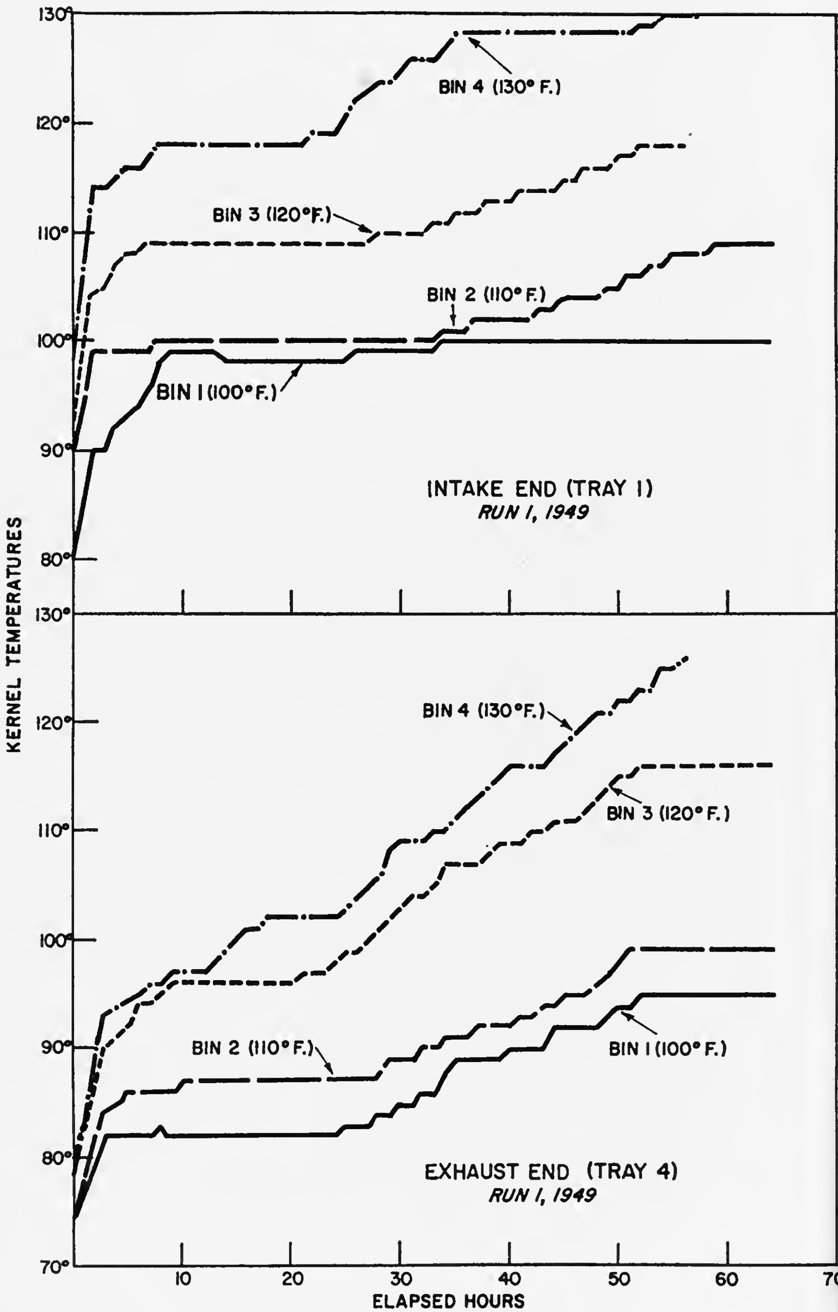
Relation between air and kernel temperatures

Drying experiments are usually reported in terms of dry-bulb temperatures of the air entering the dryer. These temperatures provide a nominal measure of conditions in the kernel. Drying is essentially a process of evaporation, and the escape of water vapor from the kernel will result in a kernel temperature lower than the temperature of the air.

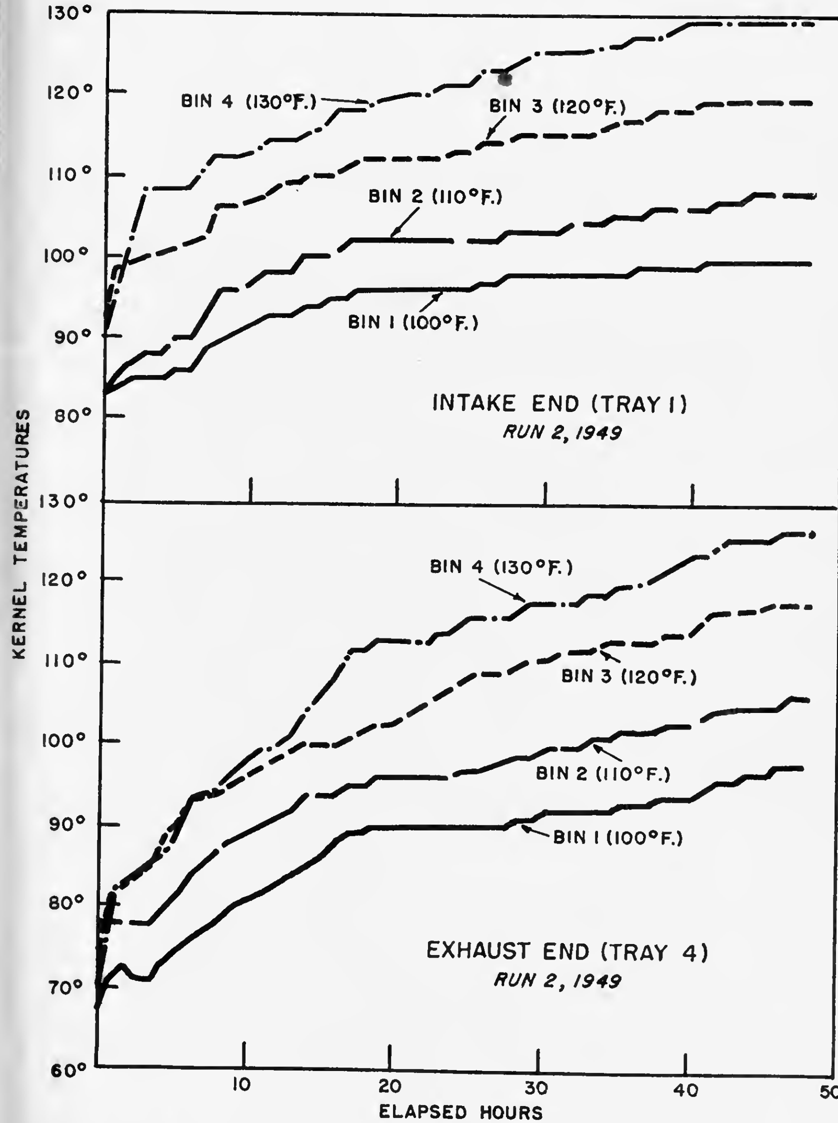
Recording the kernel temperatures by inserting thermocouples into kernels (see Figs. 3, 4, and 5) gave approximate wet-bulb readings. The readings would reach surrounding air temperatures only when evaporation of moisture from the kernels had practically ceased. Since the kernel had to be pierced in order to insert the thermocouple, evaporation might resemble the process of vapor escaping from a free surface. It is not known how moisture escapes from a whole kernel, but it may be assumed that the process is the reverse of imbibition. It has been shown (Wolf *et al.* 15, Part II) that during imbibition most of the moisture enters the dent-corn kernel through the pedicel or basal end of the tip cap. Entry of water in this manner was assumed to be due to cutinization, a process that is still incomplete when the immature ear enters the dryer.

The kernel temperatures shown in Figs. 3, 4, and 5 were recorded from thermocouples in Tray 1 at the intake end of the dryer and in Tray 4 at the exhaust end. As might be expected, the temperatures at the exhaust ends of the bins lagged considerably behind the temperatures at the intake ends. The kernels reached the ambient air temperatures only at the intake ends of the bins, and then only for a short time at the very end of the run.

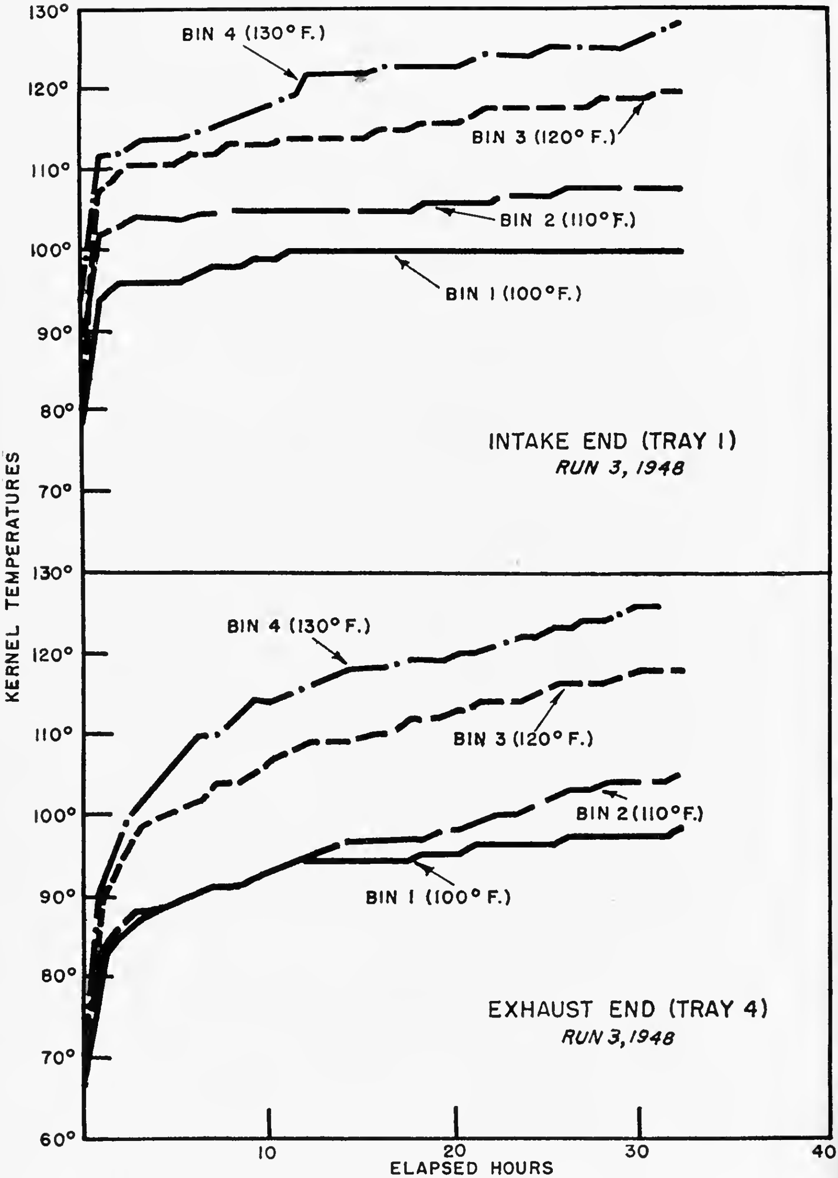
The unusual feature of the curves in Figs. 3, 4, and 5 is their obvious tendency to group into pairs, one pair being 100° and 110° F., and the second, 120° and 130° F. This tendency was much more noticeable at the exhaust ends of the bins. The differences in kernel temperatures between the 110° and 120° F. bin temperatures were greater than those within each pair. Taken alone, this fact would



