Artificial Drying and Rehydration of Popcorn and Their Effects on Popping Expansion

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By W. A. Huelsen and W. P. Bemis[1]

THE DEMAND FOR POPCORN has increased tremendously since 1942. Its popularity is due to its relatively low price and to the improved quality resulting from the introduction of hybrids.

The popcorn industry, consisting of firms marketing both raw and manufactured (popped) corn, has grown rapidly with practically no background of research on which to base its operations. Consequently each operator forms his own theories without having many facts on which to build. To add to the difficulty, much of the information which is available is either misapplied or erroneous. Such questionable information may lead an operator to doubt the quality of a crop and so reject it, even when the grower holds a written contract.

Purpose of the investigation. One of the problems about which the industry has had inadequate information is the conditioning of popcorn to secure maximum popping expansion. Popcorn is harvested in the same way as field corn but is stored in specially constructed cribs. The length of the storage varies with the moisture content at harvest. When the moisture content is around 20 percent, the popcorn is too moist and will not be ready for popping until late the following spring. On the other hand, in the fall of 1953 popcorn at Urbana, Illinois, dried in the field to 9 or 10 percent moisture and had to be stored to pick up moisture during the winter. Since consumption is concentrated primarily in the late fall and winter (Eldredge and Lyerly, 7*), a considerable portion of the crop in the northern states must be carried over for a whole year.

Storage entails a large investment in buildings and ties up capital in popcorn that must be conditioned. Costs would be greatly reduced if popcorn were harvested, dried by artificial heat, rehydrated to optimum moisture content, packaged, and sold without intervening periods of storage. The purpose of the experimental work described in this bulletin was to test the effects of the various methods of artificial drying and rehydration on the popping expansion of popcorn.

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[1] W. A. Huelsen, Professor of Vegetable Crops; W. P. Bemis, Assistant Professor of Vegetable Crops.

* This and similar numbers refer to "Literature Cited" on page 68.

Preliminary work. In tests by Huelsen and Thompson (9) with Japanese Hulless single cross Illinois 52, it appeared that popcorn could be dried with artificial heat without necessarily impairing popping expansion. The experimenters acknowledged, however, that the control of the final moisture content was difficult. They overdried the popcorn and obtained satisfactory expansion by adding sufficient water to bring it to the optimum moisture content. This method, while feasible on a small scale, is obviously impractical where large volumes must be handled. Rehydration by means of storage in artificially humidified air recommended by Dexter (4) is equally impractical for large-scale operations.

Realizing that artificial drying could not be recommended unless it were possible to control the final moisture content with some degree of precision, Bemis and Huelsen (1) experimented with steam blanching and found that this process would rehydrate overdried popcorn rapidly with good control. Since blanching is a mechanized process, the quantity of popcorn which may be handled is unlimited.

Although drying by artificial heat and steam blanching are purely mechanical processes subject to precise control, popcorn is a highly variable biological product which may be expected to respond in a rather complex manner when subjected to drying and blanching. Huelsen and Thompson (9) and Bemis and Huelsen (1) discuss several of the factors which are involved. The discussion in this bulletin will cover some of the same ground, but will also include information not published elsewhere.

MATERIALS AND TECHNIQUES

The experiments cover the four-year crop period from 1951 through 1954. Field plantings were made at successive periods each year so that ears with a wide range of maturities would be available in the fall.

The following four hybrids were planted in 1952[1] on May 14, June 5, and June 11:

Iopop 5 — (11 × 15) × (5 × 12) — white
Iopop 6 — (Purdue SG18 × 30A) × Iowa 28 — yellow
Purdue 32 — (Purdue SG30A × 18) × SA 24 — yellow
Illinois 52 — (Illinois 18 × Illinois 1) — white

[1] Since the 1951 crop results are not discussed in detail, no planting data for that year are given.

In 1953 on May 26, June 2, June 10, and June 18, plantings were made of:

Iopop 6
Iopop 7 — (27 × 29) × (5 × 12) — white
Purdue 202 — (A1-6 × SA 1490-3) — yellow
Illinois 4 — (5 × 1) — white

In 1954, Iopop 6 and Purdue 202 were planted on May 25 and June 11.

Illinois 4 and Illinois 52 are rapidly maturing hybrids and the earliest of the group. Iopop 5, Iopop 6, and Iopop 7 are midseason types followed closely by Purdue 202. Purdue 32, on the other hand, matures very slowly at Urbana and is an ideal type for experimental drying.

During the 1952 season, temperatures were slightly above normal and in the later part of the season, rainfall was below normal. In 1953 temperatures were above normal and rainfall was decidedly deficient. In addition, Stewart's disease was severe. The hybrid Illinois 4 was a complete failure and the quality of Iopop 7 was so poor it could not be used. In 1954 temperatures were much above normal and rainfall was consistently deficient.

Drying Equipment

A scale-model bin dryer was used in all of the experiments. This pilot plant consisted of four bins, each constructed as a single unit complete in itself with its own heating unit, fan, and controls so that it could be operated independently. Each bin could be adjusted to dry from room temperature to 140° F. and had sufficient excess fan capacity to permit a wide range of air velocities. For a detailed description of the dryer see the Appendix, pages 64 to 68.

Drying Runs and Moisture Tests

The experimental results were obtained from 21 drying runs. There were 6 runs in 1951 with a range of initial moistures from 16.2 percent to 26.3 percent; 6 runs in 1952 with the initial moistures ranging from 12.3 percent to 29.6 percent; 4 runs in 1953 with moistures from 12.2 percent to 40.6 percent; and 5 runs in 1954 with moistures from 16.1 percent to 50.1 percent. The ears of corn were packed carefully in the dryer trays so that each tray was filled to its maximum capacity.

Since the main object in artificial drying is to dry to a predetermined moisture content (overdried and underdried corn will not pop satisfactorily), moisture tests were taken regularly. Samples were taken for moisture tests at the beginning of each run and at approximately 4-hour intervals during the day. The method of sampling for moisture tests consisted of removing two or three ears from each tray. In 1952, the samples from Trays 1 and 2 were bulked in one lot and those from Trays 3 and 4 in another. In 1953 and 1954, the samples from each tray were tested separately. Each sample was shelled and then cleaned with a fan. Duplicate 100 gram aliquots of shelled corn were weighed out and each placed in 307 × 306 cans. The cobs were cut into suitable lengths and packed into cans of the same size. The samples were dried at least 144 hours at 176° F. in a Despatch oven equipped with forced-air circulation and operated at maximum capacity with the dampers wide open.

Since moisture tests are likely to give highly variable results, this method was checked against a vacuum oven. Several random samples of popcorn were divided into two parts. One part was dried in the manner described; the other was ground in a Wiley mill and then dried in a vacuum oven for 16 hours at 158° F. These steps were followed by storage in a desiccator for 5 hours. For the open oven test, the average of all samples was 11.15 percent moisture; for the vacuum oven test, the average was 11.36 percent. The small difference indicates that the open oven test was satisfactory.

Throughout these experiments it was considered highly desirable to find a quicker and yet reliable moisture test, but neither of the two quick methods tried checked very well with the oven test.

Difficulties in testing moisture. Actual popping tests would seem to be the logical method of determining how long popcorn should remain in the dryer. Such tests were used in 1952 and 1953, but they also proved to be unreliable. Usually an increase in popping expansion occurred when the corn approached the 13-percent moisture level. A period followed when expansion remained nearly the same. Then as the corn became too dry, expansion decreased. However, a sample rarely reached its maximum popping expansion immediately after removal from the dryer. The unequal distribution of moisture within the kernels as well as from ear to ear prevented maximum expansion at that time even when the average moisture content was at the optimum. After the corn was shelled and allowed to equilibrate for several weeks, popping expansion almost always increased.

In fact it was hardly possible to draw a representative sample of reasonable size from the dryer. Ears varied widely in moisture content as they came from the field and did not dry out at the same rate. Even in a highly efficient dryer, the rate of moisture loss was not the same in all parts of the mass of popcorn. A volume of corn averaging 12 percent moisture contained ears ranging from 8 to 14 percent. Thus there were two inherent sources of error which will explain some of the discrepancies in the moisture percentages to be discussed later. Of course, variations in moisture content are progressively reduced as the average moisture decreases.

Moisture relationships between cobs and kernels in the field. Huelsen and Thompson (9) observed that the cobs of Illinois Hybrid 52 had a higher moisture content at harvest than the kernels. Higher cob moistures at harvest were noted in all the hybrids used in these experiments except in instances where the popcorn dried to an unusually low moisture content in the field. These differences were investigated further in an experiment consisting of a comparison of the maturities of Iopop 6 and Purdue 202 harvested three times a week beginning August 27 and ending November 18. (Data for Purdue 202 are shown in Table 1; the data for Iopop 6 are omitted because the results were similar.) All samples were dried at room temperature and reconstituted with water to 12.5 percent moisture before popping.

At the start of the experiment when the kernel moisture of the two hybrids was about 50 percent (Table 1), the cobs contained only slightly more moisture. With the exception of a short initial period (August 27 to September 1), the cobs of the two hybrids dried at the same rate in the field until September 24. The kernels of the two hybrids also dried at practically the same rate between August 27 and September 24, a period which was nearly rainfree, the total rainfall (coming in two showers, one on August 30 and another on September 20) being 0.15 inch. Between September 24 and October 1, the Iopop 6 kernels lost moisture more rapidly than the Purdue 202 kernels. After October 1, the drying rates of the kernels were the same, Iopop 6 maintaining a consistently lower moisture content than Purdue 202. Between October 4 and October 18, the Purdue 202 cobs continued to lose moisture, but the Iopop 6 cobs changed very little. After October 18, the changes of moisture content in either hybrid were very slight. Considering the moisture loss from both the kernels and the cobs, these comparisons show that Iopop 6 dried more efficiently in the field.

In spite of the fact that the two hybrids differed in their maturities, the moisture relationship between the cobs and the kernels remained the same in each hybrid. Therefore by plotting a curve, it would be possible to predict the cob moisture if the kernel moisture were known. This knowledge would be of value to the buyer who purchases the popcorn directly from the field, since the shelling percentage could be readily computed.

Measures of maturity. A principal purpose of the experiment was to determine when Iopop 6 and Purdue 202 could be considered fully mature. One method of determining maturity was to secure the popping expansions[1] of properly conditioned samples. (The data for Purdue 202 are shown in Table 1.) As the result of systematic testing of room-dried samples, it was found that the two hybrids could be considered fully mature when the kernel moisture at harvest varied between 35 and 30 percent. Below 30 percent moisture, the popping expansions of properly conditioned popcorn failed to increase any further, as shown by the ratios in the last column of Table 1.

Another measure of maturity consisted of determining the dry weights of the kernels (column 4, Table 1). The dry weights of Iopop 6 did not change materially after the moisture content reached 29.8 percent. In Purdue 202, the equivalent point was 30.6 percent. In column 5 of Table 1, the ratios between the dry weights per kernel of Purdue 202 and the average dry weights per kernel of all lots harvested below 30 percent moisture have been calculated. When the ratios reached about 96 percent of the average, there were no further increases in popping expansion.

The relationship between dry weight per kernel and popping expansion may be used as the basis for prediction. If the dry weight is known, it is possible to predict the popping expansion. For this purpose the equation $x = c\frac{yz}{ba}$ is proposed in which

a = average weight in grams of popping sample measured in the 6-ounce cup provided with the official volume tester.
b = average dry weight per kernel in milligrams.
c = average popping expansion.
y = dry weight per kernel in milligrams of sample tested.
z = same as a, except that it is the weight of the sample under test.

An example from the first line of Table 1 gives the following:

$$\frac{9.55}{15.35} \times \frac{182}{195.93} \times 38.53 = 22.26$$

The actual expansion was 22.5 volumes. The values of *z* and *a* have to be determined experimentally for each hybrid, but this presents no difficulties.

The correlations between the actual popping expansions and those calculated from the equation are 0.990 for Iopop 6 and 0.989 for Purdue 202. The coefficient for the two hybrids combined is 0.976.

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[1] For explanation of how popping expansion is measured, see page 17.

Table 1. — Moisture Content at Harvest, Dry Weights of Kernels and Cobs, and Popping Expansion in Purdue 202 Popcorn

Harvest date (1954)	Rainfall (inches)	Kernels			Cobs		Popping expansion at 12.5 percent moisture	
		Percent moisture	Dry weight[a] (milligrams)	Percent of average dry weights of samples harvested under 30 percent moisture	Percent moisture	Dry weight per cob (grams)	Volumes[b]	Percent of average expansion of samples harvested under 35 percent moisture
8-27	....	48.3	9.55	62.2	49.0	21.10	22.5	58.4
8-30	.08	43.5	12.15	79.2	47.0	22.50	30.75	79.8
9-1	....	41.6	12.25	79.8	46.3	22.35	31.0	80.4
9-3	....	41.2	13.15	85.7	47.4	21.65	34.0	88.2
9-6	....	37.6	13.95	90.9	46.7	23.10	35.0	90.8
9-8	....	33.9	14.80	96.4	47.5	23.00	39.0	101.2
9-10	....	32.1	14.60	95.1	48.1	22.40	38.5	100.0
9-13	....	31.4	15.05	98.0	49.0	22.65	39.25	101.9
9-15	....	30.6	14.90	97.1	48.6	22.85	40.0	103.8
9-17	....	28.1	15.35	....[c]	44.9	22.95	38.5	....[c]
9-20	.07	26.5	15.25	....	45.2	22.80	39.25	....
9-22	....	24.9	15.50	....	43.0	22.50	37.5	....
9-24	....	23.3	15.25	....	41.8	22.70	38.25	....
9-27	....	21.3	15.20	....	36.6	22.35	38.25	....
9-29	.09	19.9	15.45	....	33.2	24.00	38.5	....
10-1	.09	22.6	15.55	....	38.5	22.75	37.25	....
10-4	.45	19.8	15.95	....	33.7	23.40	38.0	....
10-6	.11	18.0	15.15	....	27.0	22.45	39.25	....
10-8	....	17.5	15.55	....	25.3	23.45	39.25	....
10-11	2.21	17.1	14.80	....	24.8	22.65	38.5	....
10-13	.52	17.5	14.70	....	27.2	22.90	38.5	....
10-15	.67	17.7	15.80	....	28.7	24.00	37.75	....
10-18	.01	16.6	15.45	....	22.4	24.60	38.0	....

[a] Average weight per kernel harvested under 30 percent moisture, 15.35 milligrams.
[b] Average popping expansion of kernels harvested under 35 percent moisture, 38.53 volumes.
[c] Ratios were calculated only to the point where no further changes occurred.

Table 2. — Differences in Moisture of Cobs and Kernels Before and After Drying at 110° F., 1952

Run number	Hybrid	Part of bin[a]		Initial moisture			Hours in dryer	Moisture loss per hour (percent)		Final moisture		
		Trays 1-2	Trays 3-4	Cobs	Kernels (percent)	Difference		Cobs	Kernels	Cobs	Kernels (percent)	Difference
1	Iopop 5	x		26.4	15.0	11.4	23	.69	.25	10.5	9.3	1.2
			x	26.4	15.0	11.4	23	.42	.17	16.7	11.2	5.5
1	Iopop 6	x		28.6	19.9	8.7	23	.88	.44	9.8	8.4	1.4
			x	28.6	19.9	8.7	23	.72	.37	12.0	11.4	.6
1	Purdue 32	x		40.2	26.3	13.9	47	.74	.33	5.4	10.7	−5.3
			x	40.2	26.3	13.9	47	.71	.30	6.8	12.2	−5.4
1	Illinois 52	x		16.8	15.7	1.1	12	.59	.44	9.7	10.4	− .7
			x	16.8	15.7	1.1	12	.62	.44	9.3	10.4	−1.1
2	Iopop 5	x		22.7	14.7	8.0	35.5	.54	.19	3.4	7.8	−4.4
			x	22.7	14.7	8.0	35.5	.51	.21	4.7	7.1	−2.4
2	Iopop 6	x		21.0	15.5	5.5	23.5	.49	.26	9.4	9.3	0.1
			x	21.0	15.5	5.5	23.5	.56	.25	7.7	9.7	−2.0
2	Purdue 32	x		41.2	26.6	14.6	47.5	.71	.31	7.6	12.0	−4.4
			x	41.2	26.6	14.6	47.5	.69	.30	8.2	12.2	−4.0
2	Illinois 52	x		40.0	21.0	19.0	35.5	1.01	.34	4.1	7.8	−3.7
			x	40.0	21.0	19.0	35.5	1.01	.35	4.2	8.6	−4.4

[a] Since heated air flows from the top to the bottom of the bin, Trays 1 and 2 should dry faster than Trays 3 and 4.

Table 3. — Differences in Moisture of Cobs and Kernels Before and After Drying at 110° F., 1953

Run number	Hybrid	Tray in bin	Initial moisture: Cobs	Initial moisture: Kernels (percent)	Initial moisture: Difference	Hours in dryer	Moisture loss per hour: Cobs (percent)	Moisture loss per hour: Kernels (percent)	Final moisture: Cobs	Final moisture: Kernels (percent)	Final moisture: Difference
1	Iopop 6	1	41.9	21.4	20.5	24	1.48	.52	6.4	9.0	−2.6
		2	40.7	24.6	16.1	36.5	.90	.39	8.0	10.5	−2.5
		3	52.9	33.4	19.5	60.5	.80	.42	4.7	8.0	−3.3
		4	58.1	39.5	18.6	60.5	.90	.52	3.8	8.1	−4.3
1	Purdue 202	1	39.6	24.9	14.7	36.5	.82	.38	9.7	10.9	−1.2
		2	38.5	24.2	14.3	44.5	.67	.31	8.5	10.6	−2.1
		3	45.6	33.3	12.3	48.5	.65	.40	6.4	9.3	−2.9
		4	52.4	40.6	11.8	60.5	.78	.51	5.1	9.6	−4.5
1	Iopop 7	1	11.2	9.0	2.2	12.5	.56	+.02	4.2	9.2	−5.0
		2	36.4	11.2	25.2	12.5	1.34	+.06	19.6	12.0	7.6
		3	43.3	26.8	16.5	36.5	.89	.45	10.9	9.9	1.0
		4	45.4	24.8	20.6	44.5	.73	.32	12.9	10.3	2.6
3	Iopop 6	1	12.1	12.2	−.1	15.0	+.09	.13	13.4	10.3	3.1
	Purdue 202	2	20.4	14.7	5.7	36.0	.42	.17	5.3	8.6	−3.3
	Iopop 6	3	12.1	12.2	−.1	15.0	.25	.14	8.3	10.1	−1.8
	Purdue 202	4	20.4	14.7	5.7	19.5	.53	.17	10.0	11.4	−1.4
3	Purdue 202	1	37.9	23.4	14.5	36.0	.85	.38	7.3	9.7	−2.4
	Iopop 6	2	30.5	17.6	12.9	36.0	.68	.26	5.9	8.2	−2.3
	Purdue 202	3	37.9	23.4	14.5	36.0	.77	.33	10.2	11.4	−1.2
	Iopop 6	4	30.5	17.6	12.9	36.0	.68	.24	5.9	8.7	−2.8
3	Iopop 6	1	51.2	31.0	20.2	47.5	.85	.41	10.8	11.0	− .2
	Purdue 202	2	47.5	29.6	17.9	60.0	.72	.36	4.0	7.9	−3.9
	Iopop 6	3	51.2	31.0	20.2	47.5	.93	.46	6.9	9.3	−2.4
	Purdue 202	4	47.5	29.6	17.9	60.0	.70	.35	5.3	8.9	−3.6
3	Iopop 6	1	30.5	17.6	12.9	47.5	.48	.16	7.6	10.0	−2.4
	Purdue 202	2	37.9	23.4	14.5	60.0	.47	.20	9.5	11.6	−2.1
	Iopop 6	3	51.2	31.0	20.2	84.0	.53	.25	6.8	10.2	−3.4
	Purdue 202	4	47.5	29.6	17.9	84.0	.46	.22	9.1	11.2	−2.1

Moisture relationships in the dryer. During artificial drying the cobs dried more rapidly than the kernels (Tables 2 and 3), and in some instances the percentage loss of moisture from the cobs was more than twice as great as that from the kernels. At the end of the drying run (Tables 2 and 3; Figs. 1, 2, and 3), the cobs usually contained less moisture than the kernels. The principal exceptions were Iopop 5 (Table 2) and Iopop 7 (Table 3). Both of these hybrids have thick ears and large cobs, many of which are fasciated. Purdue 32 and Purdue 202 have slender cobs; Iopop 6 has cobs slightly thicker, and Illinois 52 has cobs somewhat thicker than those of Iopop 6.

