# EFFECT OF ARTIFICIAL DRYING ON THE HYGROSCOPIC PROPERTIES OF CORN[1]

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### ABSTRACT

The equilibrium moisture content (EMC) and the equilibrium relative humidity (ERH) of shelled corn artificially dried in a pilot dryer and in the laboratory were determined. Samples dried at air temperatures of 140°F. and above adsorbed less water at relative humidities of 70–80% than those dried at lower temperatures. The ability to adsorb moisture progressively decreased with increased drying temperature. The effect seems to be permanent with case hardening not substantially involved. Corn dried with temperatures of 140°F. and above supported a higher ERH than corn of the same moisture dried with room air. The increase in ERH with increased drying temperature was inversely proportional to the decrease in EMC. The other variables in the drying treatments — airflow rates, batch and continuous-flow drying methods, and initial corn moisture — did not significantly affect EMC or ERH.

Artificially dried corn with its higher interseed relative humidity should be stored at 0.5 to 1% lower moistures than naturally dried corn to prevent mold development. The moisture content and the ERH of a sample of corn can be readily determined and may be useful in indicating previous drying history and in the evaluation of drying methods.

Warehousemen have reported difficulty in the storage of artificially dried corn. Bailey (1) reported that "Increases in blue-mold damage to corn stored in a terminal elevator usually, but not always, take place with artificially dried corn." He reports further that the spread of mold in naturally dried corn is "much slower than in artificially dried grain."

Studies of the effect of artificial drying on the market quality and storability of field-shelled corn were initiated in 1959 under a joint project of the Purdue University Agricultural Experiment Station and the USDA Agricultural Marketing Service. This paper reports on changed hygroscopic properties of dried corn that are probably related to storage behavior and other quality factors.

## Equipment and Methods

*Drying Treatments.* The drying studies extended over three crop years and included tests in the laboratory and in a pilot drying plant. Three commercial hybrids grown on the Purdue University Agronomy

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farm were used in the tests. The corn dried in the pilot dryer was harvested with a field sheller or corn combine, while both machine- and hand-shelled corn was used in the laboratory tests.

The pilot dryer was a tower-type dryer typical of those at country elevators in the eastern part of the Corn Belt. Variables in the tests with the pilot dryer included air temperatures of 140°, 190°, and 240°F., airflow rates from 36 to 72 c.f.m. per bu., batch and continuous-flow drying methods, and initial corn moisture levels ranging from 20 to 30%. The final corn moisture content was between 12 and 14% in most of the tests. Control samples were dried in screen-bottomed trays with forced circulation of room air at 80°F. or less.

Drying in the laboratory was done by passing air at specified dry-bulb and dewpoint temperatures through thin layers of corn contained in screen-bottomed trays.

The temperatures reported are those of the drying air. The corn dried in the laboratory was within 2° to 5°F. of the air temperature. The maximum corn temperature in the pilot dryer was below the drying air temperature. With 240°F. drying air, the corn temperature reached 160°F.; with 190°F. and 140°F. drying air, the corn temperatures were 144°F. and 114°F., respectively.

*Storage Procedures.* Corn, after the various drying treatments, was kept in paper bags in the laboratory until dried to moistures between 8 and 12%. This allowed inoculation of the seed with water suspensions of spores of storage fungi (species of the *Aspergillus glaucus* group), bringing the moisture to 14% before storage. Some samples were allowed to equilibrate without addition of water. Samples of 30 to 40 g. were put in perforated plastic containers and stored in 2.7-liter desiccators at selected relative humidities for observations of storage mold development and of equilibrium moisture content. Air was bubbled successively through water, a saturated salt solution, and then into the salt solution in the bottom of the desiccator. Salts and the humidities maintained were: ammonium sulfate, 80%; sodium chloride, 75%; and strontium chloride, 70%. Near-constant temperatures in the 70°–80°F. range were maintained in all tests.

*Moisture Measurements.* Moisture determinations made by different methods in different phases of the tests are identified as follows:

Official air oven (5): 15 g. of whole seed dried in air oven for 72 hr. at 103°C. (Official method for grading standard.)

Two-stage air oven: 10 g. of whole seed air-dried, two 2-g. samples ground to 20-mesh and oven-dried at 130°C. for 1 hr.

Electric moisture meter — dielectric type.

Electric meters were used to determine moisture levels of large lots of corn prior to final drying treatment. Moisture contents were also calculated using weight changes from a previously determined moisture level. Moistures are reported on a wet basis.