Internal temperatures of kernels at intake and exhaust ends of bins of sweet corn having an initial kernel moisture of 53 percent, wet basis, and dried at 100°, 110°, 120°, and 130° F. (Run 1, 1949). (Fig. 3)



Internal temperatures of kernels at intake and exhaust ends of bins of sweet corn having an initial kernel moisture of 41 percent, wet basis, and dried at 100°, 110°, 120°, and 130° F. (Run 2, 1949). (Fig. 4)



Internal temperatures of kernels at intake and exhaust ends of bins of sweet corn having an initial kernel moisture of 24.4 percent, wet basis, and dried at 100°, 110°, 120°, and 130° F. (Run 3, 1948). (Fig. 5) indicate that between 110° and 120° F. there was a marked increase in drying efficiency during the early stages of drying, followed by a temperature increase — or, assuming that the readings were wet-bulb, a reduced wet-bulb depression occurred at 120° F.

Measuring dryer efficiency

By means of moisture ratios. The length of the drying period is governed by the temperature, rate of air movement, and vapor pressure of the entering air. The drying rate can be determined by means of moisture tests and by appropriate wet- and dry-bulb temperature readings of the intake and exhaust air.

Oven-moisture tests are an accurate means of determining the moisture contents of the ears, but as mentioned previously, this method is subject to considerable sampling error. It does, however, give a good approximation of the effect of varying temperatures on the drying rates. Crop moistures are usually reported on the wet basis (a typical example is given by Myers and Rogers (8)). As shown by Perry *et al.* (9), however, this method of reporting the drying rate is misleading, since both the amount of moisture in the sample and the total weight of the sample are changing. A more correct method of expression is the moisture ratio "T" (Tables 3, 4, and 5), which is the ratio between moisture content M of the sample on the wet basis, and 100 minus M, the bone dry matter. The formula used in Tables 3, 4, and 5 was T equals M divided by 100 minus M.

The samples taken from the two top trays are labeled "intake," and those from the two bottom trays, "exhaust." The sampling errors in Tables 3 and 4, where the initial moisture content of the corn was high, were relatively slight. The sampling errors in Table 5, on the other hand, were large. These errors were attributed to the comparatively low initial moisture — only 24.4 percent. It was observed repeatedly that moisture variation from ear to ear became relatively greater as the corn reached an average kernel moisture of 20 percent; below 20 percent, the trend was reversed.

The differences in the hourly drying rates of the kernels from one end of the bin to the other were slight (Tables 3, 4, and 5), indicating a high degree of efficiency. The cobs showed a wider variation, probably because the ratio of total water removed was much greater in the cobs than in the kernels.

The loss of water per hour increased in relation to the drying temperature, although the differences in the drying rates of the kernels between the 100° and 110° F. bins were very small. There was a considerable increase in efficiency between the 110° and 120° F. bins. This result is consistent with the kernel temperatures shown in Figs. 3, 4, and 5. The drying rate between 120° and 130° F. showed a considerable increase. The drying rates of the cobs also increased in relation to the temperatures, but unlike the kernels, there was no unusual increase in drying efficiency in the 120° F. bin.

By means of vapor pressures. The difference between the vapor pressures of the intake and exhaust air leaving the bin, expressed as moisture pickup, is a better measure of the condition of the corn than the moisture tests. The latter are beset with sampling errors. Moisture pickup can be measured quickly at any time, and it gives the operator a fairly accurate indication of how rapidly drying is progressing.

The moisture pickups for Runs 1 and 2, 1949, are plotted in Fig. 6, and those for Run 3, 1948, in Fig. 7. Drying temperatures and moisture pickup are in direct relationship, the maximum pickup occurring in the 130° F. bin and the minimum in the 100° F. bin. The curves are practically linear during the early stages of drying, followed by a definite curvilinear trend. Although less moisture remains in the ears toward the end of each run (Tables 3, 4, and 5), this trend is not entirely due to the reduced moisture content. Data to be discussed in the next section show that as drying proceeds, air velocity increases.

Another set of experiments presented later will show that when temperatures are held constant and air velocities vary, moisture pickup and air velocity have an inverse relationship. Up to a certain point, efficiency may be measured in terms of moisture pickup; but if moisture pickup is too high, it means that the air is becoming saturated because of slow air movement. From the standpoint of the plant operator, a moisture pickup approximating that shown for the 110° F. bin (Figs. 6 and 7) would approach the maximum pickup consistent with good seed germination.

Air velocity in relation to drying temperatures

The most common fault in sweet-corn seed dryers is lack of fan capacity, resulting in slow movement of air. In some instances, the air reaches the saturation point, and, since the ears farthest from the air intake heat up the slowest, the air is cooled and moisture condenses on the corn. This moisture causes the ears to become moldy, which, in turn, impairs the germination. Increasing the air flow requires more heating capacity. Although rapid air flow will speed up drying, it also reduces the moisture pickup.

Theoretically, the ideal air velocity and the one most economical of fuel would occur when the air comes close to saturation at the exhaust end, but no dryer can be operated that efficiently. In the case of sweet corn, the spread in kernel-moisture content between intake and exhaust ends of the dryer during drying may be too large, resulting in damaged germination at the exhaust end and overdrying at the intake end. No definite rules can be laid down, since no two dryers are alike. Experienced commercial operators believe that reducing the kernel moisture from 45 percent to 12 percent, wet basis, in 72 hours with an intake temperature of 110° F. is a desirable rate of drying.

The air velocities of the three runs under discussion showed an increase as drying progressed. As explained previously, this increased velocity is due to shrinkage of the ears, causing a reduction in the bulk of the corn, which, in turn, opens small air passages. The increases in velocity (Table 6) tend to be somewhat more rapid at the higher temperatures and accelerate slightly toward the latter part of the run.

Table 3. — Rate of Drying Sweet-Corn Ears at Four Temperatures Indicated by the Parts of Water Remaining in the Kernels and Cobs per Part of Bone Dry Matter, Run 1, 1949[a]

Elapsed hours	Parts of water remaining and removed							
	100° F.		110° F.		120° F.		130° F.	
	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust
	Remaining in kernels (T)							
0	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
8	.71	.95	.88	.96	.81	.80	.86	.80
16	.92	.68	.67	.69	.76	.74	.40	.52
24	.61	.64	.56	.69	.41	.46	.33	.45
32	.40	.51	.36	.52	.27	.41	.19	.24
40	.38	.45	.33	.34	.18	.26	.10[b]	.20[b]
48	.34	.38	.21	.29	.11[b]	.17[b]	.07	.10
56	.23	.32	.17	.21	.08	.07	.06	.09
64	.16	.19	.10	.18	...	...	...	...
Total parts of water removed	.97	.94	1.03	.95	1.02	1.06	1.03	1.03
Loss per hour	.015	.015	.016	.015	.021	.019	.026	.021
	Remaining in cobs (T)							
0	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
8	1.56	1.86	1.50	1.63	1.38	1.44	1.44	1.33
16	1.86	1.38	1.38	1.27	1.08	1.22	.59	1.04
24	1.08	1.04	1.00	1.13	.69	.82	.39	.79
32	.73	.92	.61	1.00	.59	.61	.27	.30
40	.59	.73	.52	.64	.19	.35	.09[b]	.28[b]
48	.43	.69	.32	.30	.15[b]	.11[b]	.03	.10
56	.25	.44	.14	.25	.04	.06	...	.06
64	.19	.23	.05	.14	...	...	...	...
Total parts of water removed	1.51	1.47	1.65	1.56	1.55	1.64	1.61	1.60
Loss per hour	.024	.023	.026	.024	.032	.029	.040	.033

Note: for explanation of "T," see page 21.

[a] Initial moisture percentages on the wet basis were 53.0 percent in the kernels and 62.9 percent in the cobs.

[b] Sufficient moisture removed so that corn would store safely. Total water removed calculated from this point.

Table 4. — Rate of Drying Sweet-Corn Ears at Four Temperatures Indicated by the Parts of Water Remaining in the Kernel and Cobs per Part of Bone Dry Matter, Run 2, 1949[a]

Elapsed hours	Parts of water remaining and removed							
	100° F.		110° F.		120° F.		130° F.	
	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust
	Remaining in kernels (T)							
0	.69	.69	.69	.69	.69	.69	.69	.69
8	.43	.52	.47	.54	.28	.52	.37	.33
16	.35	.37	.27	.37	.27	.32	.19	.35
24	.28	.30	.16	.35	.19	.19	.14[b]	.15[b]
32	.25	.32	.15	.16	.09[b]	.10[b]	.05	.08
40	.20	.20	.09[b]	.15[b]	.05	.04	.05	.05
48	.08	.12	.06	.11	.06	.05	.04	.05
Total parts of water removed	.61	.57	.60	.54	.60	.59	.55	.54
Loss per hour	.013	.012	.015	.014	.019	.018	.023	.022
	Remaining in cobs (T)							
0	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
8	.82	.92	.82	1.13	.52	1.13	.67	.67
16	.47	.67	.43	.67	.52	.43	.41	.56
24	.39	.43	.16	.61	.19	.25	.14[b]	.14[b]
32	.28	.41	.09	.25	.06[b]	.15[b]	.01	.01
40	.22	.20	.04[b]	.14[b]	.02	.05	.02	.04
48	.04	.05	.03	.10	.02	.02	.01	.02
Total parts of water removed	1.46	1.45	1.41	1.36	1.44	1.45	1.36	1.36
Loss per hour	.030	.030	.044	.034	.045	.036	.057	.057

Note: for explanation of "T," see page 21.
[a] Initial moisture percentages on the wet basis were 41.0 percent in the kernels and 60.3 percent in the cobs.
[b] Sufficient moisture removed so that corn would store safely. Total water removed calculated from this point.