Huelsen and Thompson (9) noted that at the end of the drying runs, Illinois 52 cobs contained slightly more moisture than the kernels. They suggested using this difference to rehydrate overdried kernels by storing the ears for a short period before shelling. This method would be of no value with hybrids having slender cobs or with hybrids having thicker cobs which have dried to very low moisture contents.

Drying Rate

The drying rate depends upon the movement of heated air passing around the ears. Increasing the temperature, the velocity of the air, or both will accelerate drying. The drying rate may be determined by moisture tests and by recording changes in the exhaust air. Both methods were used in these experiments. (The methods of taking moisture tests were described in "Drying Runs and Moisture Tests.")

Changes in the exhaust air were determined by means of wet and dry thermocouples placed at the intake (A in Fig. 17) and exhaust (B in Fig. 17).[1] The methods of calculation are best illustrated by an actual calculation. Assume that the intake readings are 109° F. dry bulb and 71° wet bulb and the exhaust readings are 93° dry bulb and 67° wet bulb, then

(1) $109° - 71° = 38°$ depression = 13 percent relative humidity at 109°.

(2) Saturation pressure at $109° = 2.5196$ inches of mercury.

(3) $2.5196 \times .13$ R.H. = .3275 vapor pressure of heated intake air.

(4) $93° - 67° = 26°$ depression = 23.5 percent relative humidity at 93°.

[1] The relative humidities at 30 inches of mercury were determined from U. S. Weather Bureau tables using the differences between the wet and dry readings in the usual way. Vapor pressures were taken from tables published by the American Society of Heating and Ventilating Engineers entitled "Thermodynamic Properties of Moist Air, 29.921 Inches of Mercury." The saturation pressure readings as inches of mercury are used throughout this publication.

(5) Saturation pressure at 93° = 1.5600 inches of mercury.
(6) 1.5600 × .235 = .3666 vapor pressure of exhaust air.
(7) From above, 2.5196 — .3275 = 2.1921 vapor pressure deficit of entering air.
(8) From above 1.5600 — .3666 = 1.1934 vapor pressure deficit of exhaust air.
(9) 2.1921 — 1.1934 = .9987 moisture pickup.

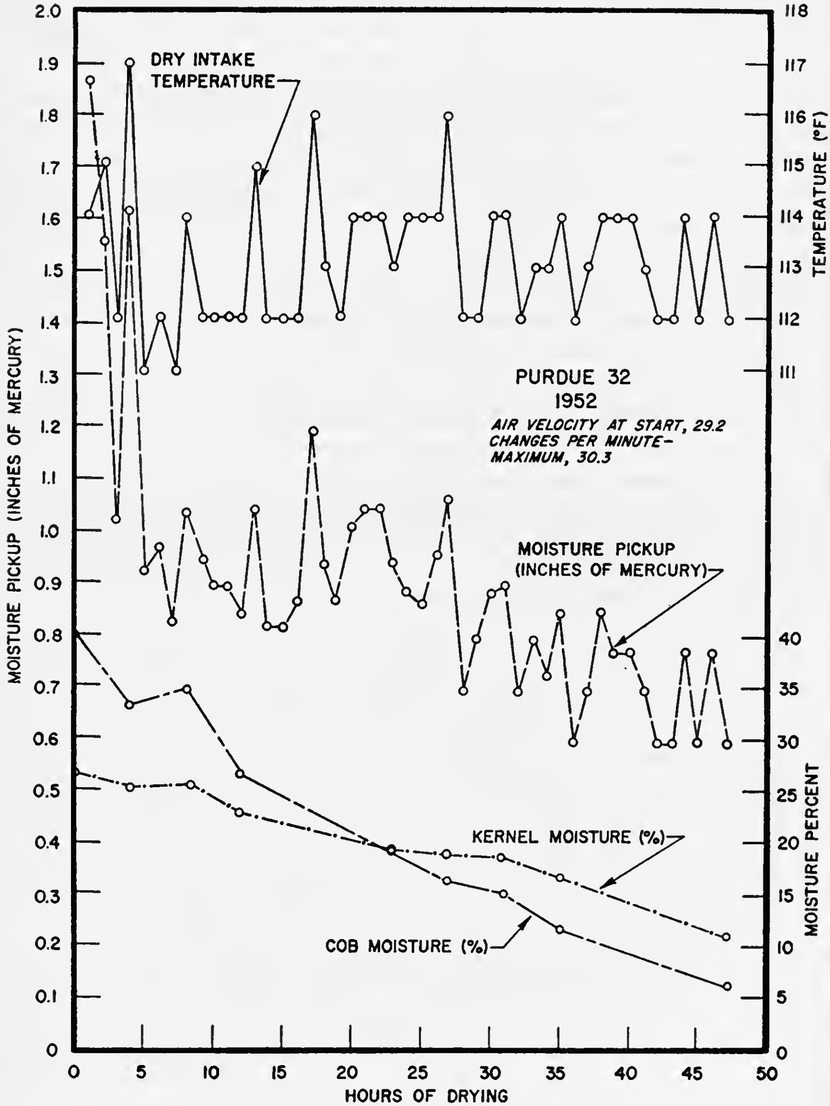
The above steps may be shortened considerably as follows:

$$2.5196 \times (1.00 - .13) \text{ minus } 1.5600 \times (1.00 - .235) = .9987.$$

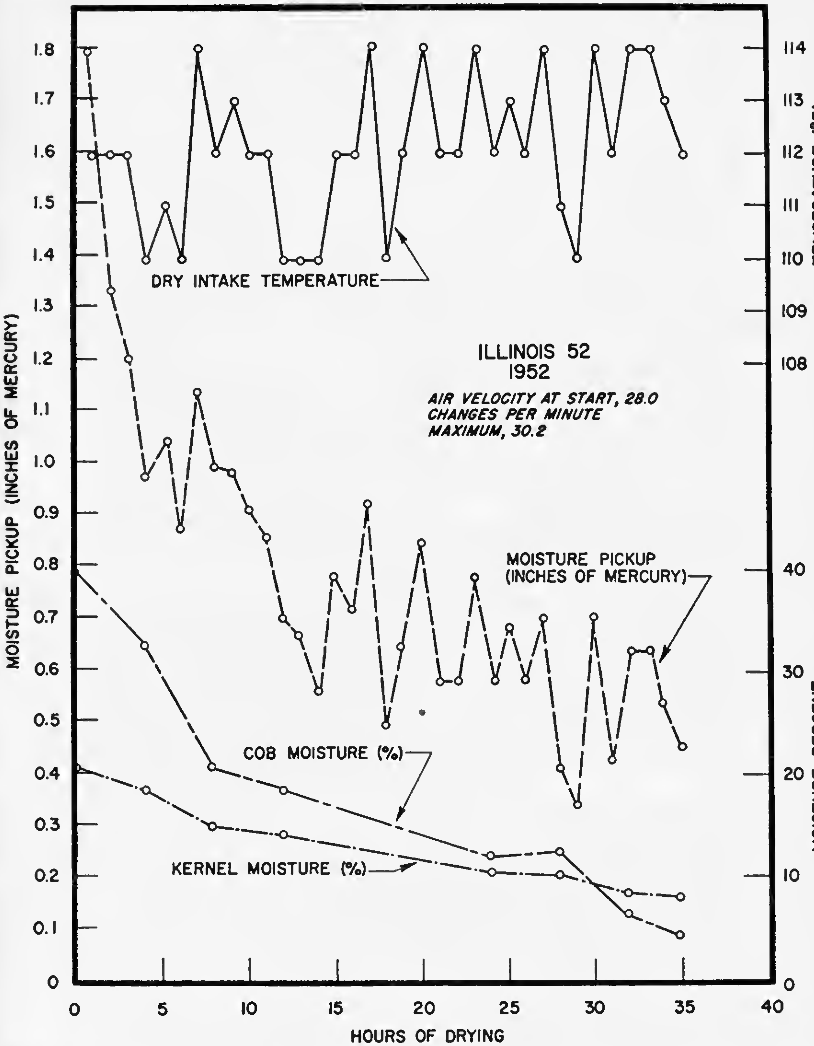
The vapor pressure deficit of the air is a convenient term to express its theoretical drying power. In the example above, the deficit in the exhaust air is somewhat large indicating that more corn could have been dried had it been piled deeper in the bin. The difference between the intake and exhaust vapor pressure deficits is the theoretical moisture absorbed by the air from the corn, and this moisture pickup is a direct expression of the rate of drying.

Differences in recording. The moisture pickup values (Figs. 1, 2, and 3 for example) show relatively large fluctuations at each hourly reading. These fluctuations, which were not due to faulty recording instruments, may be explained by considering the functioning of the instruments used. With the Brown 12-station strip-chart recorder, each station is recorded every six minutes. The curves were drawn from spot readings taken every hour, that is, each tenth recording. Thermocouples give an instantaneous response to temperature fluctuations and represent the readings at a particular moment. There is no lag as there is with a mercury thermometer and with the thermostats regulating the temperature. Each thermostat lag or overrun of the intake temperatures is recorded instantaneously. The variations in moisture-pickup values were, therefore, entirely functional, owing to the variations in dry intake temperatures which, in turn, were owing to lag in the thermostats. Foxboro recording thermographs were also used as a check on the thermocouples, but because of lag in these instruments, the momentary temperature fluctuations were not recorded.

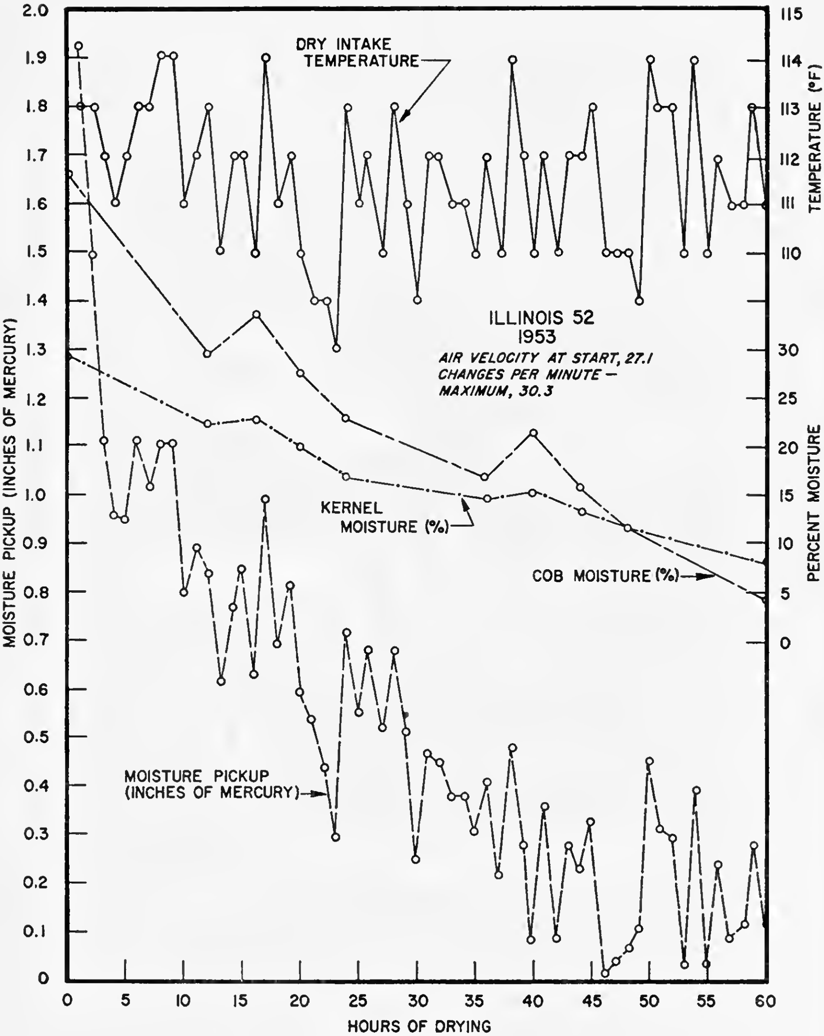
The moisture-pickup curves in Figs. 1, 2, and 3 followed the same general trend as the curves showing the actual changes in moisture content of the cobs; that is to say, there was a rapid drop the first few hours of drying followed by a more uniform rate of loss. The rate of loss from the kernels was considerably more uniform throughout the entire drying period than that from the cobs. Theoretically the moisture pickup would be reduced to zero if the corn were allowed to remain in the dryer long enough.



The moisture-pickup curves in this figure and in Figs. 2 and 3 follow the same general trend as the curves showing the actual changes in the moisture content of the cobs. There was a rapid drop the first few hours of drying followed by a more uniform rate of loss. The rate of loss from the kernels was considerably more even throughout the drying period. (Fig. 1)



The percents of moisture loss from the cobs and kernels of Illinois 52 form a pattern similar to that of Purdue 32 shown in Fig. 1. The principal difference is that the smaller cobs of Purdue 32 lose moisture more rapidly than those of Illinois 52. (Fig. 2)



The curves for the 1953 crop of Illinois 52 parallel those for 1952. The moisture-pickup values for Figs. 1, 2, and 3 show relatively large fluctuations at each hourly reading. As explained on page 13, these fluctuations were due to the functioning of the instruments used. (Fig. 3)

Air changes per minute. The air velocities are not plotted, but they were recorded periodically with an anemometer. The extreme velocities of the three runs recorded in Figs. 1, 2, and 3 as changes of air per minute ranged from 27.1 to 30.3. The air velocities were somewhat slower at the beginning of each run and tended to increase slightly as the corn lost moisture and the volume shrank.

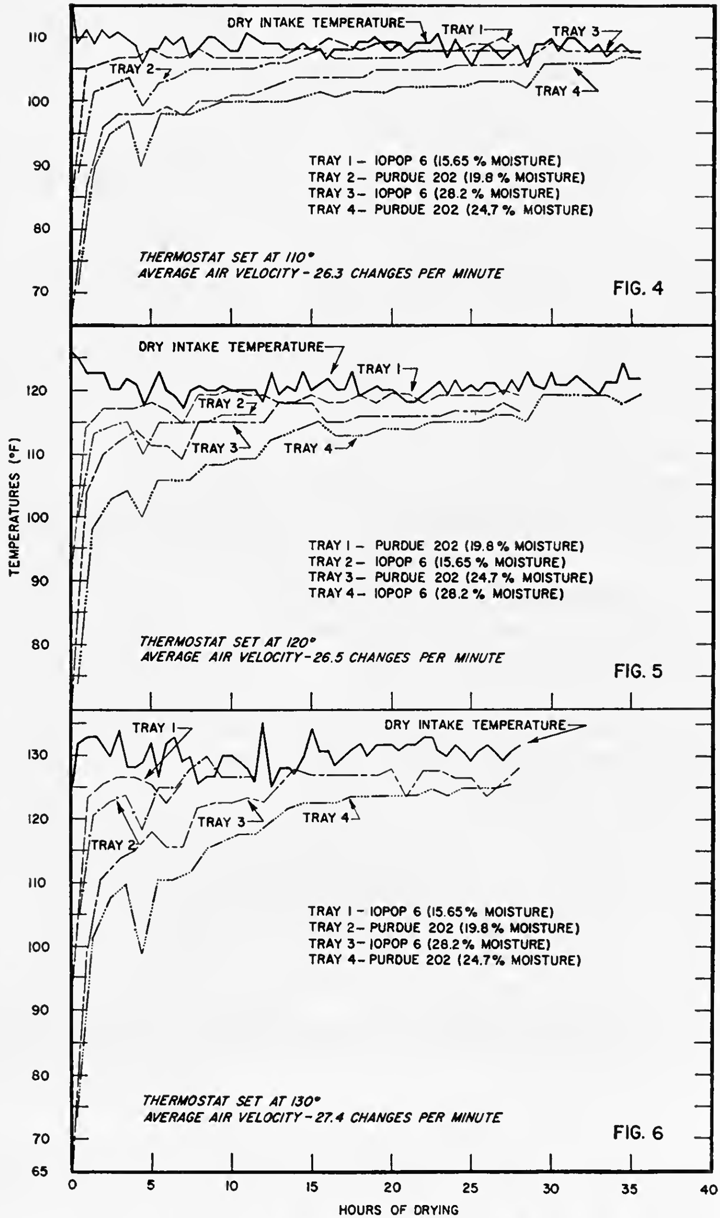
The drying in these experiments was considerably more rapid than in the usual commercial dryer where 10 changes of air per minute is regarded as adequate. Ramser (11) in a report of 53 drying tests with field corn in farmers' cribs showed that the average air flow varied from 4.6 to 7.7 cubic feet per bushel of ear corn. This rate equals 1.8 to 3.1 changes of air per minute. Such a slow drying rate would still be too rapid if the recommendations of Brunson and Smith (2) were to be followed. These investigators maintained that rapid artificial drying was the cause of low popping expansion and suggested a rate low enough so that the moisture loss would not exceed 1 percent a day.

Drying at high temperatures. A temperature of 110° is commonly used in seed-corn dryers. Since it has no adverse effect on germination, that temperature was used in most of the drying runs. In 1951, Huelsen and Thompson (9) used air intake temperatures as high as 130° without any apparent adverse effects on popping, but they worked with partially loaded bins and gave no details showing the actual temperatures of the air surrounding the ears. Their experiments were repeated with fully loaded bins of Iopop 6 and Purdue 202 dried at temperatures of 110°, 120°, and 130° F. The actual temperatures surrounding the ears were recorded by thermocouples placed in the center of each tray (Figs. 4, 5, and 6). As would be expected, the temperatures increased as the drying period advanced and the top tray (Tray 1), nearest to the heat, was the warmest. The temperature differences between trays were greatest in the 130° bin and least in the 110° bin. The effects of these temperatures on the popping expansion of corn are discussed on pages 24 and 26.

Popping Technique

Unless a satisfactory method is worked out, gross errors are likely to occur in measuring popping volume. The method in common use, consisting of measuring out a unit volume of raw corn, popping, and then measuring the volume again, is basically crude. Several refinements briefly described by Huelsen and Thompson (9) have been worked out.

The equipment used for popping was the "Official Volume Tester" usually described as the "O.V.T." (manufactured by C. Cretors and Co., Chicago, Illinois). The tester was equipped with a pyrometer, and



Iopop 6 and Purdue 202 were dried at three different temperatures: 110°, 120°, and 130° F. Thermocouples placed in the center of each tray in the bins recorded the actual temperatures surrounding the ears. The temperature differences between trays were greatest in the 130° bin and least in the 110° bin. (Figs. 4, 5, and 6) the measuring column was extended so that expansions up to 40 volumes could be read directly. The popping compound or "seasoning" used in all the experiments consisted of 59 milliliters of hydrogenated coconut oil, which was dumped into the pan and brought to 470° F. before the popcorn was added.