*Relative Humidity Measurements.* The relative humidity in the interseed air was measured in corn of known moisture levels and related to the method of drying. One or more electric hygrometer elements (4) of suitable range were placed in a closed container of corn and the relative humidity read periodically with an indicating instrument. Accuracy of the elements when checked over the salt solutions listed above was close to ±1.5% as specified by the manufacturer.

## Discussion and Results

*Equilibrium Moisture Content (EMC).* Observations on the EMC of artificially dried grain were made on samples from the pilot dryer in 1959. The moisture contents of corn stored at 80% r.h. and 73°–76°F. for 5 weeks were:

| | *Average Equilibrium Moisture Content* |
|---|---|
| | % |
| Nine control samples dried at room temperature .......... | 15.52 |
| Nine samples dried at 140°, 190°, or 240°F. ................ | 15.07 |

The difference of 0.45% in equilibrium moisture content was significant at the 0.01 level. The two-stage air oven method was used for moisture determinations.

Samples of corn dried without heat were autoclaved (250°F. for 15 min.) and compared to similar samples not autoclaved (Table I). The

TABLE I

EQUILIBRIUM MOISTURE CONTENT OF AUTOCLAVED AND NONAUTOCLAVED CORN AS DETERMINED AFTER 10 WEEKS' STORAGE AT 75 AND 80% R.H. AND AT 73° TO 77°F.

| TREATMENT | ORIGINAL MOISTURE CONTENT | STORAGE RELATIVE HUMIDITY | EQUILIBRIUM MOISTURE CONTENT[a] | |
|---|---|---|---|---|
| | | | Air Oven[b] | Weight |
| | % | % | % | % |
| Nonautoclaved | 11.8 | 75 | 14.5 | 14.4 |
| Autoclaved | 12.2 | 75 | 13.2 | 13.3 |
| Nonautoclaved | 12.8 | 80 | 15.7 | 15.4 |
| Autoclaved | 13.1 | 80 | 14.2 | 14.0 |

[a] Average of three replicates.
[b] Determined by the two-stage air oven method.

autoclaving lowered the EMC from 1.1 to 1.5 percentage points.

Small samples of corn from the 1960 crop were dried from 23.0% to about 13% moisture in the laboratory at air temperatures of 80°, 120°, 160°, and 200°F. Drying time ranged from 0.5 hr. at 200°F. to 24 hr. at 80°F. These samples were further dried at room temperature to about 8% moisture before exposure to air at 80% r.h. After 4 weeks at 80%, the samples were exposed at 70% r.h. for 7 weeks to determine if the shift in EMC associated with drying held regardless of whether equilibrium was approached by adsorption or desorption. The changes in moisture content determined by weight are shown in Fig. 1. Under both adsorption and desorption, the corn dried at 200°F. reached moisture contents about 1% lower than the same corn dried at 80°F. Thus, the shift in equilibrium was not explained by sorption hysteresis.

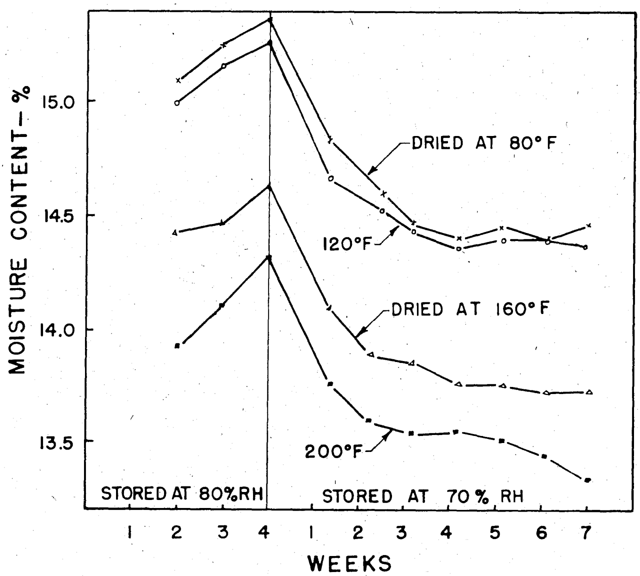


Fig. 1. Moisture contents of corn dried at various temperatures and stored at 80% r.h. for 4 weeks and then stored at 70% r.h. for 7 weeks at 76°–78°F.