The decreases in moisture pickup (Figs. 6 and 7) were due mostly to the reduced moisture in the corn, but some of the decreases were due to the greater velocity of air toward the end of the run. Velocity will be discussed in greater detail later in this bulletin.

Biological Factors

Drying at excessively high temperatures will, of course, result in damage to the seed, but this situation seldom, if ever, occurs in actual commercial seed curing. Practically all of the difficulties encountered in commercial drying are due to inefficiency — too little air and too little heat. The damage to the corn is probably due to a combination of long exposure to air having a relatively high vapor pressure and to the development of molds.

Factors affecting germination and seedling growth

Bin temperatures. The cold-test germination results of the three runs under discussion (Table 7) show that when the initial moisture content was as high as 53 percent (Run 1, 1949) the only extensive damage to the final germinations occurred in the 120° and 130° F. bins. Little or no emphasis should be placed on the initial germination of 89 percent, which was 11 percent below the control. As explained previously, this sample was dried at 100° F. in another dryer, and the germination should have been compatible with that of the 100° F. bin. Damage to germination was severe in the 130° F. bin, and less so in the 120° F. bin.

The only material damage to the final germinations sustained in Run 2, 1949 (Table 7), was in the 130° F. bin, despite the relatively high initial moisture content of 41 percent. At an initial moisture of 24.4 percent, the final germinations showed only minor damage when dried at the three lower temperatures; slightly more damage was apparent in the 130° F. bin.

The average and final germinations in Table 7 representing the most immature corn showed that more damage occurred at the intake ends than at the exhaust ends of the 120° and 130° F. bins. As indi-

Table 5.—Rate of Drying Sweet-Corn Ears at Four Temperatures Indicated by the Parts of Water Remaining in the Kernels and Cobs per Part of Bone Dry Matter, Run 3, 1948[a]

Elapsed hours	Parts of water remaining and removed							
	100° F.		110° F.		120° F.		130° F.	
	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust
	Remaining in kernels (T)							
0	.32	.32	.32	.32	.32	.32	.32	.32
4	.28	.27	.28	.30	.23	.18	.30	.20
8	.25	.27	.18	.20	.16	.19	.20	.20
12	.20	.23	.15	.23	.18	.18	.12[b]	.16[b]
16	.25	.16	.11	.19	.14	.18	.10	.14
20	.22	.18	.16	.15	.12[b]	.12[b]	.11	.11
28	.15	.12	.14[b]	.11[b]	.09	.08	.06	.06
32	.12[b]	.10[b]	.08	.09	.06	.08	.04	.05
Total parts of water removed	.20	.20	.18	.21	.20	.20	.20	.18
Loss per hour	.006	.007	.006	.008	.010	.010	.017	.009
	Remaining in cobs (T)							
0	.69	.69	.69	.69	.69	.69	.69	.69
4	.56	.49	.56	.61	.44	.32	.92	.32
8	.64	.54	.19	.44	.22	.30	.44	.33
12	.44	.43	.19	.54	.30	.28	.09[b]	.30[b]
16	.41	.22	.10	.37	.15	.27	.12	.20
20	.47	.33	.22	.11	.11[b]	.18[b]	.08	.12
28	.22	.15	.14[b]	.06[b]	.05	.05	.03	.04
32	.14[b]	.09[b]	.05	.06	.04	.06	.02	.03
Total parts of water removed	.55	.54	.55	.58	.58	.64	.60	.57
Loss per hour	.017	.019	.020	.029	.029	.023	.050	.028

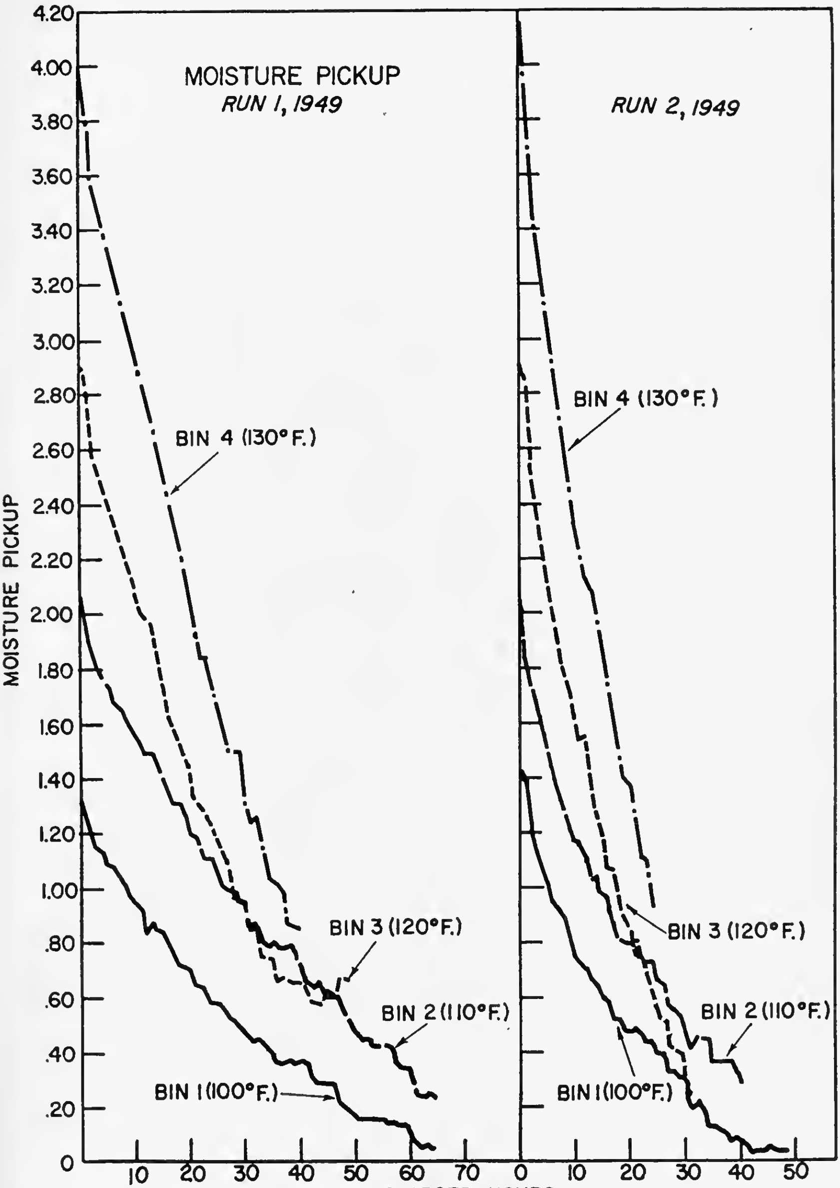
Note: for explanation of "T," see page 21.
[a] Initial moisture percentages on the wet basis were 24.4 percent in the kernels and 41.3 percent in the cobs.
[b] Sufficient moisture removed so that corn would store safely. Total water removed calculated from this point.

Table 6. — Air Velocities Expressed as Changes of Air per Minute in Three Runs of Corn With Different Initial Kernel Moistures and Dried at Four Temperatures

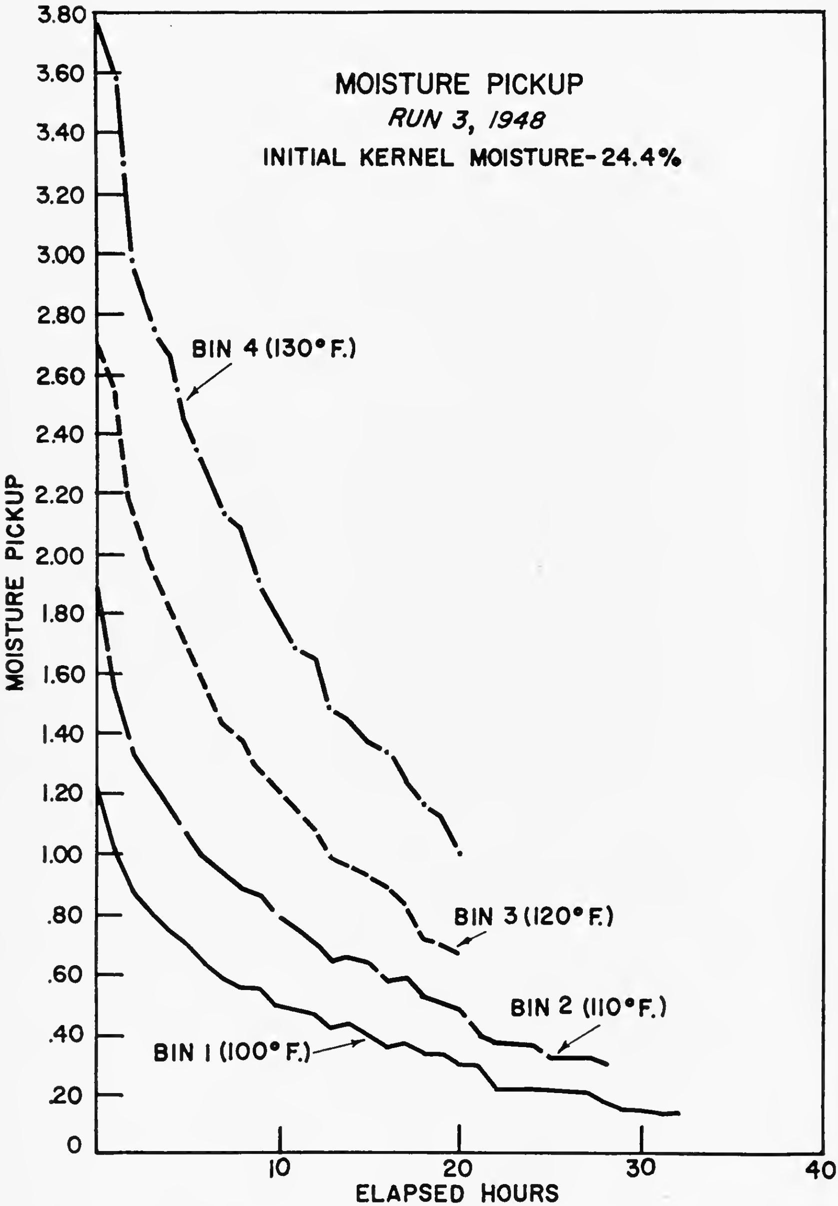
Elapsed hours	Changes of air per minute			
	100° F.	110° F.	120° F.	130° F.
Run 1, 1949 — initial kernel moisture, 53.0%				
10 (initial velocity)	22.4	24.0	24.0	25.2
	(Increase over initial velocity)			
15	3.0	.6	2.2	2.0
21	4.3	3.4	2.3	2.5
23	4.1	4.2	4.6	3.9
36	6.2	4.6	7.7	5.1
38	6.9	6.3	8.7	5.9
44	6.6	7.0	9.6	8.2
64	9.8	6.9	...	...
Run 2, 1949 — initial kernel moisture, 41.0%				
0 (initial velocity)	24.7	24.6	25.2	25.8
	(Increase over initial velocity)			
4	.4	.7	1.0	.9
7	.4	2.1	2.7	1.9
18	3.4	6.0	5.5	6.3
20	5.4	7.0	...	...
28	6.9	7.1	6.9	6.2
32	7.3	7.2	8.1	5.7
42	7.9	8.3	9.4	9.8
Run 3, 1948 — initial kernel moisture, 24.4%				
4 (initial velocity)	28.9	27.7	29.1	27.3
	(Increase over initial velocity)			
8	1.1	1.2	1.3	1.3
14	3.2	3.7	2.8	2.2
16	4.3	3.5	5.0	3.1
29	2.8	5.9	4.2	4.7
34	5.3	6.1	3.7	7.4

cated by the final germination, there was considerable damage at the intake end of the 120° F. bin. The damage was even more severe in the 130° F. bin, but in the 100° and 110° F. bins the differences were minor. At an initial moisture content of 41 percent, the only noticeable difference between intake and exhaust ends occurred in the 130° F. bin (Table 7), where the final germination was considerably less at the intake end. In the more mature sample with 24.4-percent initial moisture, the ears at the exhaust end of the 130° F. bin were the only ones showing any real damage (Table 7). This condition, which was the reverse of the trend in previous runs, may have resulted because the corn at the exhaust end required 4 more hours drying time.