The volume of raw popcorn was measured in the 235-milliliter cup provided with the popping device, but extreme variations in weight as high as 4.7 percent were noted. The variations in Table 4 alone exceed 3 percent. The method used throughout these experiments consisted of pouring five measures from each sample and weighing them individually. The sample actually popped was a weighed sample, the weight being the average of the five measures. It was soon noted that the measured samples would vary in weight from 170 grams to 200 grams, and that the variations were governed by the moisture content, the hybrid, and its maturity at harvest.

Popping expansion was measured in volumes. The cup mentioned above, which was used to measure the amount of raw popcorn dumped into the pan, represented one volume. If the popping expansion was 31 volumes, the one cup of raw popcorn had expanded to 31 cups of popped corn. An expansion of 30 volumes is the minimum now acceptable to the trade.

The possibility of using a weighed instead of a measured sample was explored further, and the results shown in Table 4 are typical of a series of experiments. The popping expansion was calculated on the basis of both a 195-gram sample and a 200-gram sample. The 200-gram sample represented the weight per measure of popcorn when the moisture was low (7.35 percent in Table 4). The 195-gram sample represented the weight at the optimum moisture of about 12.5 percent (Table 4). On the 200-gram basis, the maximum deviation of the calculated expansion from the actual expansion was 1.1 volumes high and on the 195-gram basis, it was 0.6 volumes too low. These deviations are no greater than the variations among measured samples. Accordingly a weighed instead of a measured popping sample may just as well be used, but it is first necessary to establish the volume-weight relationship for each lot at some moisture percentage close to the optimum.

The data in Table 4 show that kernel moisture, weight per sample, and popping expansion are associated. Weight per sample and moisture content have a functional relationship as indicated by the correlation coefficient of -0.980. The regression coefficient suggested that volumetric sample weights might be used to predict the moisture content, but there was considerable variation from one lot to another, the governing factors again being the variety and its maturity at harvest.

Table 4. — Kernel Moisture, Weight of Samples, and Popping Volume, Iopop 6

(Harvested at 15.5 percent moisture, overdried by artificial heat, and rehydrated with water)

Rehydrated moisture content[a] (percent)	Average weight of measured sample (grams)[b]	Popping expansion[c]				
		Actual volumes	Calculated volumes of constant weights of 200 grams	Deviation	Calculated volumes of constant weights of 195 grams	Deviation
7.35	200.2	21.7	21.7	0	21.1	−.6
8.00	199.4	24.0	24.1	.1	23.5	−.5
8.50	198.8	25.7	25.8	.1	25.2	−.5
9.05	198.0	26.7	27.0	.3	26.3	−.4
9.45	197.8	28.7	29.0	.3	28.3	−.4
10.20	197.4	29.7	30.1	.4	29.3	−.4
10.80	197.6	31.7	32.1	.4	31.3	−.4
10.95	195.8	32.7	33.4	.7	32.6	−.1
11.45	196.2	34.0	34.7	.7	33.8	−.2
12.20	195.4	34.5	35.3	.8	34.4	−.1
12.55	195.8	35.7	36.5	.8	35.6	−.1
13.20	195.2	35.7	36.6	.9	35.7	0
13.55	194.8	35.2	36.1	.9	35.2	0
14.15	194.6	34.5	35.5	1.0	34.6	.1
14.65	193.4	33.5	34.6	1.1	33.8	.3
15.00	194.0	32.5	33.5	1.0	32.7	.2
15.85	193.0	31.5	32.6	1.1	31.8	.3

[a] Correlation between moisture content and volumetric sample weight = −0.980.
[b] Sample weights are averages of five measures.
[c] Popping expansions are averages of two tests each.

FACTORS AFFECTING POPPING EXPANSION

Biological as well as mechanical factors will affect popping expansion. Hybrids differ in their inherent ability to pop satisfactorily, and environmental conditions during the growing season will cause variations from one season to the next in any given hybrid. Mechanical factors such as drying conditions and moisture content, in so far as they can be varied artificially, also affect popping expansion.

Effect of Kernel Moisture on Popping Expansion

All investigators who have worked on the problem emphasize the importance of moisture in relation to popping volume. Carr and Ripley (3) and Weatherwax (13) recognized the importance of moisture content, but concluded that optimum popping expansion was possible through a rather wide range of kernel moistures. Willier and Brunson (14) noted that popping expansion varied little between 10.1 and 12.7 percent moisture, but their readings were all below 20 volumes. Today, with hybrids, at least 30 volumes expansion is expected. Stewart (12) in his extensive investigations considered 13 to 15 percent moisture to be the optimum range for popping, but he did not determine whether there were any varietal differences. Eldredge (5) showed that Iopop 6 expanded 30 volumes or more between 10 and 16 percent moisture in contrast with Iopop 5, Iopop 7, and Purdue 32 which had a much narrower range. Judging from the published work, popping expansion does not vary greatly within the moisture range of 2 or 3 percent near the optimum. The minima and maxima stated by different investigators vary according to the method of determining the moisture content and probably according to seasonal and varietal differences.

The relationship between popping expansion and moisture content in five of the six hybrids used in these experiments is plotted in Fig. 7. Since 30 volumes is regarded by the trade as satisfactory expansion, comparisons may be made on that basis. Purdue 202 expanded 30 volumes or more within the range of 9 to 15 percent moisture; Purdue 32 and Iopop 6 within 10 to 15 percent; whereas Illinois 52 had a range of only 11 to 14 percent. Iopop 5 barely reached 30 volumes at about 13 percent moisture. Owing to their greater versatility, Iopop 6, Purdue 32, and Purdue 202 are much better suited for commercial use than Illinois 52 and Iopop 5.

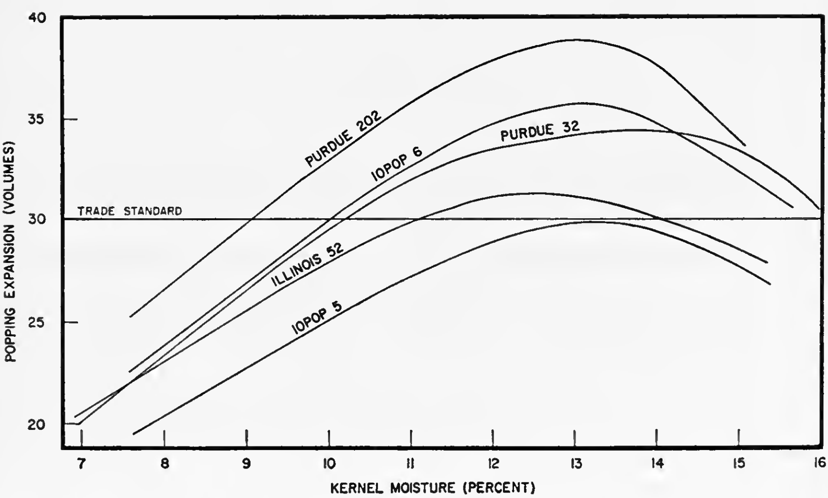
Effect of Maturity on Popping Expansion

Huelsen and Thompson (9) observed that when the moisture content of the artificially dried hulless hybrid Illinois 52 exceeded 24.4 percent at harvest, popping expansion tended to decrease. In 1953, samples of Iopop 6 and Purdue 202 were harvested over a wide range of maturities, beginning at about 40 percent moisture, and dried both by artificial heat and at room temperature. All the samples were overdried and then rehydrated as near to 13 percent moisture as possible. The results (Table 6) show that the popping expansions of the room-dried samples of both hybrids started to decline when the moisture content at harvest was above 33 percent. When the lots were dried at 110°, there was a marked reduction in popping expansion if the moisture content at harvest exceeded 24 to 25 percent. Since it was possible that the 13-percent moisture level might not be the optimum for immature corn, such samples were rehydrated to a series of different levels ranging from 9.5 to 14.5 percent, but the results were not significantly different (Table 6).

As far as possible, somewhat similar comparisons were made of the four hybrids harvested in 1952 (Table 5), but maturity was much further advanced and there was no trend such as that in Table 6. It appears then that artificial drying will have the least injurious effect if popcorn is harvested at moistures not exceeding 25 percent.

Table 5. — Moisture Content at Harvest, Method of Drying, and Popping Expansion, 1952

Harvest moisture percent	Room dried			Artificially dried at 110° F.		Difference in popping expansion
	Rehydrated	Moisture percent	Popping expansion	Moisture percent	Popping expansion	
			Iopop 5			
20.6	No	9.50	26.2	9.55	27.2	1.0
19.4	Yes	12.20	30.5	11.20	28.8	−1.7
18.0	No	9.95	26.2	10.00	27.2	1.0
15.5	No	9.05	24.0	10.05	25.0	1.0
15.0	No	9.75	24.5	10.10	25.5	1.0
14.7	Yes	12.20	29.0	.....	....	...
14.4	No	8.75	21.5	9.75	25.0	3.5
			Iopop 6			
19.8	Yes	12.00	34.8	11.75	36.5	1.7
19.7	Yes	12.80	37.2	10.75	34.0	−3.2
18.9	Yes	12.40	37.8	11.00	35.2	−2.6
17.6	Yes	12.20	35.0	11.10	32.8	−2.2
16.8	No	9.00	30.0	9.65	28.5	−1.5
16.2	No	9.35	30.0	10.05	33.0	3.0
15.5	Yes	12.20	36.8	11.05	36.2	− .6
			Purdue 32			
29.6	No	10.40	33.0	11.10	33.5	.5
26.8	No	9.85	29.7	10.80	33.0	3.3
26.6	Yes	12.40	38.0	12.85	32.0	−6.0
24.4	Yes	12.30	33.5	13.05	29.5	−4.0
21.2	Yes	12.15	38.0	12.75	34.2	−3.8
			Illinois 52			
21.0	No	8.85	25.2	8.90	23.8	−1.4
21.0	Yes	12.45	29.0	.....	....	...
15.7	Yes	11.80	31.5	10.10	30.0	−1.5
12.3	No	8.25	24.5	8.90	25.0	.5



The relationship betwen popping expansion and moisture content in five hybrids. Thirty volumes expansion is considered a satisfactory standard by the popcorn industry. Accordingly, Iopop 6, Purdue 32, and Purdue 202 are much better suited to commercial use than Illinois 52 and Iopop 5. (Fig. 7)

Table 6. — Moisture Content at Harvest, Method of Drying, and Popping Expansion of Rehydrated Samples, 1953

Harvest moisture percent	Room dried		Artificially dried (110°)		Difference in popping expansion		Expansion (volumes) of immature popcorn artificially dried at 110° F. and reconstituted to moisture percentages of—		
	Moisture percent	Popping expansion (volumes)	Moisture percent	Popping expansion (volumes)	Volumes	Percent	9.5-10.5	11.5-12.5	13.5-14.5
Purdue 202									
40.60	12.95	31.5	12.90	17.0	−14.5	−46.0	17.5	17.2	17.0
34.15	13.10	35.5	14.05	23.5	−12.0	−33.8	24.0	23.5	23.5
33.30	12.90	38.8	12.70	27.8	−11.0	−28.4	27.5	27.8	27.2
28.05	12.95	38.0	13.05	34.0	−4.0	−10.5	35.0	34.5	34.0
24.95	12.95	39.0	13.30	36.5	−2.5	−6.4	....[a]	....[a]	....[a]
24.70	12.90	35.2	13.50	35.0	− .2	− .6	....	....	....
24.25	12.80	39.5	13.40	35.8	−3.7	−9.5	....	....	....
21.45	12.90	40.2	13.70	36.0	−4.2	−10.4	....	....	....
19.80	12.90	39.2	13.70	37.2	−2.0	−5.1	....	....	....
18.35	13.15	40.2	12.90	36.8	−3.4	−8.5	....	....	....
Iopop 6									
39.50	12.40	22.2	13.10	11.5	−10.7	−48.2	11.5	11.0	11.5
33.80	13.15	33.2	13.80	25.0	−8.2	−24.7	26.0	25.0	25.0
33.40	12.80	36.2	12.70	27.0	−9.2	−25.4	26.0	28.0	27.0
28.65	12.95	37.2	12.95	33.0	−4.2	−11.3	33.5	33.5	29.5
28.20	13.00	34.8	13.50	30.2	−4.6	−13.2	....[a]	....[a]	....[a]
24.60	12.85	36.5	13.10	35.5	−1.0	−2.7	....	....	....
22.20	12.80	38.5	13.50	35.5	−3.0	−7.8	....	....	....
21.35	12.80	33.5	12.85	31.5	−2.0	−6.0	....	....	....
15.65	12.50	36.2	13.25	33.5	−2.7	−7.5	....	....	....
14.10	12.90	32.0	13.45	32.2	.2	.6	....	....	....

[a] At this moisture level, the popcorn was considered mature.

Effect of Artificial Drying on Popping Expansion

Huelsen and Thompson (9) reported that artificial drying at temperatures up to 130° F. had no adverse effects on the popping expansion of the 1951 crop of Illinois 52. Further experiments in 1952 with three additional hybrids (Table 5) showed that some lots of artificially dried popcorn failed to pop as well as comparable room-dried checks.

The 1953 and 1954 experiments were laid out with the specific purpose of determining the relation between drying and popping expansion. The 1953 results (Table 6) showed that the damage to popping expansion caused by artificial drying decreased as maturity advanced. However, the reductions in Table 6 appear to be unusually large because the room-dried controls in many instances exceeded what may be regarded as normal expansion for the hybrids. For example, Nelson (10) reported an average of 35.2 volumes expansion for Purdue 202 and 33.1 volumes for Iopop 6. Eldredge (6) noted that the average expansion of Purdue 202 ranged from 36.1 to 41.4 volumes in a 3-year period, and the averages of Iopop 6 in a 4-year period ranged from 33.7 to 38.9 volumes.

From the results in Tables 5 and 6, it would appear that artificial drying impairs popping expansion in some manner. All the lots reported in these two tables were dried at 110° F., the temperature almost universally used in seed-corn dryers. This temperature has no adverse effect on germination and no satisfactory explanation except immaturity can be advanced as the cause of the reduction in popping expansion. Rapid drying could create an internal moisture gradient within the kernel which might have an adverse effect on expansion, but this condition would correct itself in a matter of a few days.

In 1953, the popping expansions of Purdue 202 and Iopop 6 harvested at two maturities and dried on the ear at three temperatures (110°, 120°, and 130°) were compared (Table 7). All the artificially dried lots had a lower expansion than the room-dried controls, but there was no evidence that the 130° temperatures caused any more damage than the 110° temperature. With respect to maturity, the more mature lot of Purdue 202 suffered the greater damage, but in Iopop 6, the situation was reversed. Position in the dryer seems to have been the important factor affecting the expansion of the Purdue 202 lots, since the upper trays were exposed to higher temperatures than the lower trays, as shown in Figs. 4, 5, and 6. In Iopop 6, this relationship was reversed except at the 130° drying temperature.

Owing to the contradictory nature of the data in Table 7, further work on the question was undertaken in 1954. Corn was dried on the

Table 7. — Effect on Popping Expansion of Drying Popcorn on the Ear at Three Different Temperatures and in Different Positions in the Bin, Run 4, 1953

Average changes of air per minute	Bin temperature (°F.)	Tray in bin[a]	Hours in bin	Kernel moistures (percent)			Cob moistures (percent)			Popping expansion at 13.0 percent moisture (volumes)	
				Initial	Final	Average hourly loss	Initial	Final	Average hourly loss	Dried by heat	Room-dried increase
					Purdue 202						
26.30	110	2	28.0	19.80	10.90	.32	30.5	9.5	.75	37.2	2.0
26.30	110	4	35.5	24.70	12.40	.35	43.5	9.6	.95	35.0	.2
26.54	120	1	28.0	19.80	9.65	.36	30.5	6.0	.88	36.0	3.2
26.54	120	3	28.0	24.70	10.60	.50	43.5	9.3	1.22	34.5	.7
27.44	130	2	11.5	19.80	12.40	.64	30.5	8.5	1.91	36.5	2.8
27.44	130	4	28.0	24.70	9.40	.55	43.5	8.4	1.25	34.5	.7
					Iopop 6						
26.30	110	1	28.0	15.65	8.80	.24	22.1	6.0	.58	34.5	1.7
26.30	110	3	35.5	28.20	11.65	.47	52.0	11.1	1.15	30.2	4.5
26.54	120	2	11.5	15.65	9.90	.50	22.1	9.5	1.10	35.0	1.2
26.54	120	4	35.5	28.20	8.60	.55	52.0	7.7	1.25	31.2	3.5
27.44	130	1	7.0	15.65	10.85	.69	22.1	12.0	1.44	33.5	2.8
27.44	130	3	28.0	28.20	7.90	.72	52.0	7.4	1.59	32.2	2.5

[a] Tray 1 was closest to the source of heat.

ear at four different temperatures with both room-dried and outdoor-dried controls. The controls consisted of ears placed in onion-mesh sacks, some of which were hung in a dry attic and others hung outdoors under the roof of a loading platform having a southern exposure.

The outdoor controls, which dried more slowly than the room-dried controls, were consistent in giving slightly better popping expansions. The results in Table 8 show that almost without exception artificial drying had a slight adverse effect on popping expansion even when unheated forced air was used, but none of the lots fell below 30 volumes. When heat was applied, the damage was slightly greater, but no consistent trend appeared as the temperatures increased. However the two lots in Table 8 had relatively low initial moisture contents and therefore would not incur as much damage as lots with a high initial moisture content.

Speed of drying seems to be the factor which has the adverse effect on popping expansion. The outdoor controls popped the best, the room-dried were next best, and the artificially dried were lowest in popping expansion.

Effect of air velocity during drying. Drying time is affected not only by the temperature of the air but also by its velocity. Increasing the air velocities during artificial drying will speed up the moisture loss from the ears. Two runs having four different air velocities at 110° were completed in 1954 (Tables 9 and 10). Four lots in these runs (Purdue 202 at 40.7 and 33.3 percent moisture and Iopop 6 at 37.8 and 32.5 percent moisture) were very immature. In these four lots, the ears from the bins with the lowest air velocities popped the best, but, with one exception, all were below 30 volumes. The popping expansions were reduced when the air velocities were increased above 10.8 changes of air per minute. Air velocities had no consistent effect on the remaining four lots, the moisture content of which ranged from 22.0 to 29.6 percent.

Position of tray and popping expansion. In 1952 each bin was loaded with a single harvest of a hybrid and since tray temperatures and drying rates decrease from the top to the bottom of the bin, as shown in Figs. 4, 5, and 6, a further comparison of the effects of drying rates was possible. Part of the data appears in Table 11. Selection of the lots for inclusion in Table 11 was determined by the uniformity of the kernel moisture from Tray 1 to Tray 4 at the completion of the drying run. Uniformity of moisture content was made the basis of choice so that the popping expansion could be measured without rehydrating the popcorn.