In a second laboratory test the upper range of drying temperatures was extended to 300°F. Corn at an initial moisture of 25% was dried to between 12.0 and 12.6%. Part of each dried sample was ground to 20 mesh and held along with whole-seed samples at 80% r.h. The relationship of the drying air temperature and EMC is shown in Fig. 2. The results check with those in the previous experiment and show little further shift in equilibrium when temperatures were increased from 200° to 300°F. Ground corn showed a lower moisture content than the whole seed. A one-stage oven method was used for moisture measurements on the ground corn and may account for the lower moisture, but the same relationship between equilibrium moisture content and drying temperatures exists for whole and ground corn. Thus, case hardening is little involved in the decreased moisture adsorption of corn dried with heat.

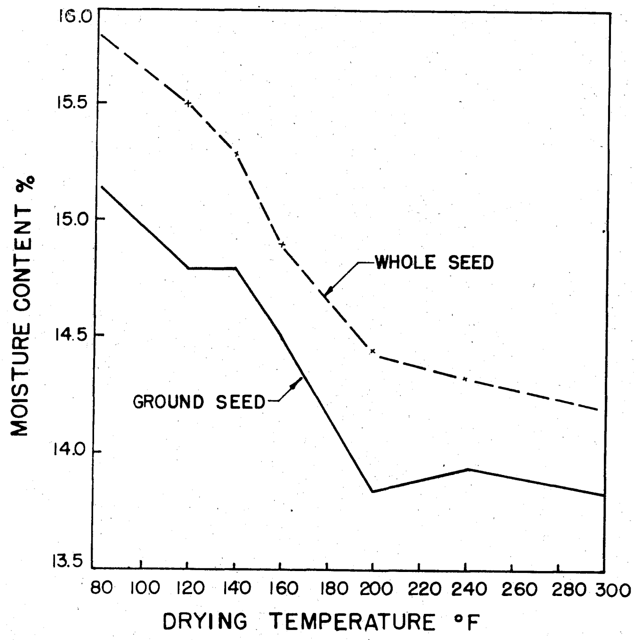


Fig. 2. Equilibrium moisture content of corn dried at various temperatures and stored whole and ground for 5 weeks at 80% r.h. and 80°F.

Brandenburg and Harmond (2) report a shift in the EMC of the straw of fiber flax dried with heated air that was independent of case hardening.

Observation on EMC was concluded with samples from the 1961 crop dried in the pilot dryer. The average and the range of the moisture contents of the samples after exposure to 80% r.h. and 80°F. for 1 month are in Table II. Temperatures of 140°, 190°, and 240°F. resulted in average reductions in the EMC of 0.4, 0.7, and 0.8%. The differences from the control were significant at the 0.01 level. Variables other than temperature — airflow rate, initial moisture level, and drying method — affected the average equilibrium moisture level 0.1% or less, and were not significant.

Since the two-stage oven method was used to determine moisture

TABLE II

EFFECT OF DRYING AIR TEMPERATURE ON THE EQUILIBRIUM MOISTURE CONTENT OF SAMPLES FROM 1961 PILOT DRYING TESTS

| DRYING AIR TEMPERATURE | NUMBER OF TESTS | EQUILIBRIUM MOISTURE CONTENT [a] | |
|---|---|---|---|
| | | Average | Range |
| °F. | | % | % |
| Room (control samples) | 5 | 15.2 | 15.0–15.4 |
| 140 | 6 | 14.8 | 14.5–14.9 |
| 190 | 7 | 14.5 | 14.4–14.8 |
| 240 | 6 | 14.4 | 14.2–14.6 |

[a] Moisture content determined by two-stage air oven (two replications) after 1 month's exposure to air at 80% r.h. and 80°F.

content in most of the tests, this method was checked against the "official air oven" method (5). One sample dried with room air and one sample from each of the drying temperatures used in the pilot drying tests were compared. The original moisture content and the final moisture content after 1 month at 80% r.h. were determined by both methods (Table III). The two-stage method gave 0.14 to 0.53% higher moisture contents than the whole-seed method. The official whole-seed determination confirmed that the moisture adsorption of corn is reduced by heating, but that the change may be slightly exaggerated when the two-stage oven is used.