The green weights of the seedlings are often considered a somewhat more accurate measure of viability than germination tests alone. The green weights to be discussed were taken from the seedlings that had been through the cold test, and are really an extension of the results in Table 7.



Rate of drying two lots of sweet corn at 100°, 110°, 120°, and 130° F. expressed as moisture pickup. Curves are terminated as close to 12-percent kernel moisture as possible. (Initial kernel moisture, wet basis, was 53 percent for Run 1, 1949, and 41 percent for Run 2, 1949.) (Fig. 6)



Rate of drying sweet corn with 24.4-percent initial kernel moisture, wet basis, at 100°, 110°, 120°, and 130° F. expressed as moisture pickup. Curves are terminated as close to 12-percent kernel moisture as possible. (Run 3, 1948.) (Fig. 7)

Table 7. — Cold-Test Germination Percentages of Sweet Corn Dried at Four Temperatures to as Close to 12-Percent Kernel Moisture as Possible, and Sampled Periodically During the Drying Runs[a]

Elapsed hours	100° F.				110° F.				120° F.				130° F.			
	Intake		Exhaust		Intake		Exhaust		Intake		Exhaust		Intake		Exhaust	
	Control	Increase	Control	Increase	Control	Increase	Control	Increase	Control	Increase	Control	Increase	Control	Increase	Control	Increase
Run 1, 1949 — initial kernel moisture, 53.0%																
8	100	−2	100	−4	100	−2	100	−6	100	−2	96	2	96	−16	96	0
16	96	3	96	2	96	−1	98	−7	98	−6	98	1	98	−11	98	−2
24	98	−1	98	−4	98	−6	98	−1	98	−7	98	−1	98	−47	94	−6
32	94	−1	94	2	94	1	94	1	94	−3	98	−4	98	−69	98	−11
40	98	−2	98	−1	98	−1	96	1	96	−3	96	−3	96	−56	96	−19
48	96	1	95	−4	95	−5	95	3	95	−1	95	−1	..	...	98	−16
56	98	−4	98	0	98	−4	98	−2	..	...	100	−4	..	...	..	...
64	100	−2	100	4	100	−4	96	−3	..	...	..	...	..	...	..	...
Average		−1.0		−0.6		−2.8		−1.8		−3.7		−1.4		−39.8		−9.0
Run 2, 1949 — initial kernel moisture, 41.0%																
8	99	−1	99	0	99	−1	99	−1	99	−2	97	−3	97	−2	97	3
16	97	2	97	2	97	0	98	1	98	1	98	−1	98	−3	98	−4
24	98	0	100	−4	100	−2	100	−3	100	−3	100	0	100	−38	99	−7
32	99	−1	99	−1	99	−1	99	0	99	−1	98	−3	..	...	..	...
40	98	0	98	0	98	1	98	0	..	...	..	...	..	...	..	...
48	98	−3	96	0	..	...	..	...	..	...	..	...	..	...	..	...
Average		−0.5		−0.5		−0.6		−0.6		−1.2		−2.3		−14.3		−2.7
Run 3, 1948 — initial kernel moisture, 24.4%																
4	98	−5	98	−9	98	−3	98	0	98	−3	96	−1	96	2	96	−3
8	96	−1	96	−6	96	−9	97	−7	97	−1	97	−4	97	−3	97	−1
12	97	1	98	0	98	−7	98	1	98	−3	98	−3	98	−2	92	0
16	92	6	92	6	92	2	92	6	92	4	99	−3	..	...	99	−8
20	99	−3	99	−5	99	−2	97	0	97	−1	97	−1	..	...	..	...
28	97	1	97	−8	97	0	97	−2	..	...	..	...	..	...	..	...
32	98	−4	..	...	..	...	..	...	..	...	..	...	..	...	..	...
Average		−0.7		−3.7		−3.2		−0.3		−0.8		−2.4		−1.0		−3.0

[a] Germination of samples equaled 89 percent at start of Run, 1, 1949; 100 percent at start of Run 2, 1949; and 93 percent at start of Run 3, 1948.

A comparison of the final green weights of the run with 53-percent initial kernel moisture (Table 8) with the final germination tests in Table 7 shows that the corn in the 120° and 130° F. bins was damaged considerably. The final green weights of the run with 41-percent initial kernel moisture (Table 9) indicated damage in all four bins. The damage became very severe in the 130° F. bin. This result does not quite agree with the final germinations (Table 7), which show severe damage in the 130° F. bin but practically none elsewhere. When the initial kernel moisture was 24.4 percent (Table 10), the final green weights showed only minor damage in all bins, but the germination tests (Table 7) in the 130° F. bin indicated moderate damage.

These minor inconsistencies may be reconciled if the method of calculating the green weights for the 5 replication averages is considered. These averages were calculated by dividing the total green weights by the *actual* number of seedling survivors, *not* by the number planted. The averages were often too high because of the greater amount of room for each seedling when the germination was low. Calculating averages on the basis of a 100 percent theoretical stand can lead to another type of distortion. Despite the inconsistencies, the use of drying temperatures as high as 120° F. is not recommended when the initial kernel moistures are above 40 percent. When the moisture is as low as 24 percent, there may be some justification for drying at a temperature of 120° F., although drying at this temperature is not recommended. A temperature of 110° F. is the maximum safe temperature.

Table 8.—Average Green Weights of Seedlings Grown From Sweet Corn Harvested at 53-Percent Kernel Moisture, Dried at Four Temperatures, and Sampled Periodically During the Drying Run (Run 1, 1949)

Elapsed hours	100° F.		110° F.		120° F.		130° F.	
	Weight (grams)	Percent of control	Weight (grams)	Percent of control	Weight (grams)	Percent of control	Weight (grams)	Percent of control
0	.72	82.8	.72	82.8	.72	82.8	.72	82.8
8	.77	88.5	.76	87.4	.73	83.9	.66	80.1
16	.68	85.0	.72	90.5	.69	88.5	.58	73.7
24	.74	88.8	.75	85.2	.78	88.0	.58	69.5
32	.72	92.9	.65	83.3	.62	76.8	.38	45.2
40	.72	86.1	.76	91.6	.62	75.6	.45	54.8
48	.78	93.9	.74	87.5	.58	69.6	.38[a]	48.6[a]
56	.72	96.6	.66	89.1	.66[a]	85.9[a]	...	....
64	.76[a]	97.4[a]	.76[a]	93.2[a]	...	....	...	....
Averages[b]	.74	91.2	.72	88.5	.67	81.2	.50	62.0

[a] Represents actual end of run. When intake and exhaust ends of bins differed, the weights were taken on the basis of the last trays to be removed from the bin.
[b] Not including initial sample.

PHYSICAL AND BIOLOGICAL FACTORS INVOLVED IN DRYING AT DIFFERENT AIR VELOCITIES

Physical Factors

One of the methods used in drying sweet-corn seed over 40 years ago consisted of constructing a vertical kiln with a warm air furnace at the bottom. The natural upward movement of the warm air was supposed to dry the corn. It did, eventually, but not before the corn became moldy and unfit to use for seed. As a result, artificial circulation proved necessary. Those commercial dryers having a free, evenly distributed circulation of air have been the most successful, and in the end, the most economical to operate, because they seldom fail to produce seed that germinates well.

Assuming that a uniform temperature can be maintained, speeding up the air circulation will hasten drying. Sweet corn exposed to drying temperatures may show progressive impairment of germination as the time of exposure is increased. The question is, what rate of air circulation is most practical at the usual bin temperature of 100° F.? Many dryers are operated at 110° F. at the source of heat, but the actual bin temperature seldom exceeds 100° F.

Relation between air velocity and kernel temperature

Two typical runs — Runs 1 and 2 in 1950 — were selected for detailed critical analysis. Run 1 had an initial kernel moisture of 43.3 percent, and Run 2, 63.8 percent. The actual air velocities of both runs

Table 9. — Average Green Weights of Seedlings Grown From Sweet Corn Harvested at 41-Percent Kernel Moisture, Dried at Four Temperatures, and Sampled Periodically During the Drying Run (Run 2, 1949)

Elapsed hours	100° F.		110° F.		120° F.		130° F.	
	Weight (grams)	Percent of control	Weight (grams)	Percent of control	Weight (grams)	Percent of control	Weight (grams)	Percent of control
0	.82	94.3	.82	94.3	.82	94.3	.82	94.3
8	.78	90.7	.82	94.8	.84	94.5	.81	88.0
16	.76	83.0	.82	93.3	.75	89.3	.72	85.7
24	.76	88.4	.76	87.9	.77	88.5	.58[a]	60.6[a]
32	.84	95.4	.76	86.9	.77[a]	89.3[a]	...	....
40	.76	89.4	.78[a]	87.4[a]	...	....	...	....
48	.68[a]	73.8[a]	...	....	...	....	...	....
Averages[b]	.76	86.8	.79	90.1	.78	90.4	.76	86.8

[a] Represents actual end of run. When intake and exhaust ends differed, the weights were taken on the basis of the last trays removed from the bin.
[b] Not including initial sample.