Table 8. — Effect on Popping Expansion of Drying at Four Temperatures and in Different Positions in the Bin, Run 4, 1954

Average changes of air per minute	Bin temperature (° F.)	Hours in bin	Kernel moisture (percent)			Cob moisture (percent)			Popping expansion at 12.5 percent moisture (volumes)		
			Initial	Final	Average hourly loss	Initial	Final	Average hourly loss	Dried by heat	Room-dried increase	Outdoor-dried increase
Purdue 202, Tray 2											
24.07	80	64.5	22.4	12.0	.16	39.0	19.4	.30	35.2	1.3	1.8
25.54	100	23.5	22.4	12.7	.41	39.0	7.0	1.36	35.2	1.3	1.8
26.29	110	23.5	22.4	11.9	.45	39.0	7.2	1.35	33.0	3.5	4.0
28.90	120	16.5	22.4	11.6	.65	39.0	10.6	1.72	33.5	3.0	3.5
Purdue 202, Tray 4											
24.07	80	64.5	22.4	12.4	.16	39.0	7.7	.49	34.0	2.5	3.0
25.54	100	40.5	22.4	11.6	.27	39.0	8.5	.75	35.0	1.5	2.0
26.29	110	28.0	22.4	11.8	.38	39.0	10.3	1.02	34.0	2.5	3.0
28.90	120	19.5	22.4	12.4	.51	39.0	10.7	1.45	34.0	2.5	3.0
Iopop 6, Tray 1											
24.07	80	47.5	18.2	12.4	.12	27.8	11.2	.35	33.0	1.5	2.8
25.54	100	19.5	18.2	12.4	.30	27.8	10.2	.90	32.0	2.5	3.8
26.29	110	19.5	18.2	11.0	.37	27.8	8.1	1.01	32.5	2.0	3.3
28.90	120	16.5	18.2	10.5	.64	27.8	8.3	1.18	30.8	3.7	5.0
Iopop 6, Tray 3											
24.07	80	64.5	18.2	12.3	.09	27.8	11.1	.26	34.5	0	1.3
25.54	100	28.0	18.2	11.7	.23	27.8	17.6	.36	33.5	1.0	2.3
26.29	110	23.5	18.2	11.8	.27	27.8	9.9	.76	32.5	2.0	3.3
28.90	120	16.5	18.2	12.1	.37	27.8	13.3	.88	31.0	3.5	4.8

Table 9. — Effect on Popping Expansion of Changes in Air Velocities, Run 1, 1954
(Bin temperature, 110° F.)

Average changes of air per minute	Hours in bin	Kernel moisture (percent)			Cob moisture (percent)			Popping expansion at 12.5 percent moisture (volumes)		
		Initial	Final	Average hourly loss	Initial	Final	Average hourly loss	Dried by heat	Room-dried increase	Outdoor-dried increase
Purdue 202, Tray 1										
10.78	54.25	28.8	12.3	.30	45.9	8.7	.68	35.0	3.5	3.5
14.94	54.25	28.8	11.3	.32	45.9	7.6	.71	35.2	3.3	3.3
24.54	47.50	28.8	11.0	.37	45.9	9.2	.77	33.0	5.5	5.5
28.58	54.25	28.8	10.1	.34	45.9	7.8	.70	33.2	5.3	5.3
Purdue 202, Tray 3										
10.78	71.25	40.7	12.0	.40	48.6	6.5	.59	24.8	3.7	6.7
14.94	71.25	40.7	9.9	.43	48.6	7.1	.58	18.2	10.3	13.3
24.54	54.25	40.7	11.2	.54	48.6	8.7	.74	17.0	11.5	14.5
28.58	54.25	40.7	11.3	.54	48.6	8.6	.74	17.2	11.3	14.3
Iopop 6, Tray 2										
10.78	71.25	29.6	9.7	.28	46.6	6.3	.56	31.8	4.0	4.7
14.94	47.50	29.6	12.4	.36	46.6	10.7	.76	31.5	4.3	5.0
24.54	47.50	29.6	10.2	.41	46.6	7.7	.82	31.0	4.8	5.5
28.58	47.50	29.6	10.2	.41	46.6	8.7	.80	31.0	4.8	5.5
Iopop 6, Tray 4										
10.78	71.25	37.8	11.8	.36	50.1	9.6	.57	24.0	7.5	7.8
14.94	71.25	37.8	9.8	.39	50.1	10.4	.56	19.8	11.7	12.0
24.54	54.25	37.8	10.1	.51	50.1	8.2	.77	18.5	13.0	12.3
28.58	54.25	37.8	10.2	.51	50.1	8.2	.77	20.2	11.3	11.6

Table 10. — Effect on Popping Expansion of Changes in Air Velocities, Run 2, 1954
(Bin temperature, 110° F.)

Average changes of air per minute	Hours in bin	Kernel moisture (percent)			Cob moisture (percent)			Popping expansion at 12.5 percent moisture (volumes)		
		Initial	Final	Average hourly loss	Initial	Final	Average hourly loss	Dried by heat	Room-dried increase	Outdoor-dried increase
Purdue 202, Tray 2										
10.87	64.0	24.6	9.6	.23	43.6	7.2	.57	36.5	1.7	1.3
19.12	51.5	24.6	10.7	.27	43.6	8.1	.69	37.0	1.2	.8
21.81	47.0	24.6	10.9	.29	43.6	9.6	.72	36.2	2.0	1.6
29.46	40.0	24.6	11.9	.32	43.6	8.2	.88	37.8	.4	0
Purdue 202, Tray 4										
10.87	69.5	33.3	12.0	.31	49.4	9.8	.57	31.0	7.2	6.8
19.12	69.5	33.3	10.3	.33	49.4	6.3	.62	28.2	10.0	9.6
21.81	51.5	33.3	12.6	.40	49.4	6.8	.83	27.8	10.4	10.0
29.46	51.5	33.3	11.8	.42	49.4	8.3	.80	28.0	10.2	9.8
Iopop 6, Tray 1										
10.87	40.0	22.0	10.5	.29	42.0	8.3	.84	33.5	1.5	2.5
19.12	40.0	22.0	10.2	.30	42.0	9.3	.82	33.2	1.8	2.8
21.81	40.0	22.0	9.6	.31	42.0	11.4	.76	30.8	4.2	5.2
29.46	40.0	22.0	9.5	.31	42.0	7.4	.86	33.0	2.0	3.0
Iopop 6, Tray 3										
10.87	64.0	32.5	11.0	.34	50.6	7.7	.67	29.0	6.0	7.0
19.12	64.0	32.5	9.3	.36	50.6	8.8	.65	27.5	7.5	8.5
21.81	51.5	32.5	10.2	.43	50.6	17.1	.65	27.8	7.2	8.2
29.46	47.0	32.5	11.3	.45	50.6	9.8	.87	27.0	8.0	9.0

There were only minor variations between trays in the Iopop 5 runs, but the popping expansion fell below the standard of 30 volumes. Rehydration of samples from each run gave a maximum of only 31 volumes, indicating that this hybrid has a lower inherent popping capacity than the three others used.

The Iopop 6 runs in Table 11 indicate that differences in the drying rates of the two upper trays from those of the two lower trays were slight. The increased popping expansions of the lower trays may usually be accounted for by the fact that the moisture contents were closer to the optimum for popping. The results of the two Purdue 32 runs and the two Illinois 52 runs may be explained in the same way. Figs. 4, 5, and 6 show that, except for the early part of the drying period, the temperatures in the trays did not vary much. With lower air velocities, however, the temperatures within a bin will differ more widely.

Further comparison of the effect of position in the bin is possible from the data (Table 8) of popcorn dried at four different temperatures and in two bin positions. One lot of Purdue 202 and one of Iopop 6 were employed in this run, and the popping expansions of each hybrid were directly comparable. There is no evidence in Table 8 that bin position had any effect on expansion even though the ears in the lower trays dried more slowly than those in the upper trays.

Drying on the ear compared with drying shelled corn. Preliminary experiments in 1953 indicated that shelled popcorn would require only one-fourth to one-third as much time as corn on the ear to dry at 110° to a comparable moisture content. The shelled-dried popcorn, however, showed a marked reduction in popping expansion compared with that dried on the ear.

The results of the detailed experiments in 1954 appear in Tables 12 and 13. The initial moisture contents of the four lots of popcorn involved ranged from 16.1 percent to 20.8 percent, the latter being about the upper moisture limit for shelling. The shelled corn required only one-half to about one-third as much time to dry as the ear corn even though the air velocities were greatly reduced owing to the small air spaces between the shelled kernels. Compared with its ear-dried equivalent, each shelled-dried lot had a reduced popping expansion (Tables 12 and 13). Extremely rapid drying is the only reason that can be advanced for this reduction in expansion. The kernels of the shelled-dried lots were examined for injury to the pericarp caused by the corn sheller, but the amount of injury was slight.

Table 11. — Effect of Tray Position in Bin on Popping Expansion, 1952

Hybrid	Harvest moisture percent	Tray (Bin temperature 110° F.)	Popping moisture	Popping expansion (volumes) Actual	Popping expansion (volumes) Increase over Tray 1	Moisture loss per hour[a] (percent)
Iopop 5	15.0	1	9.25	23.3		
		2	10.20	24.5	1.2	.25
		3	10.15	25.5	2.2	
		4	10.35	26.5	3.2	.17
Iopop 5	14.4	1	8.60	21.2		
		2	8.35	20.5	−.7	.20
		3	8.60	20.5	−.7	
		4	9.20	22.8	1.6	.22
Iopop 5	15.5	1	9.85	23.8		
		2	9.75	25.0	1.2	.38
		3	9.90	25.8	.8	
		4	10.75	27.2	3.4	.35
Iopop 5	18.0	1	9.55	25.8		
		2	10.25	26.5	.7	.38
		3	10.00	26.0	.2	
		4	11.40	27.8	2.0	.27
Iopop 5	20.6	1	9.65	26.2		
		2	9.65	27.0	.8	.52
		3	9.90	27.8	1.6	
		4	9.95	28.8	2.6	.46
Iopop 6	15.5	1	10.70	34.5		
		2	10.80	36.2	1.7	.26
		3	11.65	37.5	3.0	
		4	11.10	36.0	1.5	.25
Iopop 6	16.8	1	9.30	26.0		
		2	9.45	29.0	3.0	.32
		3	9.60	29.0	3.0	
		4	10.40	31.8	5.8	.35
Iopop 6	17.6	1	10.05	29.0		
		2	11.10	33.2	4.2	.48
		3	11.15	32.0	3.0	
		4	11.85	34.2	5.2	.46
Iopop 6	16.2	1	9.60	29.8		
		2	10.55	32.2	2.4	.32
		3	10.15	32.2	2.4	
		4	10.65	34.0	4.2	.29
Iopop 6	18.9	1	10.30	33.5		
		2	11.65	35.2	1.7	.36
		3	11.25	36.2	2.7	
		4	11.85	36.5	3.0	.31
Iopop 6	19.7	1	10.20	29.5		
		2	10.55	32.5	3.0	.40
		3	11.30	34.8	5.3	
		4	11.00	35.0	5.5	.35
Purdue 32	26.8	1	9.85	30.5		
		2	10.50	32.0	1.5	.36
		3	11.15	32.5	2.0	
		4	11.15	33.2	2.7	.34
Purdue 32	29.6	1	10.15	31.8		
		2	10.90	32.8	1.0	.39
		3	11.95	33.5	1.7	
		4	12.10	32.2	.4	.35
Illinois 52	21.0	1	8.70	22.8		
		2	9.05	23.0	.2	.34
		3	8.85	23.8	1.0	
		4	9.45	25.5	2.7	.35
Illinois 52	12.3	1	7.20	19.0		
		2	7.45	21.5	2.5	.23
		3	7.55	20.5	1.5	
		4	7.75	21.5	2.5	.22

[a] Trays 1 plus 2 compared with 3 plus 4.

Table 12. — Effect on Popping Expansion of Drying Ear Corn and Shelled Corn at Two Temperatures, Run 3, 1954

Average changes of air per minute	Bin temperature (°F.)	Method of drying	Tray in bin	Hours in bin	Kernel moisture (percent)			Cob moisture (percent)			Popping expansion at 12.5 percent moisture (volumes)		
					Initial	Final	Average hourly loss	Initial	Final	Average hourly loss	Dried by heat	Room-dried increase	Outdoor-dried increase
						Purdue 202							
27.44	110	On ear	2	31.0	20.8	11.8	.29	34.8	11.2	.76	36.8	−.6	.7
14.64	110	Shelled	2	11.5	20.8	12.4	.73	34.8	...	...	33.5	2.7	4.0
27.44	110	On ear	4	31.0	20.8	13.0	.25	34.8	12.3	.73	36.5	−.3	1.0
14.64	110	Shelled	4	14.5	20.8	12.9	.54	34.8	...	...	31.8	4.4	5.7
24.48	120	On ear	2	24.0	20.8	11.4	.39	34.8	7.7	1.13	36.5	−.3	1.0
16.22	120	Shelled	2	11.5	20.8	11.0	.85	34.8	...	...	30.8	5.4	6.7
24.48	120	On ear	4	31.0	20.8	10.0	.35	34.8	8.8	.84	36.8	−.6	.7
16.22	120	Shelled	4	14.5	20.8	11.3	.66	34.8	...	...	30.0	6.2	7.5
						Iopop 6							
27.44	110	On ear	1	27.0	18.6	9.8	.33	28.5	6.9	.80	33.0	2.2	3.2
14.64	110	Shelled	1	8.5	18.6	11.1	.88	28.5	...	...	29.0	6.2	7.2
27.44	110	On ear	3	27.0	18.6	11.5	.26	28.5	9.4	.71	35.2	0	1.0
14.64	110	Shelled	3	11.5	18.6	12.5	.53	28.5	...	...	31.2	4.0	5.0
24.48	120	On ear	1	24.0	18.6	8.8	.41	28.5	5.4	.96	32.0	3.2	4.2
16.22	120	Shelled	1	6.0	18.6	11.0	1.27	28.5	...	...	29.0	6.2	7.2
24.48	120	On ear	3	24.0	18.6	9.7	.37	28.5	8.9	.82	33.2	2.0	3.0
16.22	120	Shelled	3	11.5	18.6	10.5	.70	28.5	...	...	29.2	6.0	7.0

Table 13. — Effect of Popping Expansion of Drying Ear Corn and Shelled Corn at Two Temperatures, Run 5, 1954

Average changes of air per minute	Bin temperature (°F.)	Method of drying	Tray in bin	Hours in bin	Kernel moisture (percent)			Cob moisture (percent)			Popping expansion at 12.5 percent moisture (volumes)		
					Initial	Final	Average hourly loss	Initial	Final	Average hourly loss	Dried by heat	Room-dried increase	Outdoor-dried increase
					Purdue 202								
23.0	110	On ear	2	27.0	18.3	10.2	.30	24.8	8.7	.60	33.2	2.8	2.3
16.5	110	Shelled	2	11.5	18.3	11.0	.63	24.8	...	...	30.5	5.5	5.0
23.0	110	On ear	4	27.0	18.3	10.8	.28	24.8	8.7	.60	34.5	1.5	1.0
16.5	110	Shelled	4	14.5	18.3	11.4	.48	24.8	...	...	32.0	4.0	3.5
24.8	120	On ear	2	24.0	18.3	9.4	.37	24.8	5.6	.80	32.0	4.0	3.5
18.5	120	Shelled	2	7.0	18.3	12.6	.81	24.8	...	...	31.5	4.5	4.0
24.8	120	On ear	4	24.0	18.3	9.7	.36	24.8	6.7	.75	32.8	3.2	2.7
18.5	120	Shelled	4	11.5	18.3	11.2	.62	24.8	...	...	30.8	5.2	4.7
					Iopop 6								
23.0	110	On ear	1	11.5	16.1	12.5	.31	20.9	9.0	1.03	30.8	4.2	4.7
16.5	110	Shelled	1	7.0	16.1	10.8	.76	20.9	...	...	28.0	7.0	7.5
23.0	110	On ear	3	24.0	16.1	10.6	.23	20.9	7.2	.57	32.2	2.8	3.3
16.5	110	Shelled	3	11.5	16.1	11.9	.36	20.9	...	...	28.2	6.8	7.3
24.8	120	On ear	1	11.5	16.1	11.0	.44	20.9	6.9	1.22	31.2	3.8	4.3
18.5	120	Shelled	1	7.0	16.1	10.4	.81	20.9	...	...	26.8	8.2	8.7
24.8	120	On ear	3	11.5	16.1	11.2	.43	20.9	11.6	.81	32.8	2.2	2.7
18.5	120	Shelled	3	11.5	16.1	9.8	.55	20.9	...	...	27.0	8.0	8.5

Effect of Chilling and Freezing on Popping Expansion

Chilling and freezing are two weather conditions which are said to injure popping expansion. Eldredge (5) states that popcorn containing 35 percent moisture exposed to temperatures of 20° or lower may pop too poorly to be salable. For the experiments reported in this bulletin, Iopop 6 and Purdue 202 were harvested the same day from four different plantings thus providing four different maturities. The husked ears were placed in the dryer trays and held in 35° cold storage for 24 hours and thus were thoroughly chilled. The trays were then placed in the dryer and dried at 110°. Comparison with suitable controls showed that chilling at 35° had no adverse effect on popping.

Two separate freezing experiments were set up and the lots were prepared in the same way. In one experiment, the corn was exposed to − 10° F. for 6 hours, and in the other, to − 10° F. for 15 hours. The ears were placed in the dryer immediately after removal from storage so that fermentation and spoilage need not be considered. The immature lots were frozen solid in each experiment. The frozen lots, along with paired controls not frozen, were then dried with forced air at 80° and 110°. The results in Table 14 show that at 80° the drying rate per hour was approximately half as great as that at 110°, but this reduction in the drying rate had no consistent effect on popping expansion. Freezing reduced the popping expansion in the two lots having 29.65 and 31.00 percent moisture (Table 14), but the two with 17.55 and 23.40 percent moisture showed little or no effect.

The experiments were continued with 7 maturities each of Iopop 6 and Purdue 202. Freezing was most injurious to popping expansion in the lots having a high initial moisture content (Table 15). Where the initial moistures were reduced to about 20 percent, there were either no injuries, or the injuries were slight.

Table 14. — Effect of Freezing and Drying Rate on Popping Expansion
(All samples were reconstituted with water to 13 percent moisture)

Hybrid	Harvest moisture percent	Frozen at −10° F. for 15 hours: Dried at 80° F.		Frozen at −10° F. for 15 hours: Dried at 110° F.		Not frozen and dried at 110° F.	
		Moisture loss per hour (percent)	Popping expansion (volumes)	Moisture loss per hour (percent)	Popping expansion (volumes)	Moisture loss per hour (percent)	Popping expansion (volumes)
Iopop 6	31.00	.23	23.8	.48	25.5	.45	30.5
	17.55	.14	36.0	.24	34.0	.25	34.0
Purdue 202	29.65	.22	26.5	.34	24.5	.32	32.5
	23.40	.18	34.2	.34	37.0	.37	36.8

Table 15. — Effect of Freezing and Subsequent Drying at 110° on Popping Expansion and Germination of Husked Popcorn

Hybrid	Harvest moisture percent	Popping expansion (volumes) at 13 percent moisture			Germination percent		
		Frozen at −10° F.	Control	Difference due to freezing	Frozen at −10° F.	Control	Difference due to freezing
		Frozen 6 hours					
Iopop 6	33.80	16.0	25.0	−9.0	14	94	−80
	23.10	30.0	33.0	−3.0	40	90	−50
	20.30	34.2	35.5	−1.3	78	100	−22
	12.00	31.5	32.5	−1.0	100	98	2
Purdue 202	34.15	17.0	23.5	−6.5	4	100	−96
	26.10	31.5	34.0	−2.5	26	100	−74
	17.40	36.5	36.0	.5	84	100	−16
	18.65	37.5	36.8	.7	96	96	0
		Frozen 15 hours					
Iopop 6	31.00	25.5	30.5	−5.0	44	96	−52
	17.55	34.0	34.0	0	86	96	−10
	12.25	36.0	36.2	− .2	92	98	− 6
Purdue 202	29.65	24.5	32.5	−8.0	44	98	−54
	23.40	37.0	36.8	.2	68	100	−32
	14.70	38.5	38.0	.5	100	96	4

The extent of the freezing injuries was also determined by germination tests (Table 15), but as shown by Bemis and Huelsen (1) germination in itself is no criterion of ability to pop.