TABLE III

COMPARISON OF OFFICIAL AIR OVEN (WHOLE SEED) AND THE TWO-STAGE AIR OVEN METHODS FOR DETERMINING EQUILIBRIUM MOISTURE CONTENT OF DRIED CORN

| DRYING TEMPERATURE | EQUILIBRIUM MOISTURE CONTENT [a] | |
|---|---|---|
| | Whole Seed [b] | Two-Stage Air Oven [c] |
| °F. | % | % |
| 70–80 | 14.93 | 15.46 |
| 140 | 14.76 | 15.16 |
| 190 | 14.46 | 14.60 |
| 240 | 14.10 | 14.36 |

[a] Average of three replicates.
[b] 15 g. of whole seed at 103°F. for 72 hr.
[c] 10 g. of seed air-dried, two 2-g. samples ground to 20 mesh at 130°C. for 1 hr.

*Equilibrium Relative Humidity (ERH).* As artificially dried corn reached a lower EMC than naturally dried corn it should, at the same moisture content, support a higher relative humidity. This hypothesis was tested by measuring the interseed humidity in sealed cans of corn that had been dried to the same moisture level but with different drying temperatures. Two 6-lb. lots of shelled corn were dried from 23.5 to 12.0% moisture content as determined by weight loss (12.1% as determined by the two-stage air oven). The two lots were placed in separate gallon cans and held at 77°F. Within 24 hr. the interseed relative humidity was 62% for the lot dried at 160°F. and 55% for the lot dried at 80°F. A week later the difference in the two humidities was reduced to 5% and after one month to about 4%. After 19 months the difference in relative humidity was about 3%.

The relative humidity supported by corn was similarly determined for the samples dried in the second laboratory test (Fig. 3). As expected, the ERH increased as the drying temperature increased. The effect of drying temperature on ERH is about inversely proportional to the effect on EMC (Fig. 2).

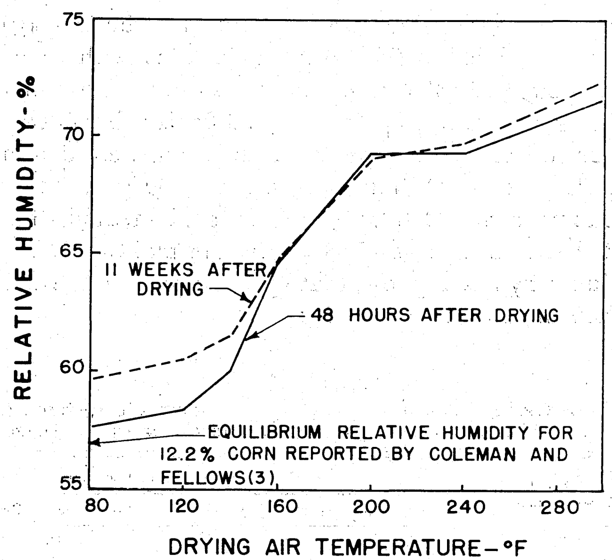


Fig. 3. Effect of drying air temperature on the relative humidity of interseed air in equilibrium with corn dried to 12.2% moisture.

The equilibrium relative humidities were studied with 12% corn to enable observation over extended periods without mold growth confounding results. Since the equilibrium moisture contents were studied in the range of 13.5 to 15.5%, the ERH of two samples dried to 14% moisture content — one with 80°F. drying air and one with 200°F. drying air — were compared. The difference in the relative humidity supported by these two samples was 8% about 48 hr. after drying, only slightly less than that with 12% corn.

Some of the relative humidities supported by the samples changed with time. In the test with the 1-gal. samples the humidity in the sample dried at 80°F. slowly increased and the difference between the two samples decreased. In the test results in Fig. 3 the upward shift in humidity after 11 weeks was greater at the lower drying temperatures. Apparently, the ERH increased with the age of the corn, but observations made on old corn do not confirm this. The ERH of one sample of 1952 corn and one other of old corn of unknown history was measured. Both showed ERH below that of the fresh test samples dried at 80°F. Possibly the samples dried at low temperatures went through a "normalizing" period following drying, which resulted in some increase in the ERH, or possibly respiration products in the sealed container were greater in samples where viability was not damaged by drying. Regardless of any change in ERH with time, a larger difference associated with the drying treatment persisted.

Since higher interseed relative humidities encourage mold growth – one of the major factors in storage losses – the moisture content for safe storage of corn dried at higher temperatures is reduced. Results suggest that artificially dried corn should be stored at moisture contents 0.5 to 1.0% lower than that recommended for naturally dried corn.

Changes in hygroscopic properties of corn can be measured readily and may be an aid in evaluating drying methods in relation to milling quality.

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