Table 10. — Average Green Weights of Seedlings Grown From Sweet Corn Harvested at 24.4-Percent Kernel Moisture, Dried at Four Temperatures, and Sampled Periodically During the Drying Run (Run 3, 1948)

Elapsed hours	100° F.		110° F.		120° F.		130° F.	
	Weight (grams)	Percent of control	Weight (grams)	Percent of control	Weight (grams)	Percent of control	Weight (grams)	Percent of control
0	1.13	97.4	1.13	97.4	1.13	97.4	1.13	97.4
4	.96	93.2	1.10	94.8	1.08	90.0	.94	90.4
8	1.01	91.8	1.01	93.5	1.00	89.3	1.08	94.7
12	1.16	95.1	.98	92.4	1.02	100.0	.98	100.0
16	1.08	100.0	1.10	100.0	1.14	93.4	1.04[a]	94.5[a]
20	1.18	96.7	1.16	95.9	1.04[a]	93.7[a]	....	....
28	1.14	95.0[a]	1.12[a]	95.0[a]	....	....	....	....
32	1.06[a]	94.6	....	....	....	....	....	....
Averages[b]	1.08	95.2	1.08	95.3	1.06	93.3	1.01	94.9

[a] Represents actual end of run. When intake and exhaust ends differed, the weights were taken on the basis of the last tray removed from the bin.
[b] Not including initial sample.

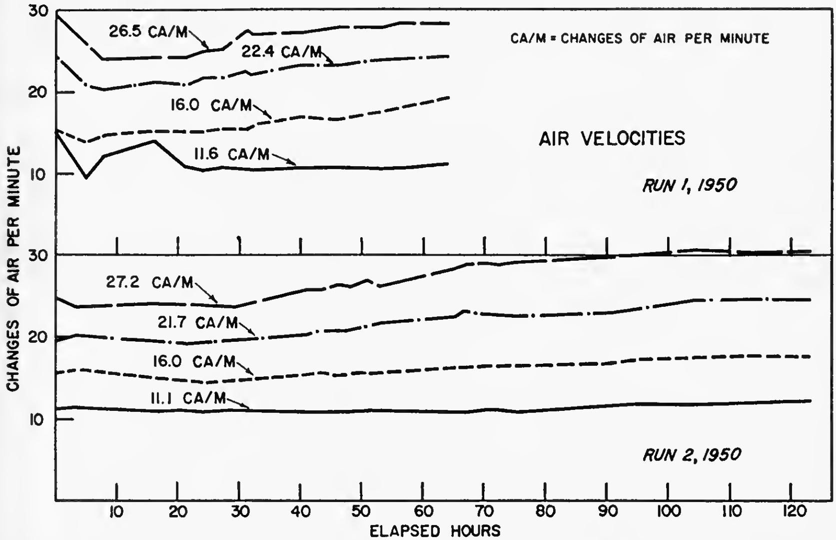
are plotted in Fig. 8. The initial velocities were set as close as possible to 25, 20, 15, and 10 changes of air per minute. Little difficulty was experienced with Run 2, but it was necessary to adjust the dampers several times during Run 1, which accounts for some of the irregularities of the curves.

A thermocouple was inserted in the kernel of a representative ear in each of the four trays in each bin (a total of 16 thermocouples). Only the four curves representing kernel temperatures at the intake and exhaust ends of Bins 1 and 4 are shown in Fig. 9.

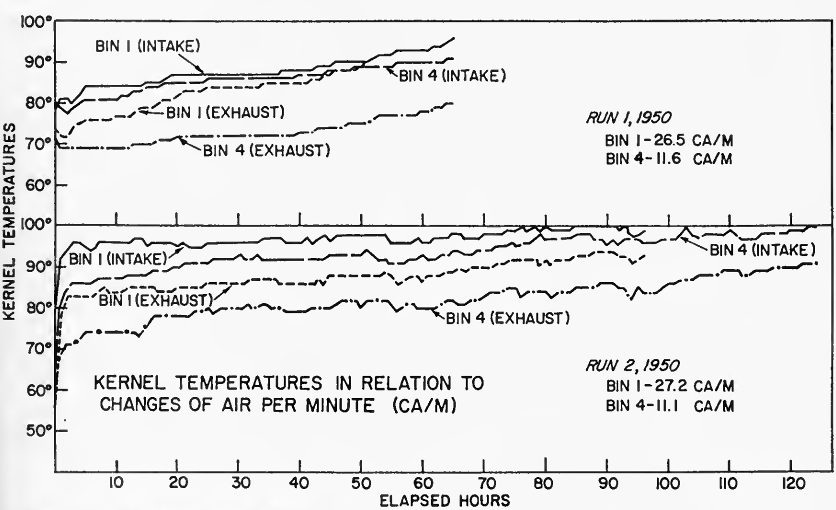
In Bin 1, representing a nominal 25 changes of air per minute, the kernel temperatures for Run 1 (Fig. 9) were lower at the exhaust end up to 51 hours — after that time they were the same. Bin 4, representing a nominal 10 changes of air per minute, had intake kernel temperatures nearly as high as those in Bin 1. This result, as well as the wide spread of kernel temperatures between intake and exhaust ends in Bin 4, could be expected. As will be shown later, the slow-moving air through Bin 4 dried the corn very slowly, and the temperature drop at the exhaust end of the bin was quite pronounced. The curves for Run 2 (Fig. 9) show virtually the same trends.

Measuring dryer efficiency in relation to air velocity

By means of moisture ratios in kernels and cobs. The most striking effect of reducing air velocities while holding the temperature constant at 100° F. was the extreme lengthening of the drying period. Thus corn with an initial kernel moisture of 63.8 percent could be dried



Changes in air velocity during two drying runs at 100° F. (Initial kernel moisture, wet basis, was 43.4 percent for Run 1, 1950, and 63.8 percent for Run 2, 1950.) (Fig. 8)



Relation between kernel temperatures at intake and exhaust ends of two bins operated at two air velocities and the same temperature (100° F.). (Initial kernel moisture, wet basis, was 43.4 percent for Run 1, 1950, and 63.8 percent for Run 2, 1950.) (Fig. 9) to the safe level of just below 12 percent, wet basis, at the intake ends of Bins 1 and 2 (Table 11). But at the same time, the kernel moistures at the exhaust ends were still too high — 15.1 percent in Bin 1, and 17.8 percent in Bin 2, wet basis. Probably at least 8 more hours of drying would have been required. In Bin 3 the corn at the exhaust end reached a safe level after 125 hours of drying, but in Bin 4 the corn still tested 19.0-percent kernel moisture, wet basis.

The results in Table 12 represent corn having a moisture content of

Table 11. — Rate of Drying Sweet-Corn Ears at 100° F. Under Four Air Velocities Indicated by the Parts of Water Remaining in the Kernels and Cobs per Part of Bone Dry Matter, Run 2, 1950[a]

Elapsed hours	Parts of water remaining and removed							
	Bin 1—27.2 ca/m[b]		Bin 2—21.7 ca/m[b]		Bin 3—16.0 ca/m[b]		Bin 4—11.1 ca/m[b]	
	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust
	Remaining in kernels (T)							
0	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
16	1.17	1.59	1.11	1.21	1.11	1.55	1.09	1.59
28	.85	1.06	.96	1.10	1.03	1.19	1.00	1.39
40	.53	.96	.66	.73	.72	1.01	.76	1.08
52	.52	.69	.53	.55	.54	.91	.49	1.08
64	.27	.47	.25	.46	.41	.55	.44	.87
68	.25	.39	.33	.45	.39	.60	.56	.80
76	.25	.26	.20	.32	.25	.52	.31	.65
88	.13	.17	.18	.24	.21	.42	.27	.64
96	.10	.18[c]	.09	.22[c]	.14	.25	.22	.40
104	...	...	...	...	.11	.21	.14	.46
112	...	...	...	...	.09	.22	.15	.34
125	...	...	...	...	.10	.14	.11	.23[c]
Total parts of water removed	1.66	1.58	1.67	1.54	1.66	1.62	1.65	1.53
Loss per hour	.017	.016	.017	.016	.013	.013	.013	.012
Final percent moisture, wet basis	9.4	15.1	8.4	17.8	9.4	12.1	10.0	19.0
	Remaining in cobs (T)							
0	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78
16	1.63	1.86	1.70	1.70	1.78	1.94	1.70	1.94
28	1.63	1.78	1.56	1.94	1.78	1.70	1.94	2.03
40	.91	1.63	1.38	1.56	1.44	1.78	1.38	1.86
52	.85	1.17	1.17	1.08	1.33	1.70	1.08	1.86
64	.32	.92	.49	.85	.96	1.22	.92	1.94
68	.25	.64	.61	.92	.79	1.27	1.17	1.63
76	.33	.52	.39	.73	.56	1.08	.76	1.56
88	.14	.22	.25	.35	.37	.89	.67	1.56
96	.08	.20	.08	.32	.19	.44	.44	.96
104	...	...	...	...	.11	.37	.20	1.08
112	...	...	...	...	.09	.32	.16	.69
125	...	...	...	...	.11	.12	.10	.49
Total parts of water removed	1.70	1.58	1.70	1.46	1.67	1.66	1.68	1.29
Loss per hour	.018	.016	.018	.015	.013	.013	.013	.010
Final percent moisture, wet basis	7.4	16.7	6.8	24.1	9.6	11.0	8.6	32.8

Note: for explanation of "T," see page 21.

[a] Initial moisture percentages on the wet basis were 63.8 percent in the kernels and 64.2 percent in the cobs.

[b] ca/m = changes of air per minute.

[c] Not dry enough to be safe. Twelve-percent kernel moisture (equal to 0.136 parts of water remaining in the kernels) is considered safe.