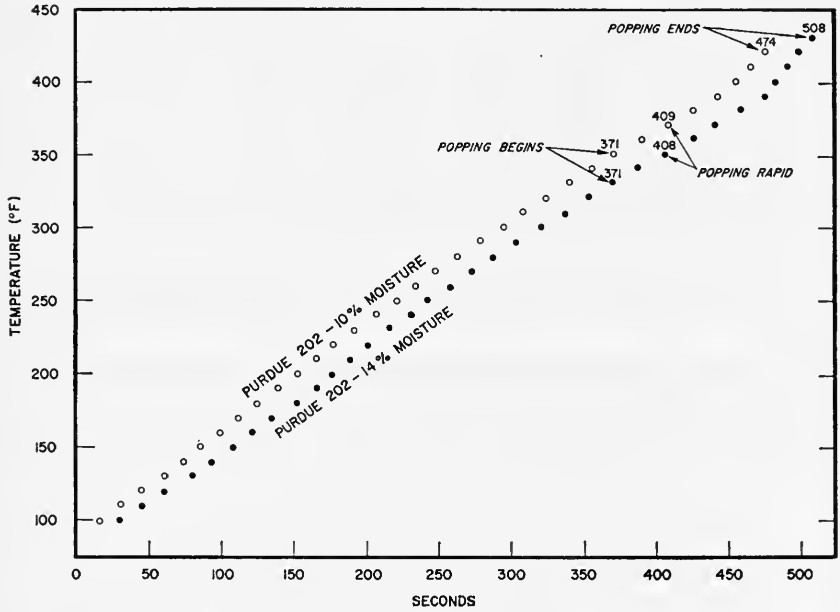
Effect of Popping Temperature on Expansion

Stewart (12) concluded that there was a definite relationship between temperature of the popper and the length of the popping period measured from the time the corn was dumped into the popper until popping ceased, but he could not measure the temperature with his equipment. He stated that expansion dropped off if the period of actual popping fell below 105 seconds or above 165. He found no advantage in preheating the popper. Carr and Ripley (3) also noted the time-temperature relationship while popping corn with lard. They found that popping started at 340° F. and proceeded rapidly at 380°.

Stewart (12) also found that the time required for a sample to pop is determined by its weight and moisture content as well as by the popping temperature. Eldredge (5) states that with samples measured in the standard 6-ounce cup, he secured the highest expansion when the thermostat of his tester was set to turn on at 360° and off at 540°. With the 3-ounce cup, optimum temperatures were 340° and 460°.

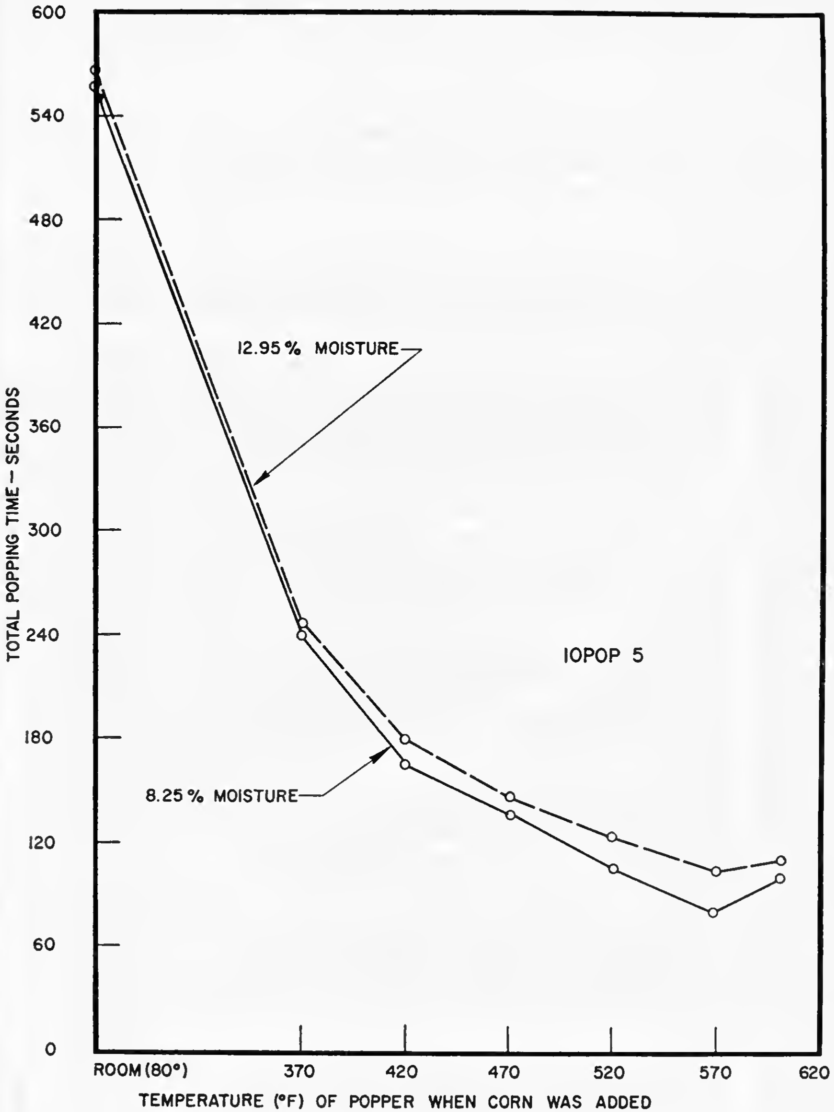
The available information being so meager, experiments were designed to determine the relationships between popping temperatures and other factors which influence expansion. The details of the experiments are reported by Huelsen and Bemis (8).

Since most of the discussion deals with time-temperature relationships, it was essential to know first whether the popper heated at a uniform rate. Stop-watch readings on two diverse samples of Purdue 202 loaded at 90° are plotted in Fig. 8 and show that the official volume tester heated at a uniform rate until popping was well started. The 13-second spread between the two curves in Fig. 8, which is due to the difference in moisture content of the two samples, represents the respective times required by the two lots to heat from 90° to 100°. One lot required 17 seconds and the other 30 seconds. This 13-second difference was maintained throughout the heating period.



Two different samples of Purdue 202 were placed in the popper at 90° F. Readings at every temperature increase of 10° demonstrated that the popper used in the experiments heated uniformly. Popping began 371 seconds after the heat was turned on and ended between 474 and 508 seconds. (Fig. 8)

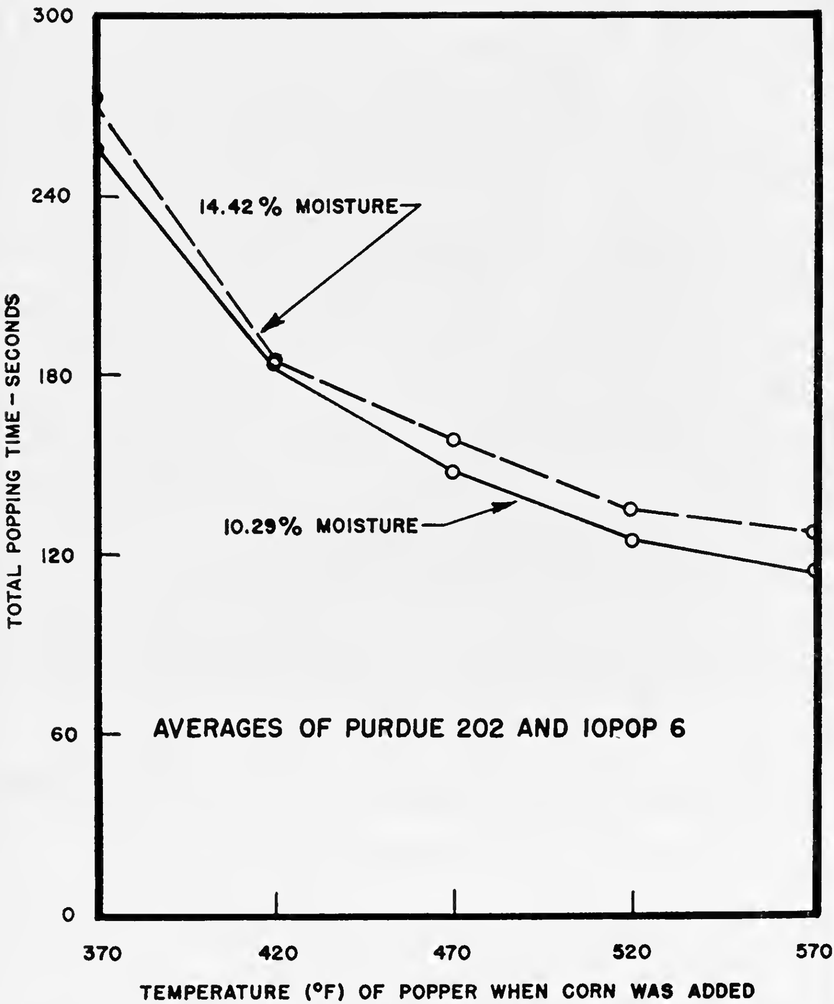
Preheat temperatures and popping time. For instruments equipped with a pyrometer, the recommended popping procedure consists of heating the oil to 470° before dumping in the corn. This temperature is probably recommended because it is satisfactory for the average fat or oil used for popping. The coconut oil used throughout these experiments has a relatively high smoking point and an initial popper temperature of 570° could be used.



Preheating the popper to increasing temperatures before dumping in the corn reduced the actual popping time. (Fig. 9)

The reduction in popping time held true even when different varieties of corn were used. See Fig. 10 on the next page.

The first series of experiments in 1952, parts of which are reported in Tables 16, 17, and 18, consisted of adding the oil, then preheating the popper to temperatures varying from 80° to 600° before adding the popcorn. (The 600° temperature was used only in part of the runs, for it caused too much smoking and was too near the point where the limit switch cut off the current.) The corn was added after the popper reached the predetermined temperature. Table 16 shows that a preheat of 570° was more effective than 470° in obtaining maximum expansion and that varying the preheat had several important effects.



See legend under Fig. 9 on the previous page. (Fig. 10)

Table 16. — Effect of Popping Temperature on Expansion of Iopop 5 at Different Moisture Levels, 1952

Percent moisture at harvest	Percent moisture when popped	Temperatures (°F.)			Time in seconds			Popping expansion (volumes)	Increase in expansion (volumes) compared with 370° preheat
		Popper preheated to	Minimum after corn is added	Popping starts	From dumping corn to start of popping	Actual popping period	Total popping period		
14.70	8.25	Room (80°)	...	380	492	63	555	15.0	...
		370	283	378	182	58	240	18.0	...
		420	328	385	118	48	166	20.0	2.0
		470	350	390	95	43	138	21.0	3.0
		520	380	398	66	41	107	22.0	4.0
		570	404	406	47	35	82	22.0	4.0
		600	410	410	56	44	100	20.5	2.5
20.55	11.35	Room (80°)	...	358	451	90	541	22.0	...
		370	285	365	158	71	229	24.5	...
		420	312	370	110	68	178	27.0	2.5
		470	344	376	82	61	143	28.5	4.0
		520	370	382	62	57	119	29.5	5.0
		570	399	399	44	48	92	31.0	6.5
19.35	12.95	Room (80°)	...	348	455	111	566	23.5	...
		370	276	350	147	98	245	27.0	...
		420	312	356	97	83	180	29.5	2.5
		470	340	365	76	71	147	30.0	3.0
		520	365	375	59	65	124	31.5	4.5
		570	390	390	44	60	104	32.5	5.5
		600	395	398	45	64	109	31.0	4.0

Table 17. — Effect of Popping Temperature on Expansion of Iopop 6 at Different Moisture Levels, 1952

Percent moisture at harvest	Percent moisture when popped	Temperatures (°F.)			Time in seconds			Popping expansion (volumes)	Increase in expansion (volumes) compared with 370° preheat
		Popper preheated to	Minimum after corn is added	Popping starts	From dumping corn to start of popping	Actual popping period	Total popping period		
16.75	9.60	Room (80°)	...	362	462	73	535	23.5	...
		370	282	369	165	60	225	26.0	...
		420	320	373	110	55	165	28.0	2.0
		470	342	378	89	51	140	30.0	4.0
		520	370	386	70	44	114	31.0	5.0
		570	396	398	48	43	91	31.5	5.5
15.50	11.65	Room (80°)	...	358	443	82	525	29.0	...
		370	280	361	160	71	231	32.5	...
		420	315	362	105	67	172	35.0	2.5
		470	340	361	85	59	144	37.0	4.5
		520	362	380	69	55	124	37.0	4.5
		570	394	398	50	45	95	38.0	5.5
		600	398	398	48	53	101	38.0	5.5
19.85	12.60	Room (80°)	...	348	455	92	547	30.0	...
		370	280	352	146	84	230	34.0	...
		420	314	360	100	69	169	37.0	3.0
		470	340	362	75	68	143	37.0	3.0
		520	368	376	59	60	119	38.0	4.0
		570	395	395	43	54	97	36.5	2.5

Table 18. — Effect of Popping Temperature on Expansion of Purdue 32 at Different Moisture Levels, 1952

Percent moisture at harvest	Percent moisture when popped	Temperatures (°F.)			Time in seconds			Popping expansion (volumes)	Increase in expansion (volumes) compared with 370° preheat
		Popper preheated to	Minimum after corn is added	Popping starts	From dumping corn to start of popping	Actual popping period	Total popping period		
26.80	9.85	Room (80°)	...	368	485	77	562	23.0	...
		370	282	371	175	69	244	25.0	...
		420	320	375	117	57	174	29.0	4.0
		470	342	380	95	52	147	30.0	5.0
		520	369	386	73	43	116	31.0	6.0
		570	395	399	55	40	95	31.0	6.0
		600	400	400	55	44	99	31.5	6.5
21.15	11.80	Room (80°)	...	345	441	99	540	30.5	...
		370	272	352	174	88	262	32.0	...
		420	315	355	110	67	177	35.0	3.0
		470	339	370	87	72	159	35.0	3.0
		520	366	370	64	54	118	37.0	5.0
		570	392	392	47	68	115	35.5	3.5
		600	392	395	46	70	116	34.5	2.5
26.55	13.60	Room (80°)	...	350	457	85	542	18.0	...
		370	270	352	176	93	269	21.0	...
		420	312	365	112	65	177	23.0	2.0
		470	340	370	87	65	152	23.5	2.5
		520	360	379	70	52	122	25.0	4.0
		570	390	391	50	47	97	22.0[a]	1.0
		600	390	390	50	53	103	23.0[a]	2.0

[a] Popped into small round balls which were hard and tough.

Table 19. — Temperature of Popper When Corn Is Added, Harvest Moisture, Moisture Content When Popped and Popping Expansion, 1953

Averages of two hybrids					Popping expansion (volumes)								
	Temperatures				Purdue 202				Iopop 6				
Moisture when popped[a]	Popper preheated to	Minimum after corn is added	Popping starts	Popping time[b]	Harvest moisture (%) 29.65	26.10[c]	14.70	Average three harvests	Harvest moisture (%) 31.00	17.55[c]	15.65	Average three harvests	Combined average both hybrids
(perct.)	(°F.)	(°F.)	(°F.)	(sec.)									
10.29	370	273	360	258	28.0	24.5	29.0	27.2	24.0	27.5	26.5	26.0	26.6
	420	312	365	182	31.0	28.0	31.5	30.2	27.0	28.0	30.0	28.3	29.3
	470	338	369	148	30.5	28.0	33.0	30.5	29.0	31.5	31.0	30.5	30.5
	520	362	378	125	32.0	29.0	33.0	31.3	30.0	33.5	....	31.7	31.5
	570	383	388	114	31.5	29.5	33.0	31.3	31.0	32.5	31.0	31.5	31.4
11.27	370	269	354	256	28.0	25.0	31.0	28.0	25.0	29.0	27.0	27.0	27.5
	420	313	360	177	31.0	27.5	34.0	30.8	28.5	32.0	31.0	30.5	30.7
	470	342	368	150	33.0	28.5	34.5	32.0	31.0	33.5	32.0	32.2	32.1
	520	361	377	125	33.0	29.0	36.5	32.8	31.0	34.0	33.0	32.7	32.8
	570	382	385	115	32.5	29.0	34.5	32.0	31.0	34.5	33.0	32.8	32.4
12.28	370	266	350	263	29.5	26.0	32.0	29.2	24.5	28.5	28.0	27.0	28.1
	420	311	359	180	31.0	29.5	36.0	32.2	29.0	32.0	32.5	31.2	31.6
	470	337	363	153	32.5	29.5	35.5	32.5	30.5	34.0	34.0	32.8	32.7
	520	360	373	128	33.0	....	37.0	35.0	32.0	35.0	34.5	33.8	34.4
	570	378	384	119	32.5	31.0	34.5	32.7	32.0	35.0	34.5	33.8	33.3
13.36	370	265	349	265	29.5	26.5	32.0	29.3	25.0	29.0	29.5	27.8	28.4
	420	310	354	183	32.0	30.0	35.5	32.5	30.0	32.0	32.5	31.5	32.0
	470	335	359	155	32.5	31.0	38.0	33.8	30.5	34.0	33.5	32.7	33.3
	520	359	370	131	33.0	32.0	36.5	33.8	31.5	34.5	35.0	33.7	33.8
	570	378	382	122	32.5	32.0	35.0	33.2	32.0	34.5	35.5	34.0	33.6
14.42	370	263	343	273	29.5	27.0	32.5	29.7	25.0	29.0	28.5	27.5	28.6
	420	309	351	185	31.0	30.5	34.5	32.0	29.0	31.5	31.5	30.7	31.4
	470	333	359	158	32.0	31.5	35.5	33.0	29.5	32.5	33.5	31.8	32.4
	520	358	367	134	33.0	32.0	36.0	33.7	31.0	33.5	35.0	33.2	33.5
	570	377	380	126	32.5	31.0	34.5	32.7	31.0	34.0	35.5	33.5	33.1

[a] Rehydrated moistures averaged for the two hybrids. The actual moistures were 10.30, 11.26, 12.26, 13.37, and 14.37 percent for Iopop 6. For Purdue 202, they were 10.28, 11.28, 12.30, 13.35, and 14.47 percent.
[b] From the time corn is added until popping is completed.
[c] Exposed to −10° F. for 15 hours prior to drying at 110° F.

Table 20. — Effect of Preheating the Popper on Popping Time of Two Hybrids Harvested at Different Maturities, 1953

Percent moisture		Actual popping time (seconds) when popper preheated to				
When harvested	When corn entered the popper[a]	370°	420°	470°	520°	570°
Iopop 6						
31.00	10.20	94	73	69	57	57
	11.15	103	75	69	63	57
	12.10	103	89	77	75	64
	13.45	108	89	85	78	71
	14.60	114	99	92	81	77
17.55	10.65	81	76	66	58	54
	11.50	84	74	71	50	59
	12.50	95	78	78	65	67
	13.40	97	88	78	74	70
	14.40	109	81	80	75	69
15.65	10.05	76	65	58	56	56
	11.10	82	73	64	58	57
	12.20	86	72	65	61	55
	13.25	89	81	77	64	59
	14.15	105	81	73	71	68
Purdue 202						
29.65	10.75	90	77	75	65	61
	11.40	95	79	70	65	55
	12.30	93	84	80	68	63
	13.04	107	88	84	71	73
	14.40	116	96	85	78	75
26.10	9.90	88	66	63	61	56
	11.10	87	72	63	58	56
	12.40	91	72	72	62	59
	13.45	92	81	77	67	66
	14.55	105	79	75	76	74
14.70	10.20	80	72	68	58	57
	11.35	89	73	64	55	56
	12.20	81	69	71	56	65
	13.20	90	75	68	63	72
	14.45	104	86	76	69	72

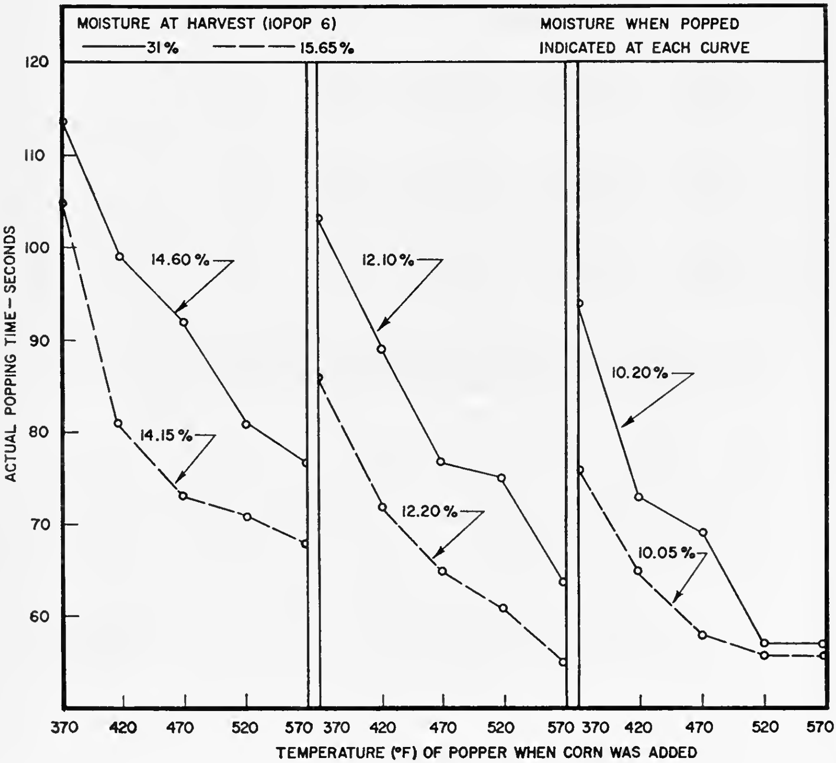
[a] Rehydrated moistures.

Temperature when corn starts to pop. When the corn was dumped into the popper at room temperature (80°), it started to pop between 345° and 380°. Preheating the popper to increasing temperatures before dumping in the corn raised the temperature when the corn began to pop, but not proportionally. When the range of preheat temperatures was 520°, that is from room temperature at 80° to 600°, the range of temperatures when corn began to pop was less than 50° (Tables 16, 17, 18, and 19).

Length of popping period. The length of the actual popping period varied in relation to the preheat temperature and the moisture content of the corn when it entered the popper. A third influencing factor was the maturity of the corn when it was harvested (Table 20 and Fig. 11). Increasing preheat temperature decreased popping time (Figs. 9 and

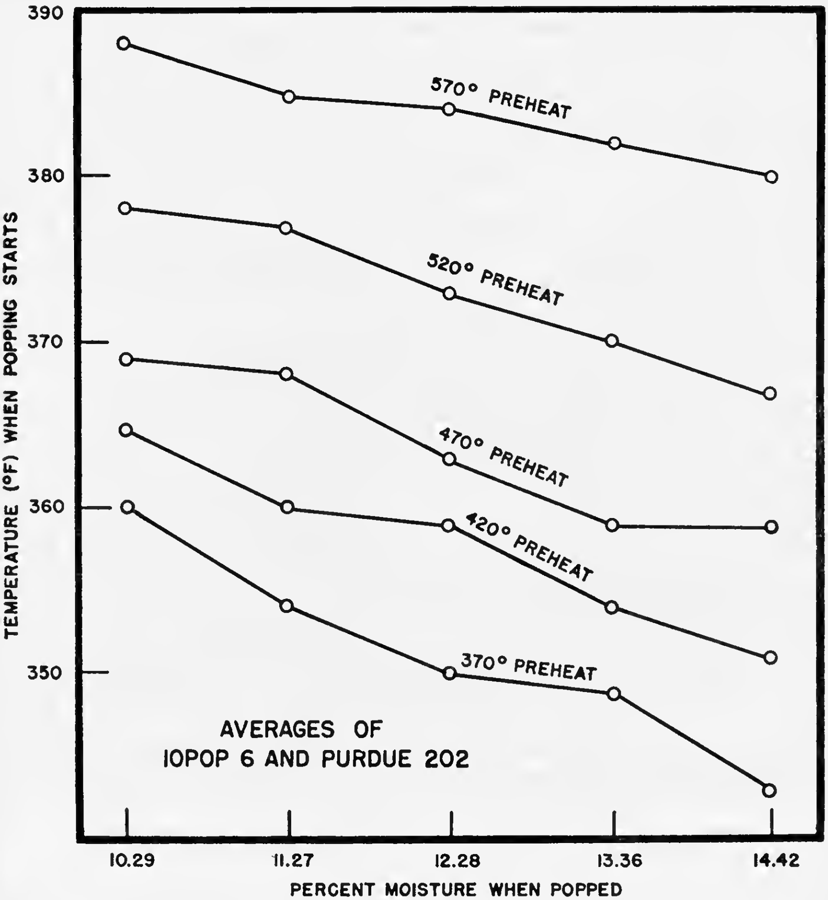
10), and increased the temperature when the corn first started to pop (Fig. 12). Moisture content when the corn entered the popper and actual popping time decreased together (Table 19, Figs. 9 and 10). Increases in preheat temperature accompanied by shorter popping time increased popping expansion. This held true irrespective of variety and maturity (Tables 16, 17, 18, 19, and Figs. 9, 10, and 13).

Maturity of popcorn. Popcorn harvested at all stages of maturity responded to increased preheating temperatures, but the total expansion of the more mature corn was almost always greater. Purdue 202 harvested at 29.65 percent moisture and dried artificially had an almost uniformly lower popping expansion at all preheat temperatures than the later harvest at 14.70 percent moisture. Iopop 6 showed similar results (Table 19 and Fig. 14).



See legend under Fig. 12 on the next page. (Fig. 11)

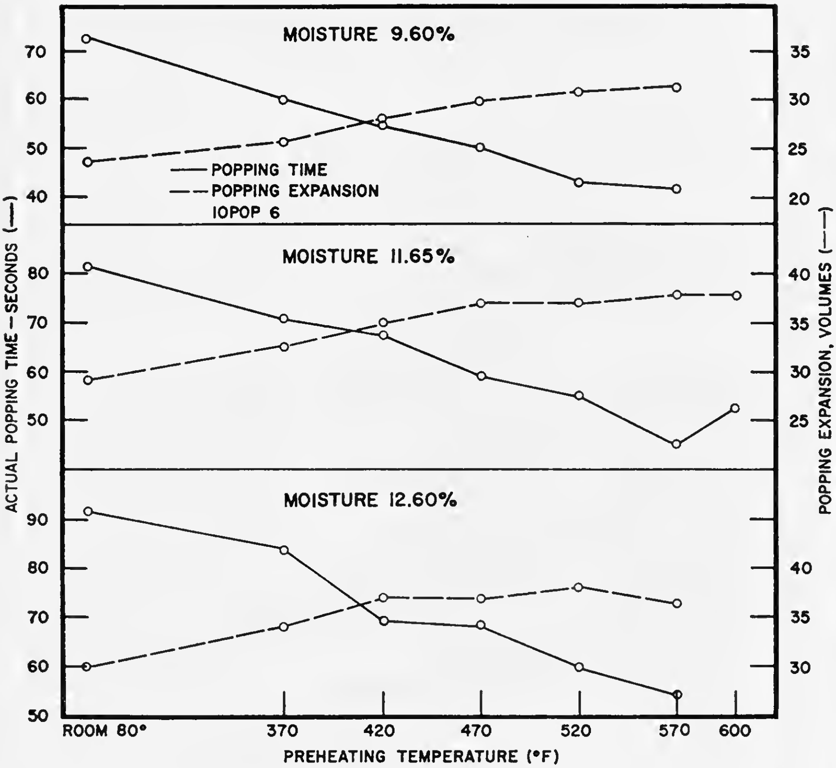
Moisture content at popping. The moisture content of the corn at the time of popping was also considered. Iopop 5 (Table 16) gave the greatest response (6.5 volumes) to increased preheating temperatures when the moisture content at popping was 11.35 percent. Iopop 6



Figs. 9 and 10 demonstrated that increasing preheat temperatures of the popper decreased popping time. As shown in Fig. 11 on the previous page, popping time was also affected by the moisture content of the corn at harvest and by the moisture content of the corn when it entered the popper.

Increasing the preheat temperatures also caused the corn to begin popping at higher and higher temperatures. However, at every preheat level, corn which entered the popper with a higher moisture content began popping at a lower temperature than corn with a lower moisture content. (Fig. 12)

(Table 17) with 9.6 and 11.65 percent moisture at popping gave somewhat greater increases in expansion than with 12.60 percent moisture. Purdue 32 (Table 18) showed the greatest increase in expansion with a moisture content of 9.85 percent and lower responses at 11.80 and

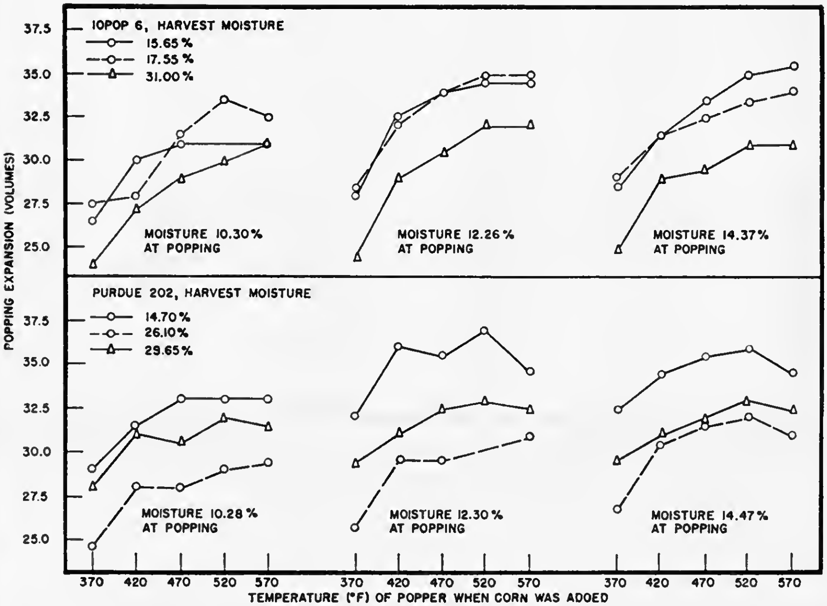


Higher preheat temperatures accompanied by shorter popping time gave increased popping expansions. Increases in expansion resulting from higher popping temperatures must not be confused with the maximum total expansion which coincided, of course, with the most favorable moisture content at popping. Iopop 6 with 9.6 and 11.65 percent moisture gave greater increases in popping expansion than with 12.6 percent. (Fig. 13)

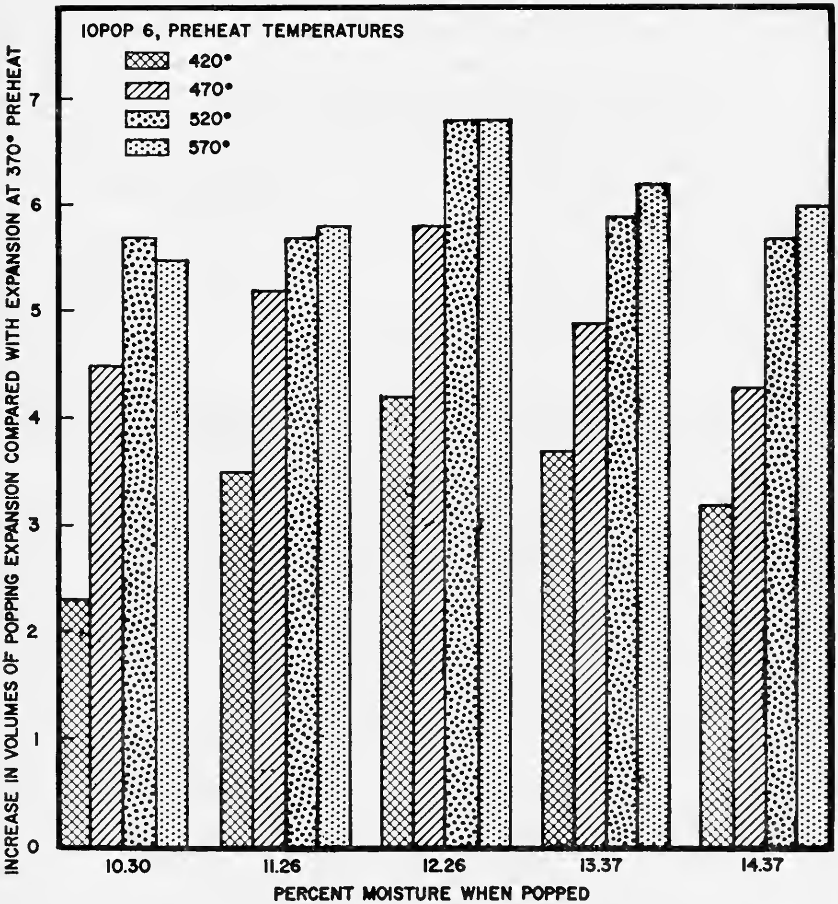
13.60 percent moisture. These increases in expansion resulting from popping temperature must not be confused with the maximum total expansions which coincided, of course, with the most favorable moisture content.

It is evident, however, that the three hybrids did not react the same to popping temperature. Similar data from the 1953 crop (Table 19) of Iopop 6 and Purdue 202 (Figs. 15 and 16) show that Iopop 6 gave greater increases in expansion in response to popping temperatures than Purdue 202. There was a slight tendency for the largest increases to be associated with a moisture content close to 12.5 percent.

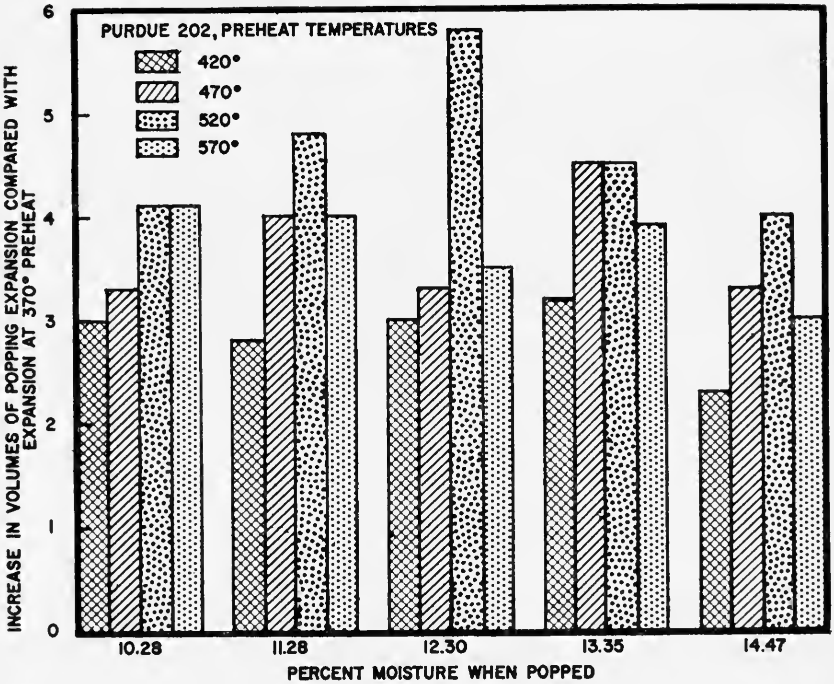
From the results above it appears that preheating the popper to 470° gave smaller popping expansions than 520° or 570°. For maximum expansion a preheat of about 550° is recommended.



Popcorn harvested at all stages of maturity responded to increased preheating temperatures, but the total expansion of the more mature corn was almost always greater. Purdue 202 harvested at 29.65 percent almost always had a lower popping expansion at all preheat levels than the later harvest at 14.70 percent. Iopop 6 showed similar results. (Fig. 14)



All hybrids responded to higher popping temperatures, but the amount of increase in expansion varied with the hybrid as well as with the temperature. Iopop 6 gave greater increases than Purdue 202 (compare Figs. 15 and 16). A preheat temperature of 470° F. is usually recommended by the popcorn industry, but these experiments show that the greatest increases followed preheat temperatures as high as 520° and 570° F. (Fig. 15)



See explanation on previous page. (Fig. 16)

REHYDRATING METHODS AND RESULTS

Overdried shelled popcorn may be rehydrated by adding water and permitting the corn to stand until the moisture equilibrates. It may also be stored in artificially humidified air as described by Dexter (4), but neither of these methods is suitable for large volumes of popcorn. Blending overdried lots with underdried lots in suitable proportions is another way to rehydrate popcorn (see pages 55 to 59). A fourth and successful method is steam blanching. Bemis and Huelsen (1) rehydrated corn at a rapid rate by steam blanching, without impairing the popping quality. Their experiments have been supplemented by a second series, and the results of the two series of experiments are brought together in this publication.

The popcorn was blanched in a specially constructed stainless steel blancher 10 feet long equipped with a 12-inch fine mesh stainless steel belt. Steam was injected at atmospheric pressure from perforated pipes located both above and below the belt, and a temperature of 208° was maintained. The speed of the blancher was regulated by means of 4-step

Table 21. — Absorbed and Free or Condensed Moisture of Three Hybrids During Four Blanching Periods, 1952-53

(Corn was dried to a constant moisture at 176° F.)

Blanching period (seconds)	Moisture percentages		
	Absorbed by kernels	Free or condensed on surface	Total
52	2.98	1.47	4.45
98	3.48	1.13	4.61
173	4.17	.93	5.10
357	5.37	.71	6.08

cone pulleys permitting stop-watch-recorded blanching periods of 52, 98, 173, and 357 seconds.

Blanching the 1952 crop. The 1952-53 experiments were handicapped by the formation of free or condensed moisture on the surfaces of the kernels. The amount of condensation shown in Table 21 was measured in the following way. The popcorn samples were dried for 168 hours at 176° F. At this time they had reached constant weight. Then duplicate 500-gram samples of each of three varieties were blanched at four different periods. One set of samples was sealed in Mason jars immediately. The other set was spread on screen trays to dry for one hour after blanching. At the end of the hour, the surfaces of the kernels were dry to the touch. The samples were then sealed in jars. After both sets of samples were permitted to equilibrate for 10 days at 80° F., they were tested for moisture content. The differences between the moisture percentages of the two sets of samples gave the approximate values for free or condensed moisture.

The results in Table 21 show that the percentage of condensed moisture decreased with the length of the blanch and the moisture directly absorbed increased. The most rapid rate of absorption occurred the first 52 seconds.