Table 12. — Rate of Drying Sweet-Corn Ears at 100° F. Under Four Air Velocities Indicated by the Parts of Water Remaining in the Kernels and Cobs per Part of Bone Dry Matter, Run 1, 1950[a]

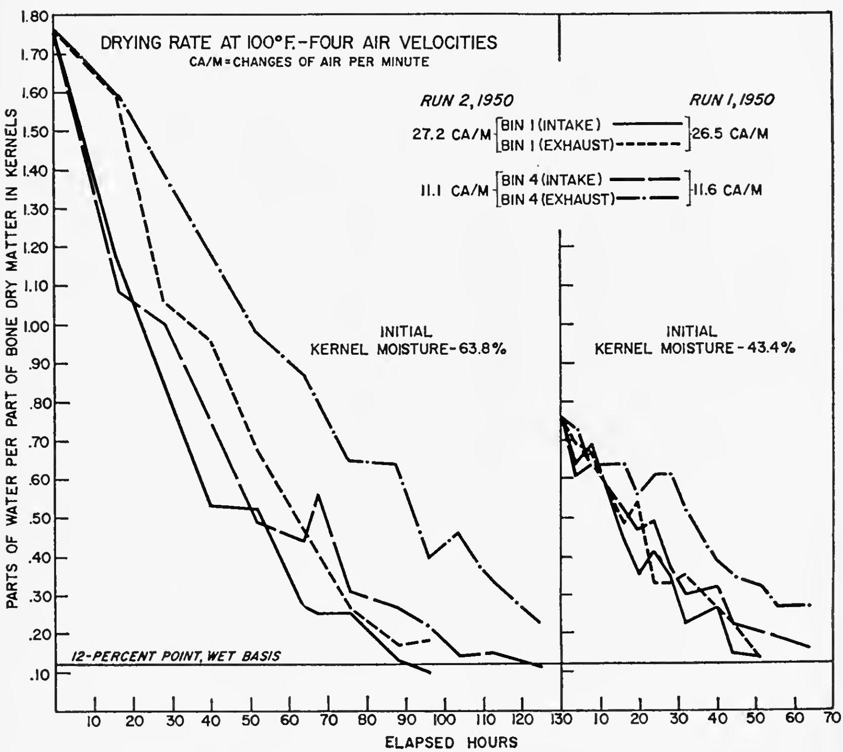
Elapsed hours	Parts of water remaining and removed							
	Bin 1—26.5 ca/m[b]		Bin 2—22.4 ca/m[b]		Bin 3—16.0 ca/m[b]		Bin 4—11.6 ca/m[b]	
	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust	Intake	Exhaust
Remaining in kernels (T)								
0	.76	.76	.76	.76	.76	.76	.76	.76
4	.64	.69	.69	.69	.89	.67	.61	.73
8	.69	.67	.61	.69	.76	.69	.64	.64
16	.44	.49	.49	.54	.67	.59	.52	.64
20	.35	.54	.49	.54	.59	.59	.47	.56
24	.41	.33	.41	.47	.59	.52	.49	.61
28	.35	.33	.27	.43	.44	.43	.37	.61
32	.23	.35	.25	.37	.43	.41	.30	.52
40	.27	.27	.19	.30	.27	.49	.32	.39
44	.15	.23	.19	.25	.32	.28	.23	.35
52	.14	.14	.14	.19[c]	.27	.32	.20	.32
56	...	...	...	...	.11	.23	.19	.27
64	...	...	...	...	.16[c]	.25[c]	.16[c]	.27[c]
Total parts of water removed	.62	.62	.62	.57	.60	.51	.60	.49
Loss per hour	.012	.012	.012	.011	.009	.008	.009	.008
Final percent moisture, wet basis	12.4	11.9	12.4	15.7	14.5	19.8	14.2	20.6
Remaining in cobs (T)								
0	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
4	1.22	1.44	1.50	1.44	1.50	1.50	1.38	1.13
8	1.33	1.27	1.33	1.50	1.56	1.50	1.44	1.27
16	1.06	1.04	.96	1.17	1.33	1.17	1.17	1.38
20	.47	1.22	1.13	1.04	1.33	1.33	1.08	1.17
24	1.00	.79	.73	1.04	1.38	1.33	1.17	1.38
28	.56	.73	.56	1.08	.96	1.00	1.00	1.22
32	.56	.61	.41	.85	1.04	.73	.85	1.27
40	.43	.39	.19	.61	.44	1.00	.82	.89
44	.16	.41	.33	.56	.85	.61	.49	.85
52	.19	.14	.41	.37	.56	.59	.44	.76
56	...	...	...	...	.09	.41	.47	.54
64	...	...	...	...	.28	.49	.35	.64
Total parts of water removed	1.31	1.36	1.09	1.13	1.22	1.01	1.15	.86
Loss per hour	.025	.026	.021	.022	.019	.016	.018	.013
Final percent moisture, wet basis	15.8	12.5	28.6	26.6	22.3	33.3	25.9	38.5

Note: for explanation of "T," see page 21.
[a] Initial moisture percentages on the wet basis were 43.4 percent in the kernels and 59.8 percent in the cobs.
[b] ca/m = changes of air per minute.
[c] Not dry enough to be safe. Twelve-percent kernel moisture (equal to 0.136 parts of water remaining in the kernels) is considered safe.

43.4 percent, which is within the range of the harvest moisture of many commercial lots. The corn in Bin 1 reached a safe moisture level after 52 hours of drying, but at the exhaust end of Bin 2 the ears were still too wet — 15.7-percent kernel moisture, wet basis. Even after 64 hours, the ears at the intake ends of Bins 3 and 4 were too wet (14.5 and 14.2 percent, respectively), and the ears at the exhaust ends were much too wet (19.8 and 20.6 percent, respectively). To dry the corn to the safe level of 12 percent would have required at least 12 hours of additional drying in Bins 3 and 4.

Slow-moving air not only lengthens the drying period, but also increases the spread in moisture content from intake to exhaust ends of the bins. When the air moves much too slowly, the ears at the exhaust ends of the bins will either fail to dry at all during the early stages of the drying period or the drying rate will be very slow. In either event, the seed is likely to be injured.

To show more graphically the differences in the drying rates at both ends of the bin, the parts of water retained per part of dry matter have been plotted for the high-velocity Bin 1 and the slow-velocity Bin 4, set at a nominal 25 and 10 changes of air per minute (Fig. 10). In Run 2, 1950, the spread between the intake and exhaust ends of



Comparison of rates of drying sweet corn at intake and exhaust ends of two bins operated at two air velocities and the same temperature (100° F.). Moistures during drying runs were calculated as moisture ratios or T values — parts of water remaining in kernels per part of bone dry matter. (Initial kernel moisture, wet basis, was 43.4 percent for Run 1, 1950, and 63.8 percent for Run 2, 1950.) (Fig. 10)

Bin 4 was much greater than the spread for Bin 1. In fact, after 64 hours of drying, the exhaust end of Bin 1 dried more rapidly than the intake end of Bin 4.

With the more mature corn used for Run 1, 1950, the differences in the drying rates of Bins 1 and 4 were not so great. In fact, the intake and exhaust ends of Bin 1 dried at nearly the same rate. In Bin 4, however, the exhaust end dried much more slowly than the intake end; otherwise there was little difference in the drying rates.

By means of vapor pressure. The moisture pickup curves (Fig. 11) for Run 2, 1950 (63.8-percent initial kernel moisture) run almost parallel over most of the drying period, indicating that the drying efficiency of the air increases inversely with the air velocity. The curves for Run 1, 1950 (43.4-percent initial kernel moisture) show essentially the same trend. The curves in Fig. 11 are about what would be expected, but they should not be interpreted to mean that the nominal 10 changes of air per minute is a better operating procedure than one of the higher velocities. Although engineering aspects such as fuel cost, heater capacity, size of fan, and bin load need to be considered, the purpose here is to discuss damage to the seed.

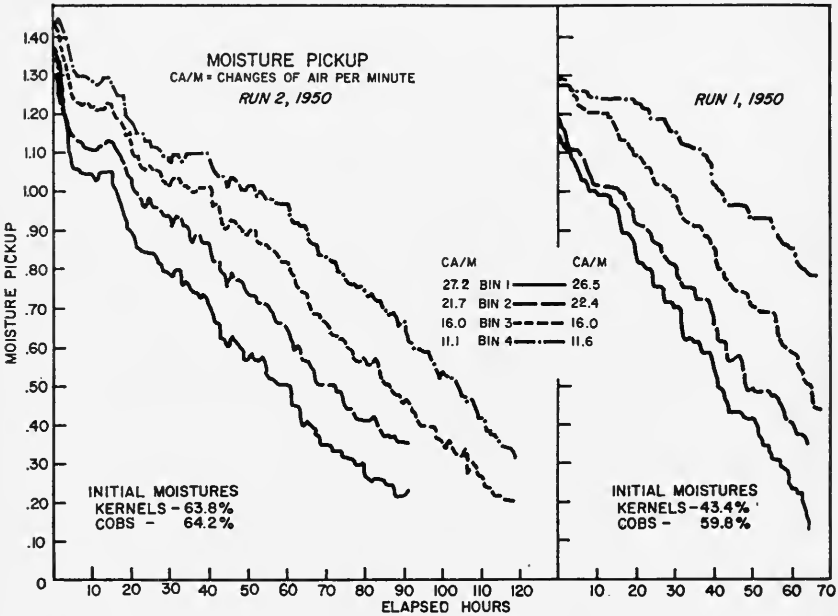
Drying does not improve the quality of the seed. It merely arrests the development of microorganisms and removes the ears from damage by weather, birds, insects, etc. The ears should be dried at the lowest possible temperature, and with the minimum air movement compatible with drying in the shortest possible time. Drying rates increase with the temperature, with a ceiling of 110° F. From the biological standpoint, however, there is no limit to the rate of air movement.

Biological Factors

Factors affecting germination and seedling growth

The final moisture tests (Tables 11 and 12) show that the ears were not always sufficiently dry to insure against spoilage. The runs were terminated on the basis of Steinlite moisture tests. These tests indicated that the ears had reached or were below 12-percent kernel moisture, but the moistures listed in Tables 11 and 12 represent the results of the more accurate oven tests. No spoilage occurred because the small samples of kernels were stored in a dry room.

The cold-test germinations were low for Run 2, 1950, and only slightly better for Run 1 (Table 13). The seed used as a check



Rate of drying two lots of sweet corn at different air velocities and the same temperature (100° F.) expressed as moisture pickup. (Initial kernel moisture, wet basis, was 43.4 percent for Run 1, 1950, and 63.8 percent for Run 2, 1950.) (Fig. 11)

germinated only 89 percent when used for Run 2, 1950, and 85 percent when used for Run 1. The check seed was a composite of the seed from Runs 1 and 3, 1950. The check seed in Run 1 had an initial moisture of 43.4 percent, and that used in Run 3 had an initial moisture of 30.9 percent. The two lots were dried rapidly at 100° F. in another dryer. The germinations listed in Table 13 were low, but they show no evidence that any harm resulted from the lengthened drying period required when the air velocity was reduced.

The green weights in Tables 14 and 15 lead to substantially the same conclusions as the germinations. There is no evidence (Table 14) that lengthened drying period had any adverse effect on seedling growth. On the basis of the final green weights alone (Table 15), there is some evidence that vigor was reduced at 16.0 and 11.6 changes of air per minute, but the results from one sampling to the next were too erratic to justify any definite conclusion.