Table 22. — Length of Blanch in Relation to Absorbed and Condensed Moisture in Three Popcorn Hybrids, 1952-53

Blanching time (seconds)		Moisture increase during blanch					
		Initial moisture content					
Increase in length of blanch	Total time	Iopop 5, 8.69%		Iopop 6, 9.89%		Purdue 32, 11.19%	
		Absorbed	Free	Absorbed	Free	Absorbed	Free
		(milligrams per second for each 100 grams)					
...	52	33.88	28.85	25.19	36.54	29.04	39.42
46	98	4.35	−6.52	4.35	−9.78	5.43	−5.43
75	173	8.66	−1.33	7.33	−.66	7.33	−5.33
184	357	.27	2.91	2.12	−.81	1.35	−.27

Table 23. — Length of Blanch in Relation to Absorbed Moisture in Two Hybrids With Different Initial Moisture Contents, 1953-54

Blanching time (seconds)		Moisture increase during blanch					
		Purdue 202, initial moistures			Iopop 6, initial moistures		
Increase in length of blanch	Total time	8.85%	9.20%	11.05%	8.05%	9.00%	9.40%
		(milligrams per second for each 100 grams)					
...	24	91.66	93.75	79.16	83.33	79.16	85.41
27	51	27.77	22.22	27.77	42.59	18.51	27.77
30	81	16.66	10.00	8.33	3.33	11.66	8.33
37	118	0	13.51	5.40	6.75	9.45	6.75
28	146	5.35	3.57	5.35	−3.57	3.57	−1.78

The experiment was repeated with the same hybrids, but this time each had a different initial moisture content. The first 52 seconds again accounted for the greatest moisture absorption (Table 22). The rate of absorption decreased sharply the succeeding 46 seconds only to increase the next 75 seconds. During the last 184 seconds, the rate decreased. The increased absorption during the third period may have been caused by the condensed moisture on the kernel surface being absorbed more rapidly. With a single exception, the free or condensed water decreased at a rapid rate as blanching proceeded.

Blanching the 1953 crop. The data given in Tables 21 and 22 were not completely satisfactory owing to the irregular length of the blanching periods and the presence of condensation. Before blanching the 1953 crop, certain changes were made in the blancher.[1] A variable speed transmission was substituted for the cone pulleys, and a second section, 11 feet long, having a separate drive was added. The second section was constructed like the original blancher except that the duct from a large blower fan was connected to the center of the hood. The blanched corn was discharged from the blancher to the second unit where it was exposed to a blast of air at room temperature for two minutes. This blast effectively removed all condensed moisture irrespective of the length of the blanch.

The variable speed transmission permitted blanching periods from about 25 to 150 seconds. The 1953 popcorn crop was blanched as nearly as possible by 30-second steps, starting with 24 seconds. The blanching periods measured with a stop watch were 24, 51, 81, 118, and 146 seconds. The moisture absorption at these speeds for samples with three different initial moisture contents is shown in Table 23. The

[1] The blancher and the drying conveyor were designed and built by the Department of Food Technology. Thanks are extended to Professor A. I. Nelson for his cooperation and permission to use the equipment.

most rapid absorption occurred during the first 24 seconds, followed in most cases by successively reduced rates the next four periods.

Summary of 1952 and 1953 crops. The moisture absorption of the five hybrids used in 1952 and 1953 is represented in a different way in Tables 24 and 25. Here again it will be noted that the first 51- or 52-seconds blanch was responsible for most of the moisture absorption. Extending the blanch tended to increase the amount of the moisture absorbed, but the rate of absorption was greatly reduced. For most purposes, a blanch of about one minute is sufficient.

The data in Tables 24 and 25 indicate that the initial moisture content of the kernels governed the amount of moisture absorbed during blanching. Since the first 51 or 52 seconds of blanching is the most important period, the moisture absorption of four hybrids during that period was compared (Table 26). Each hybrid had a different initial moisture. The 1952 data gave no indication that the initial moisture content had any consistent effect on the amount absorbed during blanching. The 1953 crop results, which were probably more reliable since condensation was practically eliminated, indicated that there was a tendency for absorption to decrease as initial moisture increased.

Table 24. — Length of Blanch, Moisture Absorbed, and Popping Expansion of Four Hybrids With Different Initial Moistures, 1952

Variety	Initial moisture (percent)	Blanching time (seconds)	Moisture absorbed (percent)	Popping expansion (volumes)		
				Initial	After blanching	Increase
Iopop 5	6.95	52	3.77	19.7	26.0	6.3
		98	3.85	19.7	25.4	5.7
		173	4.00	19.7	25.7	6.0
		357	5.20	19.7	26.0	6.3
Iopop 5	8.69	52	3.21	22.0	28.5	6.5
		98	3.11	22.0	28.0	6.0
		173	3.66	22.0	27.8	5.8
		357	4.26	22.0	28.0	6.0
Iopop 6	7.10	52	3.45	22.2	30.2	8.0
		98	3.82	22.2	30.5	8.3
		173	3.95	22.2	30.1	7.9
		357	4.52	22.2	30.2	8.0
Iopop 6	9.89	52	3.21	30.0	35.8	5.8
		98	2.96	30.0	34.5	4.5
		173	3.46	30.0	35.2	5.2
		357	3.71	30.0	34.8	4.8
Illinois 52	7.15	52	3.10	21.5	26.4	4.9
		98	3.15	21.5	26.1	4.6
		173	3.52	21.5	27.6	6.1
		357	4.12	21.5	27.2	5.7
Purdue 32	7.90	52	3.10	21.7	30.2	8.5
		98	3.25	21.7	30.0	8.3
		173	3.45	21.7	29.7	8.0
		357	4.07	21.7	30.0	8.3
Purdue 32	11.19	52	3.56	32.0	32.8	.8
		98	3.56	32.0	32.5	.5
		173	3.71	32.0	32.5	.5
		357	3.91	32.0	31.8	−.2

Table 25. — Length of Blanch, Moisture Absorbed, and Popping Expansion of Two Hybrids with Different Initial Moisture, 1953

Initial moisture (percent)	Blanching time (seconds)	Moisture absorbed (percent)	Popping expansion (volumes)		
			Initial	After blanching	Increase
		Iopop 6			
8.05	24	2.00	28.0	31.0	3.0
	51	3.15	28.0	32.0	4.0
	81	3.25	28.0	33.0	5.0
	118	3.50	28.0	34.0	6.0
	146	3.40	28.0	31.0	3.0
9.00	24	1.90	26.8	30.0	3.2
	51	2.40	26.8	31.5	4.7
	81	2.75	26.8	29.5	2.7
	118	3.10	26.8	31.5	4.7
	146	3.20	26.8	30.0	3.2
9.40	24	2.05	32.0	34.5	2.5
	51	2.80	32.0	35.5	3.5
	81	3.05	32.0	35.0	3.0
	118	3.30	32.0	36.0	4.0
	146	3.25	32.0	34.0	2.0
		Purdue 202			
8.85	24	2.20	31.0	34.5	3.5
	51	2.95	31.0	35.0	4.0
	81	3.45	31.0	36.0	5.0
	118	3.45	31.0	36.5	5.5
	146	3.60	31.0	35.5	4.5
9.20	24	2.25	31.0	33.5	2.5
	51	2.85	31.0	34.0	3.0
	81	3.15	31.0	34.0	3.0
	118	3.55	31.0	34.0	3.0
	146	3.65	31.0	34.0	3.0
11.05	24	1.90	37.5	37.0	− .5
	51	2.65	37.5	36.5	−1.0
	81	2.90	37.5	37.0	− .5
	118	3.10	37.5	36.0	−1.5
	146	3.25	37.5	36.0	−1.5

Table 26. — Effect of a 52-Second Blanch on the Popping Expansion of Five Hybrids With Different Initial Moisture Contents

Variety and crop year	Percent moisture			Popping expansion (volumes)		
	Initial	After blanching[a]	Increase	Initial	After blanching[a]	Increase
Iopop 5 1952	6.95	10.77	3.82	19.7	26.0	6.3
	8.69	11.90	3.21	22.0	28.5	6.5
	11.20	14.60	3.40	28.2	29.7	1.5
Iopop 6 1952	7.10	10.55	3.45	22.2	30.2	8.0
	8.35	12.50	4.15	25.6	35.4	9.8
	9.89	13.10	3.21	30.0	35.8	5.8
	11.25	14.40	3.15	33.0	33.4	.4
Purdue 32 1952	7.90	11.00	3.10	21.7	30.2	8.5
	9.15	13.14	3.99	28.9	34.8	5.9
	11.19	14.75	3.56	32.0	32.8	.8
	12.05	15.55	3.50	32.7	29.0	−3.7
Iopop 6 1953	8.05	11.20	3.15	28.0	32.0	4.0
	9.00	11.40	2.40	26.8	31.5	4.7
	9.85	11.70	1.85	27.0	31.0	4.0
	10.85	12.65	1.80	34.0	34.5	.5
Purdue 202 1953	8.85	11.80	2.95	31.0	35.0	4.0
	9.20	12.05	2.85	31.0	35.0	4.0
	10.10	12.35	2.25	32.5	36.0	3.5
	10.45	12.25	1.80	29.0	31.0	2.0
	11.05	13.70	2.65	37.5	36.5	−1.0

[a] The blanching time was 52 seconds for the 1952 crop and 51 seconds for the 1953 crop.

There seemed to be no relation between initial moisture content and popping expansion after blanching except to the extent that blanching increased expansion in all but a few instances where the moisture content was already close to the optimum (11 percent or higher) and no additional moisture was needed.

There were some differences in varietal response to blanching. Iopop 5 (Tables 24 and 26) and Illinois 52 (Table 24) failed to reach the 30 volumes expansion considered standard by the trade. Both hybrids were also rehydrated with water with equally unsatisfactory results. The reason for the poor response of Iopop 5 was not determined. The Illinois 52 crop was affected by severe Diplodia ear and stalk rot. The 1951 crop of Illinois 52, in which the ears were relatively free of the disease, popped satisfactorily (Huelsen and Thompson, 9).

Spoilage in blanched corn. Under certain conditions, popcorn blanched for 52 seconds, immediately dumped without cooling into 30-pound slip cover cans, and stored at 80° F. became moldy in two weeks. When the corn was cooled and the condensed moisture dried off for one hour no spoilage occurred. The 1953 crop which was dried with a blower after blanching and sealed into containers at once showed no mold.

Offsetting any possibility of spoilage were two beneficial effects of blanching: it sterilized the kernels by killing insect eggs or larvae, and it acted as a bleach. After blanching, the yellow hybrids became lighter, also brighter and more attractive; the white hybrids bleached to a more brilliant shade.

Processing blanched popcorn. Bemis and Huelsen (1) investigated the effect of processing on blanched popcorn. Three hybrids were blanched for 52 and 357 seconds and the six lots were immediately packed in 30-pound slip cover cans. After 24 hours storage at 80° F. when the free moisture was absorbed, the corn was repacked in 211 × 400 plain cans. Half of each of the six lots was sealed without a vacuum and the other half with a vacuum of 15 inches. The twelve lots were again halved, one part receiving no process and the other a process of 45 minutes at 250° F. Heat penetration studies showed that with a vacuum of 15 inches a temperature of 212° was reached in 31 minutes in the center of the can. With no vacuum the time was 37 minutes. Therefore the process time of 45 minutes was sufficient for sterilization of a dry product.

Unblanched processed Iopop 6 and Purdue 32 turned a dull orange color. The blanched lots which originally were bright yellow turned to a dull orange shade during processing. Iopop 5, which is normally amber-colored, blanched to an attractive white, but processing caused it to turn to a dull tan whether it was blanched or not.

Blanched lots developed a slightly scorched odor under processing which was not exactly objectionable, but could not be considered an asset. Processing had no effect on the odor of unblanched lots.

In the lots processed after blanching, rust developed in the can along the side seam and at the ends where the two lids join the body of the can. The rust was observed when the first cans were opened; it failed to develop further even after storage for over two years. No rust was observed in the processed cans containing unblanched corn, or in the unprocessed cans regardless of whether their contents were blanched or unblanched. The experiments led to the conclusion that processing serves no purpose and should not be recommended.

Keeping quality of blanched corn. Since it was considered possible that blanched popcorn packed in sealed cans would fail to retain its popping expansion, the canned samples were stored under various conditions and sampled periodically up to 791 days.

Canned samples were stored for 64 days in an incubator held at 98° F. These were compared with a duplicate set of samples stored for 52 days at 35° F. followed by 64 days at room temperature of 80° F. No differences in vacuum, odor, or can rust could be observed. Popping expansions did not change materially in either group.

The remaining canned samples were stored at room temperatures up to 791 days. The condensed results appear in Table 27. No deterioration of any kind could be observed in any of the treatments, and after more than 26 months' storage the popping expansions were as high as at the start of the experiment.

Rehydration by Means of Blending

A popcorn lot which still has a low popping expansion after all efforts to improve it have failed is often blended by commercial processors with a high popping lot to give a merchantable sample. Machinery suitable for large-scale operations is available. This practice suggested the possibility of blending an overdried lot of popcorn with one containing too much moisture to produce a blend having the proper moisture content. Blending, however, would only be practical if the moisture from the wet part of the sample transferred rapidly enough to the dry part so that no spoilage resulted. Such equilibration could take place by means of direct transfer of moisture from kernel to kernel through actual contact, by means of diffusion through the air, and by a combination of both methods.

Table 27. — Effect of Storage on Popping Expansion of Canned Blanched and Unblanched Popcorn
(Processed and unprocessed samples were combined)

Hybrid	Popping expansion after various periods of storage[a]											
	Not blanched				Blanched 52 seconds				Blanched 357 seconds			
	Days in storage				Days in storage				Days in storage			
	64	116	358	791	64	116	358	791	64	116	358	791
	(volumes)											
Iopop 5	22.4	22.0	22.8	23.1	29.6	29.6	29.6	30.8	30.9	29.1	30.6	31.9
Iopop 6	25.6	25.4	26.0	26.4	35.4	35.2	36.1	36.9	35.6	34.2	36.8	36.8
Purdue 32	28.9	27.9	29.5	29.5	34.8	34.0	36.0	36.6	35.2	33.9	36.6	36.6

[a] Averages of 8 replications each.

Table 28. — Moisture Changes in Purdue 202 Kernels Held at Various Relative Humidities

Relative humidity at 68° F. (percent)	Changes in percent of kernel moisture after storage periods of	
	12 hours	35 hours
Initial kernel moisture percent 8.10		
15	−.28	−.62
35	.11	.21
56	.42	.86
75	1.03	2.37
95	2.79	5.86
Initial kernel moisture percent 10.90		
15	−.38	−.91
35	0	.04
56	.36	.68
75	1.02	2.03
95	2.71	5.42

There is no method of demonstrating the rate of moisture transfer by means of direct contact, but the rate of diffusion by means of vapor pressure is shown in Tables 28 and 29. Purdue 202 kernels (Table 28) were placed in open glass petri dishes stored in desiccators containing solutions of appropriate salts which would give the desired relative humidities. The desiccators were then placed in thermostatically controlled temperature chambers. At 15 percent relative humidity, diffusion of moisture out of the kernels was rapid. Above 56 percent relative humidity, the moisture absorbed from the air increased in relation to increasing relative humidities (Table 28). It would be expected therefore that in a blend containing a high ratio of wet kernels, the diffusion of moisture would be more rapid than in a blend where the reverse was true, provided the popcorn were stored in a vapor-proof container.

Table 29. — Equilibration Rate of Iopop 5 and Purdue 32 With Different Moisture Contents

(Stored in sealed containers at room temperature)

Hybrid	Ratio of each hybrid by weight	Method of storing	Percent moisture		
			Initial	After 31 days	After 158 days
Iopop 5	25	Mixed	9.95	11.50	11.50
Purdue 32	75		13.30	12.30	12.20
Weighted average			12.46	12.10	12.02
Iopop 5	50	Mixed	9.95	10.80	11.10
Purdue 32	50		13.30	11.90	11.45
Average			11.62	11.35	11.28
Iopop 5	75	Mixed	9.95	10.20	.....
Purdue 32	25		13.30	10.80	.....
Weighted average			10.79	10.35	.....
Iopop 5	50	Separated	9.95	10.70	10.75
Purdue 32	50		13.30	12.30	11.55
Average			11.62	11.50	11.15

Table 30. — Wet Sample Blended With 13 Lots of Overdried Iopop 6

(In ratios to bring the blend to 12.5 percent theoretical moisture)

Initial moisture percent	Original samples: Popping expansion (volumes)		After blending		Blending ratios		Popping expansion (volumes) after blending as percent of maximum at time shown			
	At initial moisture	Reconstituted with water to 12.5 percent	Maximum popping expansion (volumes)	Percent moisture	Dry part	Wet part	24 hours	14 days	49 days	119 days
8.8	26.0	32.0	30.5	12.0	54.32	45.68	80.3	91.8	95.1	100.0
9.5	29.0	33.0	30.2	12.0	59.45	40.55	81.0	95.9	100.0	100.0
9.6	30.0	30.8	31.2	12.2	60.28	39.72	83.2	94.4	96.0	100.0
9.7	30.0	32.5	31.5	11.8	61.13	38.87	88.9	96.0	100.0	100.0
9.8	29.0	33.0	32.8	11.7	61.96	38.04	89.3	96.2	100.0	98.5
10.2	32.0	33.2	32.5	12.0	65.66	34.34	90.0	98.5	100.0	98.5
10.5	34.0	33.5	32.5	12.0	68.78	31.22	90.0	96.9	100.0	99.2
10.5	30.0	30.8	31.5	11.8	68.78	31.22	92.1	92.1	97.6	100.0
10.6	31.0	32.2	32.5	11.9	69.83	30.17	92.3	96.2	96.9	100.0
11.0	33.0	32.5	32.5	11.5	74.57	25.43	93.8	96.2	98.5	100.0
11.0	31.5	31.2	32.2	11.7	74.57	25.43	96.1	93.8	98.4	100.0
11.2	32.0	32.8	32.8	11.9	77.22	22.78	94.6	94.6	96.2	100.0
11.5	34.0	35.2	34.8	11.0	81.50	18.50	97.1	95.7	100.0	97.8
16.9[a]	8.0									
Average		32.5	32.1				89.9	95.3	98.4	99.5

[a] Wet sample.

The truth of this assumption is demonstrated in Table 29. Iopop 5, a white hybrid with 9.95 percent moisture was mixed with Purdue 32, a yellow hybrid with 13.30 percent moisture, in three different ratios. A fourth lot, which served as a control, consisted of a 50-50 ratio of the two hybrids kept separated but in the same sealed container. Since the two hybrids were not in physical contact, any transfer of moisture resulted from diffusion through the air. Owing to color differences, the kernels in the mixed ratios could be separated manually and then tested for moisture content. Some moisture was lost at each sampling as indicated by the decreasing averages. Iopop 5, the dry component of the blend, absorbed decreasing quantities of moisture as the ratio of Purdue 32 was stepped down.

Thirteen lots of overdried Iopop 6 (Table 30) ranging from 8.8 to 11.5 percent moisture were blended with a lot containing 16.9 percent moisture so that the blend would average 12.5 percent. Blending was done in a laboratory model of a "Twin Shell Dry Blender" (manufactured by the Patterson-Kelley Co., East Stroudsburg, Pennsylvania). None of the blends averaged 12.5 percent, probably because of the loss of moisture during handling. The blends were stored in sealed jars at 80° F. As would be expected from the results in Table 29, the blends which contained a high ratio of the wet component reached maximum popping the earliest. However, from a practical standpoint 14 days storage proved to be sufficient to bring all 13 blends to within at least 90 percent of their maximum popping expansion. The experiment was repeated with 11 lots of Purdue 202 and the results were identical.