The results of these experiments fail to coincide with other experimental results (3) and with the experience of commercial operators. The probable reason for these inconsistencies is that the slowest velocity

Table 13. — Cold-Test Germination Percentages of Sweet Corn Dried at 100° F. Under Four Air Velocities, and Sampled Periodically During the Drying Run[a]

Elapsed hours	Bin 1—27.2 ca/m[b]				Bin 2—21.7 ca/m[b]				Bin 3—16.0 ca/m[b]				Bin 4—11.1 ca/m[b]			
	Intake		Exhaust		Intake		Exhaust		Intake		Exhaust		Intake		Exhaust	
	Control	Increase	Control	Increase	Control	Increase	Control	Increase	Control	Increase	Control	Increase	Control	Increase	Control	Increase
Run 2, 1950 — initial kernel moisture, 63.8%																
16	89	−4	89	−19	89	1	89	1	89	6	88	−2	88	4	88	−3
28	88	0	88	1	88	2	95	−18	95	−18	95	−10	..	...	95	−12
40	95	−10	89	−22	89	5	89	5	89	−4	89	0	89	−2	93	−1
52	93	−4	93	−15	93	−7	93	−6	93	−1	94	−6	94	−4	94	−5
64	94	−3	94	−1	94	2	92	1	92	−3	92	0	92	−7	92	−2
68	92	−5	92	2	92	−6	92	−6	92	−5	92	0	92	−6	95	−3
76	95	−6	95	−6	95	−1	95	−6	95	0	94	−1	94	−4	94	−4
88	94	−23	94	−4	94	−3	90	−1	90	−10	90	−9	90	−1	90	3
96	90	0	91	−3	91	−1	91	2	91	−2	91	−1	91	−4	91	−1
104	..	...	..	...	..	...	..	...	91	1	91	−7	91	−2	91	−5
112	..	...	..	...	..	...	..	...	91	−2	95	−5	95	−5	95	1
124	..	...	..	...	..	...	..	...	95	−13	95	−3	95	−4	88	2
Average increase		−6.1		−7.4		−0.9		−3.1		−4.2		−3.7		−3.2		−2.5
Run 1, 1950 — initial kernel moisture, 43.4%																
4	87	3	87	5	87	3	87	1	87	−11	93	−6	93	0	93	3
8	93	−5	93	6	93	0	90	−1	90	0	90	−1	90	2	90	3
16	90	1	92	−5	92	7	92	0	92	0	92	−3	92	−4	93	0
20	93	0	93	1	93	−3	93	−4	93	3	94	−2	94	−4	94	−2
24	94	−7	94	−2	94	0	93	−4	93	−2	93	0	93	1	93	1
28	93	−2	86	5	86	3	86	4	86	8	86	0	86	7	97	−9
32	97	−10	97	−7	97	−4	97	−3	97	−3	96	−5	96	−5	96	−6
40	96	−4	96	−6	96	−7	91	4	91	0	91	−2	91	−2	91	2
44	91	3	94	−1	94	−4	94	3	94	−7	94	−1	94	−5	93	−9
52	93	2	93	1	93	−1	93	−2	93	6	96	0	96	−10	96	−14
56	..	...	..	...	..	...	..	...	96	−5	96	−10	96	1	89	−12
64	..	...	..	...	..	...	..	...	89	6	89	8	89	4	89	8
Average increase		−1.9		−0.3		−0.6		0		−0.4		−1.8		−1.2		−2.9

[a] Germination of samples equaled 89 percent at start of Run 2, 1950, and 85 percent at start of Run 1, 1950.
[b] ca/m = changes of air per minute.

in the experiments was 11.1 and 11.6 changes of air per minute. This velocity is efficient compared with that at most commercial installations, where 10 changes per minute is considered good operating procedure.

The curves in Fig. 11 show that even at the lowest velocity the moisture pickup decreased rapidly enough so that the corn was not exposed to air with a high vapor pressure for very long periods of time. The damage to seed in an artificial dryer is not due to heat alone, but to a combination of heat and high vapor pressure. Both Huelsen (3) and Kiesselbach (6) reached the conclusion that injury was progressive in relation to the length of the drying period, but their experiments dealt primarily with temperatures and initial moistures, not with air velocities. Considerable work has been done on the life span of seeds as affected by temperature and relative humidity (1, 13). Even at storage temperatures no higher than 80° F., the germination of various kinds of vegetable seeds decreased as the humidity of the air increased. Although the length of the storage periods of the seeds far exceeded the drying time in these experiments, the same principles apply.

The final moistures or "T values" (Tables 11 and 12) show that the moisture remaining in the kernels and cobs at the exhaust ends of the bins almost always exceeded the residual moisture at the intake ends. At any sampling period during the run, similar differences prevailed. In addition, the spread between intake and exhaust ends tended

Table 14. — Average Green Weights of Seedlings Grown From Sweet Corn Harvested at 63.8-Percent Kernel Moisture, Dried at 100° F. Under Four Air Velocities, and Sampled Periodically During the Drying Run (Run 2, 1950)

Elapsed hours	Bin 1—27.2 ca/m[a]		Bin 2—21.7 ca/m[a]		Bin 3—16.0 ca/m[a]		Bin 4—11.1 ca/m[a]	
	Weight (grams)	Percent of check	Weight (grams)	Percent of check	Weight (grams)	Percent of check	Weight (grams)	Percent of check
0	.51	64.6	.51	64.6	.51	64.6	.51	64.6
16	.46	58.2	.62	78.5	.60	75.9	.56	70.9
28	.46	58.2	.61	80.3	.54	73.0	.50	67.6
40	.50	67.6	.66	89.2	.55	74.3	.60	77.9
52	.51	63.8	.53	66.2	.48	65.8	.58	87.9
64	.60	90.9	.62	83.8	.54	66.7	.64	79.0
68	.58	74.4	.53	70.7	.56	74.7	.60	77.9
76	.56	70.9	.61	77.2	.49	63.6	.54	72.0
88	.58	77.3	.60	75.0	.56	66.7	.61	72.6
96	.57	68.7	.64	78.0	.56	68.3	.59	73.8
104	...	....	...	....	.54	69.2	.54	69.2
112	...	....	...	....	.60	78.9	.62	82.7
124	...	....	...	....	.54	72.0	.52	66.7
Average[b]	.54	70.0	.60	77.7	.55	70.8	.58	74.8

[a] ca/m = changes of air per minute.
[b] Not including initial sample.

Table 15. — Average Green Weights of Seedlings Grown From Sweet Corn Harvested at 43.4-Percent Kernel Moisture, Dried at 100° F. Under Four Air Velocities, and Sampled Periodically During the Drying Run (Run 1, 1950)

Elapsed hours	Bin 1—26.5 ca/m[a]		Bin 2—22.4 ca/m[a]		Bin 3—16.0 ca/m[a]		Bin 4—11.6 ca/m[a]	
	Weight (grams)	Percent of check	Weight (grams)	Percent of check	Weight (grams)	Percent of check	Weight (grams)	Percent of check
0	.65	92.8	.65	92.8	.65	92.8	.65	92.8
4	.73	104.3	.76	108.6	.66	94.3	.84	121.7
8	.67	97.1	.67	93.0	.70	93.3	.65	86.7
16	.76	100.0	.70	92.1	.69	90.8	.70	92.1
20	.73	96.0	.72	94.7	.66	85.7	.72	92.3
24	.77	98.7	.72	90.0	.81	97.6	.80	96.4
28	.75	94.9	.78	104.0	.74	98.7	.76	98.7
32	.80	100.0	.74	92.5	.76	92.7	.76	90.5
40	.78	92.8	.77	93.9	.78	97.5	.77	96.2
44	.75	96.2	.84	110.5	.75	98.7	.68	85.0
52	.80	96.4	.84	101.2	.79	105.3	.74	108.8
56	...	....	...	....	.74	108.8	.74	97.4
64	...	....	...	....	.74	89.2	.70	84.3
Average[b]	.75	97.6	.75	98.1	.74	96.0	.74	95.8

[a] ca/m = changes of air per minute.
[b] Not including initial sample.

to become greater as the air velocity decreased. The few inconsistencies were due to the difficulties of securing representative ear samples. Therefore, in a low-efficiency dryer, the spread between intake and exhaust ends is large, and to avoid underdrying at the exhaust end it would be necessary to overdry the ears at the intake end. Probably the impaired germination in a low-efficiency dryer can be partly attributed to direct damage as a result of condensation of moisture on the ears at the exhaust end early in the run; prolonged exposure to high vapor pressures; and part of the ears being underdried.

RELATION OF KERNEL AND COB MOISTURES DURING THE DRYING PERIOD

Commercial operators know that it is easiest to shell corn immediately after removal from the dryer. Holding the ears more than a few hours increases the difficulty of shelling, presumably because the cobs contain more moisture than the kernels and some of the cob moisture migrates to the kernels. No work was done on this particular phase of sweet-corn-drying problems, but using the same drying equipment, Huelsen and Thompson (4) showed that the kernels of popcorn pick up moisture from the cobs. They pointed out, however, that since the cobs represent only a small part of the total weight of the ear, the possible kernel moisture increase would be limited.

The data in Table 16 consist of the initial and final kernel- and cob-moisture percentages from 10 runs with four varying temperatures and constant air velocity and four additional runs in which the air velocities were varied and the temperature held at 100° F. Except when the initial kernel moistures were very high (64 percent, columns 1 and 2), the initial cob moistures always exceeded the kernel moistures. Substantially the same relationship was found by Huelsen and Bemis (5) in popcorn.

The experience of commercial operators would lead one to assume that at the close of a run the cob moistures would be higher than the kernel moistures. When ears are dried to kernel moistures of about 12 percent and are not shelled, the kernel moistures will usually increase, presumably absorbing most of the moisture from the cobs rather than from the air. Huelsen and Thompson (4) showed that when artificially dried popcorn ears were stored in closed jars, the kernels absorbed moisture from the cobs. The data from the 10 runs in Table 16 show that there was considerable variation in the kernel-cob-moisture relationship when the runs terminated.

Of the 10 runs where temperatures varied, the cobs at the intake ends contained a higher final percentage of moisture than the kernels 19 out of 40 times. At the exhaust end the count was 24 times. The bin temperature seemed to have no effect. Since the count fluctuated around 20, a random variation was assumed — there is an equal chance that the cob-moisture percentage may or may not exceed the kernel-moisture percentage. The cob-moisture percentages at the exhaust end of the 110° F. bin were higher than the kernel-moisture percentages 7 out of 10 times, and the cob-moisture percentages at the exhaust end of the 130° F. bin were higher than the kernel-moisture percentages 8 out of 10 times. The cob moistures were higher 5 out of 10 times in the 120° F. bin, and 4 out of 10 times in the 100° F. bin. These results scarcely support the theory that when ears are dried rapidly the cobs are apt to retain a higher percentage of moisture than the kernels at the close of the run.

In this discussion of moisture percentages the reader is cautioned against misinterpreting the results in Table 16. These moisture percentages are reported on the wet basis because it is the method used commercially. When the ear is shelled, 75 to 80 percent of the total ear weight consists of kernels; the balance is cob. Therefore, while the moisture percentage of the cobs may be slightly higher than that of the kernels, the actual weight of water in the cobs is much less than that in the kernels. If all of the cob moisture were transferred to the

Table 16.—Comparison of Kernel- and Cob-Moisture Percentages, Wet Basis, at the Beginning and End of Ten Runs With Different Temperatures and Equivalent Air Velocities and Four Runs at the Same Temperature (100° F.) and Different Air Velocities

Percent moisture at start of run, wet basis		Final moisture percentages after drying at different temperatures																			
		100° F.					110° F.					120° F.					130° F.				
		Hours in dryer	Intake		Exhaust		Hours in dryer	Intake		Exhaust		Hours in dryer	Intake		Exhaust		Hours in dryer	Intake		Exhaust	
Kernels	Cobs		Kernels	Cobs[a]	Kernels	Cobs[a]		Kernels	Cobs[a]	Kernels	Cobs[a]		Kernels	Cobs[a]	Kernels	Cobs[a]		Kernels	Cobs[a]	Kernels	Cobs[a]
53	63	64	14	+2	16	+3	64	9	−4	15	−3	48	10	+3	15	−5	40	9	−1	17	+5
49	58	68	8	−2	11	+2	52	8	−2	15	+4	44	10	−1	12	0	44	8	+1	13	+5
42	56	68	9	+3	11	0	56	9	+3	8	+2	44	9	+3	13	+3	32	11	+6	15	+4
41	60	48	7	−4	11	−6	40	8	−4	13	−1	32	8	−2	9	+4	24	12	+1	13	0
39	57	68	11	0	13	−1	40	9	−1	14	+5	32	12	+4	13	+3	28	12	+6	13	+7
32	53	40	11	+4	13	−1	32	11	0	14	+6	28	9	−1	8	−4	28	9	−2	11	+5
29	43	40	12	+1	13	+4	40	10	+4	12	+7	28	10	+3	11	+1	28	8	+1	11	+5
24	41	32	11	+1	9	−2	28	12	0	10	−2	20	11	0	11	+4	12	11	−2	14	+9
20	27	20	10	+2	7	+6	20	9	+3	5	+11	16	8	+2	5	0	16	8	0	4	+1
16	23	12	10	−4	10	−5	8	9	−4	12	+8	8	8	−4	10	−1	8	8	−4	11	−5
		Final moisture percentages after drying at 100° F. with different air velocities																			
		Bin 1—26.2 ca/m[b]					Bin 2—21.5 ca/m[b]					Bin 3—15.8 ca/m[b]					Bin 4—11.2 ca/m[b]				
64	64	96	9	−2	15	+2	96	8	−2	18	+6	125	9	0	12	−1	125	10	−1	19	+14
43	60	52	12	+3	12	+1	52	12	+16	16	+10	64	14	+8	20	+14	64	14	+12	21	+18
41	58	48	9	−2	11	−2	48	9	−4	10	−2	64	7	−3	10	−1	64	8	−2	12	+5
30	48	32	8	−4	12	−2	32	10	−2	13	+3	40	10	−2	12	+3	48	12	+4	18	+10

[a] Increase or decrease as compared with kernels.
[b] ca/m = changes of air per minute. Average of four runs.

kernels at the end of the run, the total moisture percentage of the kernels would be only slightly increased.

In general, the four runs with varying velocities (Table 16) lead to the same conclusion. Only the runs in which the final kernel moistures reached 12 percent or less should be considered. Of the 16 final intake moistures (4 for each of the four bins) only 2 were above 12 percent. Only 3 final cob moistures of the remaining 14 were higher than the final kernel moistures. Of the 16 final exhaust kernel moistures, only 8 had dried to 12 percent or lower, and in this group, 3 were paired with a higher cob moisture. All the remaining 8 lots above 12-percent kernel moisture were paired with cobs having a higher moisture percentage.

The wide spread between intake and exhaust kernel moistures, especially in the bins having the lowest air velocities, indicates that part of the shelling troubles encountered by commercial operators is due to a wide range of kernel moistures at the close of a run. This conclusion is consistent with the velocity data in Table 16, where the final kernel moistures at the discharge ends of the two lower-velocity bins were higher at the exhaust than at the intake ends. As a matter of fact, practically all of the kernel moistures at the exhaust ends of the 10 variable temperature runs were higher than those at the intake ends. At 100°, 110°, and 120° F. the exhaust ends were higher in each of the three bins 7 out of 10 times. In the 130° F. bin they were higher in 9 out of 10 runs.

PRACTICAL APPLICATION OF EXPERIMENTAL RESULTS

Since 1924, commercial drying of sweet corn has gone through a series of evolutionary changes. Not much progress was made until the late 1930's, when the increasing use of hybrids made drying with heat mandatory. The early installations constructed by seedsmen were crude. Most of the dryers used were variations of the Wisconsin bin dryer designed by the University of Wisconsin for drying field corn. Nearly all of these dryers were inefficient and lacked both sufficient heat and adequate fan capacity for drying sweet corn. Typical performance was discussed earlier in this publication.

The bin dryer is widely used for field corn in Illinois and elsewhere. When used for sweet corn, this type of dryer is inefficient because there are fundamental differences in the kind of material being dried. Field-corn seed consists almost entirely of large double-cross ears that do not shell easily when dropped into the bin. The ears are relatively free of silks and attached husks, and the initial kernel moisture rarely exceeds 25 percent.

On the other hand, practically all sweet-corn hybrids are single crosses, which means that the bin is loaded with small ears having a number of attached husks and silks. Frequently the ears are damaged by birds and ear worms, and the moisture content at harvest may be as high as 55 percent. When the bins are loaded from a conveyor (the usual practice), a dense mass of husks, shelled kernels, and silks collects in the bin under the discharge end of the conveyor. It is almost impossible for a fan to develop enough pressure to force air through this mass. Wire cones placed on the floor of the bin under the discharge end of the conveyor scatter this material, although not very efficiently. Another trouble has been the tendency for the ears in the center of the bin to dry faster than the ears in the four corners.

Usually the bins were loaded 8 feet deep, giving results like those shown in Tables 1 and 2. Some operators decreased the depth of the load; others increased both the heating and fan capacity.

Dryer construction has changed materially in the last 10 years, but few new bin dryers for sweet corn have been constructed because of the cost of the structure and the complex conveyor needed.

Several "open pit" or tunnel dryers have been constructed at a reasonable cost. This type of dryer consists of an open pit equipped with concrete retaining walls and a concrete floor. The retaining walls extend about a foot above ground level. The dimensions should be about 8 by 8 feet in cross section and from 60 to 80 feet long. Trays of corn are placed over the open pit and heated air is driven through them. Suitable wooden cross and longitudinal members are required to support the trays. A concrete apron is built around the pit to support the lift truck used to load and unload the trays. Two kinds of trays may be used — a wide, shallow type, approximately 4 by 4 feet and 14 to 15 inches deep, which can be loaded with 12 inches of corn, or a box 4 feet deep of any suitable length and width that the lift truck can handle. Whatever the size of the box or trays, the total depth of ears over the pit should not exceed 4 feet. Either the entire pit must be covered with trays of corn or some provision made to cover the unused part of the pit. For that reason, and because of the heat loss in an excessively long tunnel, the pit should not exceed 80 feet in length.

The first of these pit dryers was constructed in Idaho, and several mistakes were made that required rectifying. One of the errors was in limiting the depth of the pit to 4 feet at the intake end and tapering to 2 feet in depth at the far end. Since moving air tends to travel in a straight line, the trays nearest the intake end received little or no air at all, and those at the far end received the most. Baffles failed to remedy the situation. Another difficulty resulted because corn on one side of the pit dried faster than corn on the other side.

To obtain better air movement, the first pit was reconstructed and a second pit was built. Both the new drying pit and the old one were provided with a plenum or expansion chamber between the heating unit and the pit proper. The plenum should be 8 to 10 feet long and have the same cross-section dimensions as the pit — about 8 by 8 feet. The purpose of the plenum is to slow the velocity of the air and to equalize its movement, thus tending to eliminate the back eddies that form around the edges of a swiftly-moving column of air. Building a plenum eliminated most of the difficulties that characterized the first pit dryer described above, but did not overcome the disadvantages of the shallow pit.

The principal weakness of the pit dryer is the tendency for the trays at the far end of the pit to dry more rapidly than those at the end nearest the heat source. Building a large plenum and increasing the depth of the pit seems to be the only structural method of overcoming this handicap. An operational method is to pile additional trays of wet corn on top of the partially dried trays at the far end of the pit. This serves to heat the corn and to start drying it. As soon as the lower trays have dried sufficiently, they are removed and replaced by additional trays that have had a preliminary drying.

Whether each station over the pit should be covered with several shallow trays or one deep tray is still debatable. When four shallow trays are stacked, the bottom one dries first and the top one last. The lift truck will have to move trays 2, 3, and 4 in order to remove tray 1. Trays 2, 3, and 4 will then have to be replaced, but tray 5 can be stacked on top of tray 4, thus constantly maintaining a total of four trays at each station.

When a single box containing a 4-foot depth of corn is used, the moisture content of the top 12 inches (the slowest part to dry) will determine the time for removing the entire box. Although the use of four shallow trays will speed up the drying capacity, more labor and machine hours are required. The operator will have to determine for himself which method best fits his requirements.

The pits are usually covered with a sheet-iron roof of suitable height and with sufficient overhang to keep off the rain. Since the trays are provided with gaskets to prevent escape of air when they are stacked, it has been suggested that the top tray be covered with a sheet-iron cone having a suitable ventilator so that no superstructure of any kind will be necessary.

The heating units used are the direct type — the hot gases from an oil burner are blown directly through the corn. This type of heater is the most efficient. In some installations, soot, caused by imperfect combustion due to lack of air, discolors the seed. Soot also covers the fan blades and may unbalance the fan, leading to bearing trouble.

A pit dryer is a simple structure that is relatively inexpensive to build, but any skimping on depth of pit or size of expansion plenum is likely to lead to trouble. If there is any doubt as to the proper size, it is wise to design a plenum that may be larger than necessary and a pit that is too deep.

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5M—4-60—70398