The average popping expansions of the 13 lots in Table 30 rehydrated with water were about the same as the lots which were blended and stored for 49 to 119 days. Almost identical results were obtained with 11 overdried lots of Purdue 202, but the data are not given.

SUMMARY AND CONCLUSIONS

Drying experiments were conducted over a 4-year period with six different popcorn hybrids planted at intervals in the spring so that a wide range of maturities could be secured. The corn was dried in a specially constructed pilot plant which is a scale model of a large commercial bin dryer. Recording instruments were used to keep a continuous record of the intake and exhaust air characteristics and of the temperatures in the corn. Moisture tests of the corn were taken periodically. The vapor pressures of the intake and exhaust air were calculated and expressed as a single factor termed "moisture pickup."

Two popcorn hybrids were harvested three times a week beginning when the kernel moisture reached 50 percent and continuing for a period of 83 days. The kernels and cobs dried at different rates in the field. The cobs, as indicated by their constant dry weights, were already mature before the experiment started. They did not lose moisture, however, until the kernel moisture reached 30 percent. Even though the two hybrids Iopop 6 and Purdue 202 differed in their respective rates of maturity, the relationship between the cob and kernel moistures at harvest was the same. This constant relationship makes it possible to predict the cob moisture if the kernel moisture is known. Since there are several rapid methods of determining kernel moistures, the buyer who purchases popcorn from the field can readily compute the actual shelling percentage of ear corn.

During drying by artificial heat, the percentage of moisture loss from the cobs exceeded that from the kernels. In hybrids with slender cobs such as Iopop 6, Purdue 32, and Purdue 202, the moisture content of the cobs upon completion of drying was usually lower than that in the kernels. In Iopop 5 and Iopop 7, which have thick, frequently fasciated cobs, the reverse was true unless they were greatly overdried. Owing to these moisture differentials it is advisable to shell artificially dried corn as soon as it is removed from the dryer because the kernels of the slender-cob hybrids will lose more moisture, while the kernels from the thick-cob hybrids will absorb moisture.

Using maximum popping expansion as a criterion, it was found that Iopop 6 and Purdue 202 could be considered fully mature when the kernels reached the range of 35 to 30 percent moisture.

Dry weights per kernel were found to be closely associated with popping expansion, and an equation is proposed by means of which expansion can be predicted from the dry weights.

The dryer was operated (except in certain experiments) at the rate of 25 to 30 changes of air per minute, a rate which is about three times the air velocity of an efficient commercial dryer. Under such conditions, popcorn dried very rapidly. During the early part of the drying period, the moisture was removed from the corn at a more rapid rate than later and the cobs showed greater differences than the kernels.

Since popcorn is bought and sold on the basis of its popping expansion, accurate determination of this factor was highly desirable. Because errors up to 4.7 percent in the weights of the measured samples were noted, all samples for popping were weighed after being measured. The weights of the measured samples, which gave an approximation of the specific gravity, varied directly with the moisture content, the correlation in Iopop 6 being — 0.980. With a correlation as high as this, it appeared that moisture content could be quickly determined by means of sample weights, but it was found that although the relationship held true within a given lot, the effects of growing conditions and other factors made separate calibration for each lot necessary.

Popping expansion could be predicted with reasonable accuracy on the basis of sample weights. Using a constant weight of 195 grams for the sample, the maximum deviation of the calculated expansion from the normal expansion was only 0.6 volume low. Using the 200-gram sample, the maximum deviation was only 1.1 high.

Popping expansion varied in relation to the moisture content, but hybrids differed considerably in the range of moistures which would produce an acceptable expansion. Iopop 6, Purdue 32, and Purdue 202, which have an acceptable range covering at least 5 percentage points, are much better suited for commercial use than Illinois 52 and Iopop 5, which have a narrower acceptable moisture range.

Comparisons of rehydrated samples of Purdue 202 and Iopop 6 harvested at various maturities beginning at 40 percent moisture and dried at room temperature and at 110° showed that drying at 110° caused a consistently greater reduction in popping expansion. Such reductions, however, became smaller as maturity advanced. When the corn was harvested with a moisture content higher than 24 to 25 percent and dried by artificial heat, the reductions in popping expansion were larger than when the corn was dried slowly at room temperature. No reductions in expansion occurred with room-temperature drying unless the moisture exceeded 33 percent. When the moisture content of the corn fell below the 25 percent level, popping expansion was not reduced appreciably by artificial drying at 110°. Under normal weather conditions, it is unlikely that popcorn having a moisture content over 25 percent will ever have to be harvested.

Further investigation of the question why artificial drying caused a reduction in popping expansion indicated that speed of drying was the important factor. Drying temperatures of 110°, 120°, and 130° were compared, but there was no evidence that 130° was any more injurious than 110° even though the drying rate at 130° was more rapid. However, all the artificially dried lots had a slightly lower popping expansion than the room-dried controls. In a second experiment, popcorn was dried in the dryer without heat (80°) and at 100°, 110°, and 120°. All the artificially dried lots had a lower expansion than the room-dried controls and the room-dried, in turn, did not pop as well as the outdoor controls.

Additional comparisons of speed of drying at 110° were made by running the bins at four different air velocities. None of the artificially dried lots popped as well as the room-dried and outdoor-dried controls. Among the artificially dried lots with initial moistures of 33.3 percent or higher, the lowest air velocity of 10.8 changes of air per minute produced the best popping expansion. In more mature lots, differences in air velocity had very little or no effect on popping expansion.

The four trays in each bin also permitted internal comparisons of different rates of drying, but there was no conclusive evidence that the slightly more rapid rate of drying in the tray nearest the source of heat was any more injurious than the slower rate in the tray farthest from the heat source.

Further experiments with rate of artificial drying consisted of comparing lots of popcorn dried on the ear with identical lots dried after shelling. Shelled popcorn required only about one-half to one-third as much time to dry as popcorn on the ear, but the popping expansion of the shelled-dried lots was much reduced.

Outside of the actual increased rate of moisture loss, there was no specific factor which accounted for the fact that artificial drying might cause a reduction in popping expansion. The experiments showed that such reductions were variable. In general, the reductions became smaller as maturity advanced and drying after shelling caused more damage than drying on the ear.

Chilling husked popcorn at 35° F. for 24 hours followed by artificial drying at 110° had no adverse effect on popping expansion. Such chilling was designed to represent the conditions of a light frost. To duplicate the conditions of a hard freeze, husked ears of various maturities were frozen at — 10 F. up to 15 hours. After freezing, the ears were dried at 80° and 110°. With corn having a moisture percent below 25, freezing had a slight adverse effect on expansion, but with moistures above 25 percent, the reductions in expansion were greater.

Experiments were designed to supplement the meager information available on popping temperatures. The statements below summarize somewhat complex relationships. (The term "preheat temperature" refers to the temperature of the popper, to which oil had already been added, at the time the popcorn was dumped.)

Increasing preheat temperature increased the popping expansion.

Increasing preheat temperature reduced the length of the popping period.

Increasing preheat temperature caused popping to start at higher temperatures.

Increased maturity at harvest reduced the length of the popping period.

Popcorn harvested at all stages of maturity responded favorably to increased popping temperatures, but the total expansion of the more mature corn was almost always greater.

Increased moisture at popping increased the length of the popping period.

Increased preheat temperature accompanied by increased moisture content closer to the optimum tended to increase popping expansion, but the different hybrids varied in their responses.

A preheat temperature of about 550° gave more favorable popping expansion than the 470° usually recommended for the official volume tester.

Blanching with steam was found to be a rapid and satisfactory method of rehydrating popcorn. Blanching increased popping expansion except where the initial moisture was close to the optimum. Hybrids differed in their response to blanching, in so far as popping expansion was concerned, but those which responded poorly to blanching also responded poorly when rehydrated with water.

The blanched popcorn had considerable condensed surface moisture which decreased as the blanching period was lengthened. To dry off the condensed moisture, a second conveyor, similar to the blancher but with a blower fan attached, was added.

The quantity of moisture absorbed during blanching decreased as the initial moisture content of the corn increased. Moisture absorption was most rapid the first 24 seconds, followed by a much reduced rate the next 27 seconds. Extending the blanch beyond 51 seconds increased the quantity of moisture absorbed, but the rates of absorption tended to decrease with successive extensions of the blanching period. A blanching period of about 60 seconds appeared to be sufficient for most purposes.

Besides improving expansion, blanching improved the color of popcorn and sterilized the corn to the extent that no insects or insect eggs survived.

To determine its keeping qualities, blanched popcorn was canned with and without a 15-inch vacuum. Part of each lot was processed at 250° for 45 minutes. Processing of blanched popcorn is not recommended since a slightly scorched odor developed; the can rusted at the side seam and where the lids joined the body; and the color was adversely affected. Processing of unblanched corn affected the color, but no rust or odor developed. Storage of all the canned lots for periods up to 791 days under various conditions indicated that blanching and processing had no adverse effect on popping expansion.

Mechanical blending on a commercial scale is possible with existing machinery. This possibility led to blending lots of overdried popcorn with those too wet to pop satisfactorily, thus securing a blend with the proper moisture for optimum popping expansion. Storage of overdried popcorn under various relative humidities indicated that moisture diffused rapidly both into and out of the kernels. Movement of moisture into the kernels increased as the relative humidity increased.

Twenty-four overdried lots of Iopop 6 and Purdue 202 were blended with one wet lot of each hybrid in the proper ratios so that the blend averaged 12.5 percent. Owing to loss of moisture during blending all the blends tested lower than 12.5 percent moisture. The overdried lots were also reconstituted with water to 12.5 percent moisture. The blends averaged practically the same popping expansion as the lots reconstituted with water. Storage of 14 days is sufficient in most cases to bring the blends to within 95 percent of their maximum popping expansion.

APPENDIX

As mentioned in the text, a scale-model bin dryer was used in all of the experiments. This pilot plant consisted of four bins constructed as a single unit, each bin complete in itself with its own heating unit, fan, and controls so that it could be operated independently. Each bin had a drying range from room temperature to 140° F. and sufficient excess fan capacity to permit a wide range of air velocities. The air movement in each bin could be regulated by means of a bypass or check damper on the intake side of the fan and further by a solid shut-off damper in the pipe on the exhaust side.

The interior arrangement of a single bin is shown in Figs. 17 and 18. The heating unit consisted of an Aerofin Flexitube booster unit with a nominal tube length of 18 inches and a face area of 1.06 square feet. The fan was a Buffalo direct-connected "baby" vent set, size E, with a 7¾ inch wheel, a ¼ h.p. 1750 r.p.m. motor with a nominal rated capacity of 690 c.f.m. against ¾ inch static pressure. Air was pulled through the drier by the fan (Fig. 17).

Steam was provided by a 7.5 h.p. gas-fired steam boiler with more than sufficient capacity to operate all four bins simultaneously at 140° F. when the boiler pressure was 2.5 p.s.i. The boiler was equipped with a pressure control, but the bin temperatures were regulated by means of Minneapolis-Honeywell temperature controls wired to motorized valves regulating the steam supply to each booster coil. This arrangement permitted temperature regulation without interfering with the velocity of the air.

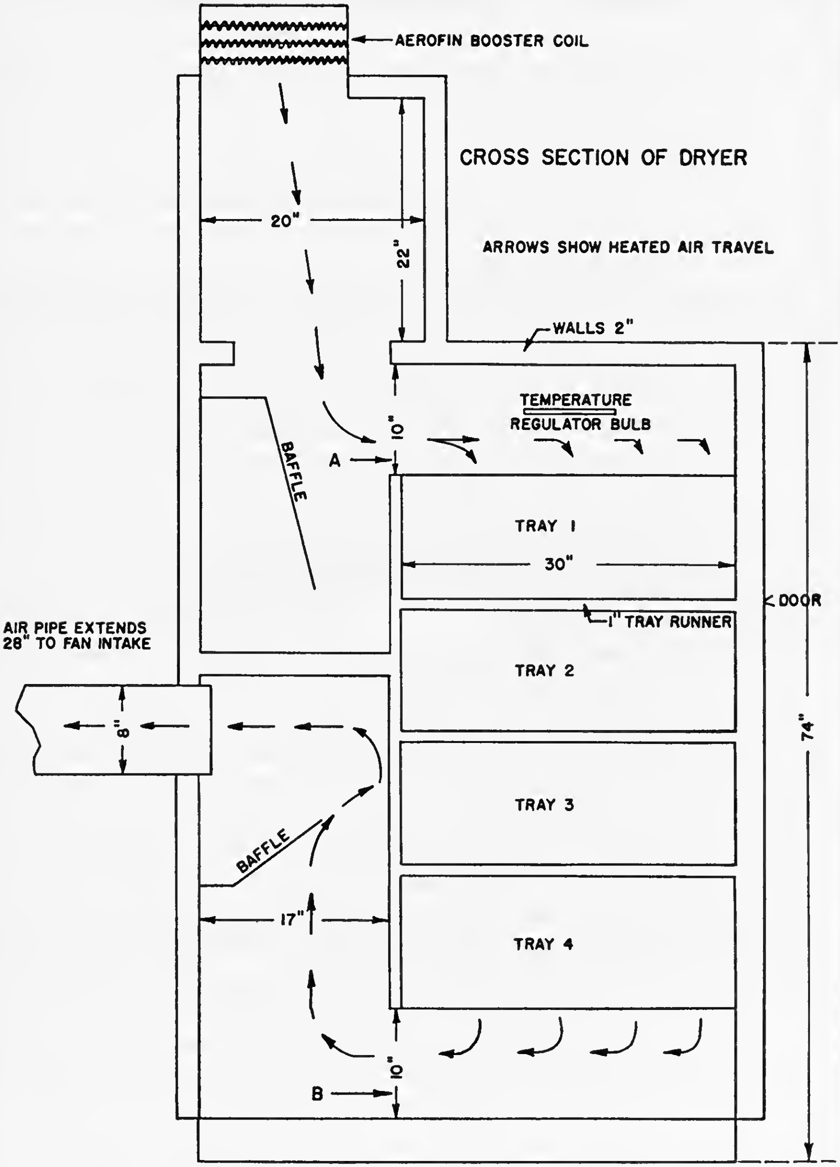
Each bin contained four trays into which the corn was loaded. The trays were provided because sampling from a bin containing a solid load is very difficult. In commercial practice the bins would be loaded solid, each having a nominal capacity of 48 inches of corn. However the net capacity of each tray was only 9½ inches of corn, giving a total depth of 38 inches when the four trays in each bin were fully loaded (Fig. 18).

Temperatures were recorded by means of two 12-station Brown strip-chart recording potentiometers. One potentiometer was wired to an automatic switch which was tripped every 30 minutes by an electric clock so that readings alternated between two separate sets of 12 thermocouples. As shown in Figs. 4, 5, and 6, Trays 1 and 3 were read on the hour and Trays 2 and 4 on the half hour. One potentiometer has 12 thermocouple stations and the other 24, a total of 36 stations, or 9 per bin.

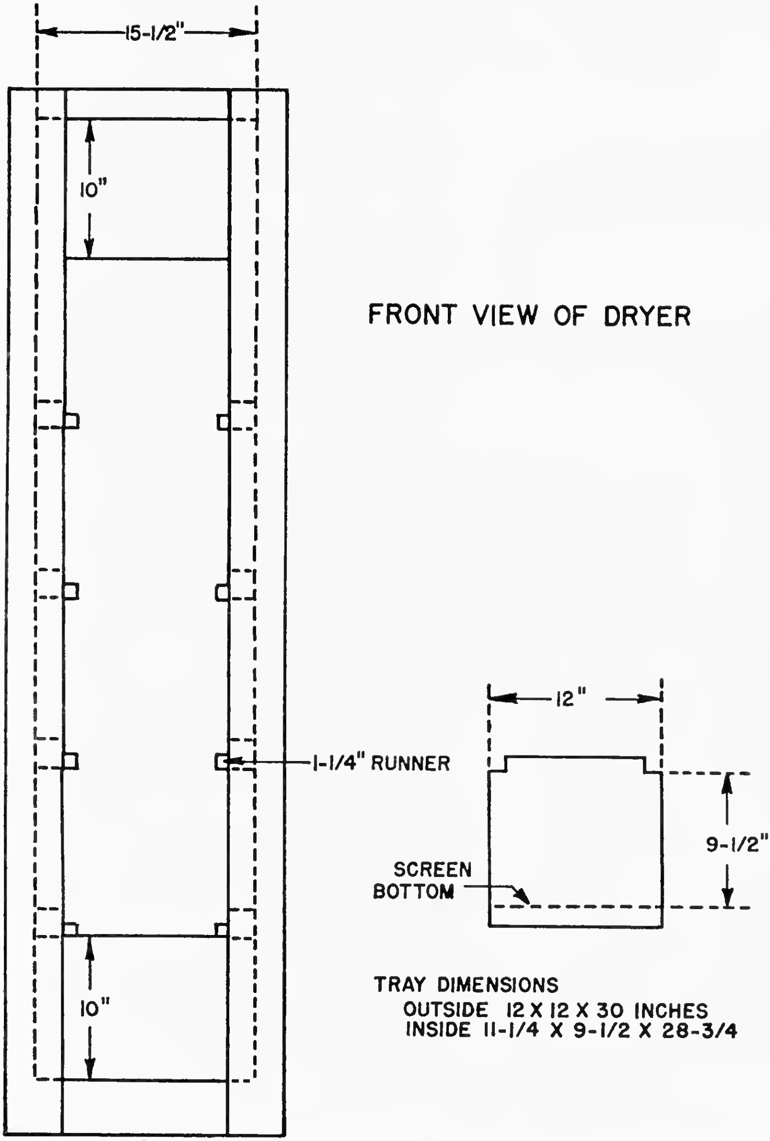
The thermocouples were made from 30-gage iron-constantan wire insulated with nylon. After welding, the couples were coated with a dielectric varnish and then sealed in 2-inch lengths of small glass tubing drawn to a point at one end. The wet-bulb thermocouples were covered with suitable lengths of white cotton shoelaces. Each wet-bulb thermocouple was inserted through a hole in a small box made of Masonite painted black. The box had no back or front and was fastened to the top of a glass jar in such a way that the air could pass directly through it. The sock was inserted through a small hole in the lid covering the jar. A dry-bulb thermocouple was mounted adjacent to it, the two being separated by one inch.

The wet-bulb readings were a source of considerable trouble because the sock had a tendency to dry out faster than the capillary action could restore the distilled water from the jar. Frequent checking was required with a sling psychrometer. The tray thermocouples were placed in the center of each tray completely surrounded by corn. The dry and wet intake couples were located at position A in Fig. 17 and the dry and wet exhaust couples at position B, Fig. 17. Both of these positions were directly in the air stream.

In order to check the temperature-regulator bulbs and the dry intake thermocouples, the extended bulb of a Foxboro recording thermometer was located adjacent to each temperature-regulator bulb. An additional check was provided by a long-stem mercury thermometer



This is a cross-section view of the dryer used in the experiments. A commercial dryer would probably not have the trays. The trays were used in the experimental work to facilitate sampling. (Fig. 17)



The front view of the dryer used in the experiments shows how the trays divided the space in the bin. (Fig. 18) which could be read from the outside. A wet- and dry-bulb mercury thermometer was also placed at position B, Fig. 17. It could be read through a plexiglass window in the exhaust plenum and was used to check the wet and dry exhaust couples.

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