MOISTURE RELATIONS IN GERM, ENDOSPERM, AND WHOLE CORN KERNEL[1]

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ABSTRACT

Sorption-desorption isotherms were established for whole yellow dent corn kernels as well as germ and endosperm fragments at 74°F. over the range of 11 to 97% relative humidity. All three isotherms were sigmoid and showed hysteresis loops. The equilibrium moisture content of the germ was lower than that of the endosperm up to a relative humidity of 88%. At this point both germ and endosperm reached a level of 21% moisture content dry basis (17.35% wet basis). Above this level the germ took up water much more rapidly than the endosperm. The constants of the empirical equation proposed by Henderson were solved for the germ, endosperm, and whole kernel. Desorption isotherms were computed, using these constants, and compared with the observed isotherms. The endosperm showed best fit, but no coincidence was found for the germ.

The hygroscopic properties of corn kernels have been investigated only in part, mainly in relation to drying and storing of the crops. The moisture contents of shelled corn exposed to different atmospheres of relative humidity (r.h.) were determined by Bailey (1), Coleman and Fellows (2), Brockington *et al.* (3), Thompson and Shedd (4), Hubbard *et al.* (5), and Hall and Rodriguez-Arias (6). The sorption-desorption isotherms were constructed at different temperatures and were found to be sigmoid in shape. Such isotherms were classified by Brunauer and co-workers (7,8) as of type II, the shape being generally attributed to multimolecular adsorption. The mathematical characteristics of equilibrium moisture curves of some agricultural materials were studied (9), and an empirical equation was established.

Data on the relative moisture contents of the germ and endosperm of corn under various relative humidities are not available, although the difference in water sorption by the germ and endosperm was shown by Sprague (12) in a study of germination of corn. However, it is known that the germ has more affinity for water at higher relative humidities (10,11) and its tissues swell more readily. On the other hand, it is harder to remove moisture from the endosperm, since it is surrounded by other tissues and contains only small unconnected intercellular spaces. It has been suggested that the difference between

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the rates of moisture intake causes strains to be set up and the bonding material at the interface between the germ and endosperm is weakened, and this tends to free the germ from the endosperm (10).

One of the major purposes of tempering in the corn dry-milling process is to achieve this separation and to obtain an increased yield of germ and consequently of oil. The kernels are usually tempered to 18–25% moisture content, but the optimal moisture level has not yet been established, although investigation of this problem is under progress (13).

This study was undertaken to establish the sorption-desorption isotherms of the germ and endosperm, in addition to that of the whole kernel. This information was needed in investigating the mechanical properties of dry shelled corn as affected by moisture history.

Materials and Methods

The corn used in this study was yellow dent hybrid (Pa 444) from the 1964 crop with about 13% moisture content. It was ear-dried by ambient temperature and hand-shelled.

Experiments were made to determine the percent moisture in the whole kernel, the germ, and the endosperm after the whole kernel reached equilibrium with air of a series of relative humidities from 11 to 97%. The desired humidities were maintained in 160-mm. desiccators by means of saturated salt solutions (Table I).

TABLE I
SATURATED SALT SOLUTIONS AND THEIR RELATIVE HUMIDITIES AT 74°F.

Salt	Relative Humidity	Literature Reference	Salt	Relative Humidity	Literature Reference
K_2SO_4	97.0	14	NaBr	58.7	15, 16
KNO_3	92.5	14	K_2CO_3	43.9	16
KCl	84.8	15	$MgCl_2$	32.9	16
NaCl	75.5	14, 16	$KC_2H_3O_2$	22.9	16
$Na_2CrO_44H_2O$	66.7	15	LiCl	11.1	16

The desiccators were evacuated in the lower vapor-pressure range (11–70%) to accelerate moisture transfer. All desiccators were kept in a controlled-temperature chamber at 74°F. (23.3°C.).

The samples for the sorption experiments were initially vacuum-dried at room temperature to about 5% moisture; the samples for the desorption experiments were equilibrated first at 97% r.h.

The samples were weighed periodically until constant weight was maintained. Time allowed for attainment of equilibrium varied from 1 to 3 weeks, depending on the humidity shift. Mold growth was prevented in the high-humidity chambers by placing an open dish of toluene in the chambers.

When equilibrium was reached, germ and endosperm samples were prepared by hand-dissection. The moisture content was determined for the whole kernel, germ, and endosperm. The air-oven method (103°C. and 72 hr.) (17) for whole corn was used, rather than the two-stage procedure, to eliminate possible moisture interchange during grinding. Sample size for the moisture content determination was about 2 g. for whole corn and endosperm but only 200–300 mg. for the germ.

Moisture percentage in this paper is expressed on a dry-matter basis.

Results and Discussion

Sorption-desorption isotherms for the germ, endosperm, and whole corn kernel were established at 74°F. (Figs. 1 and 2).

Replicate moisture content determinations for whole kernel and endosperm checked within 0.1%. Since the germ samples were much smaller, results of two to four replicates checked within 0.5% and the mean value was taken.

Moisture contents of the germ, endosperm, and whole kernel in equilibrium with ten relative humidities at 74°F. as well as the difference between sorption and desorption are shown in Table II.

All three isotherms were sigmoid and showed hysteresis loops. The

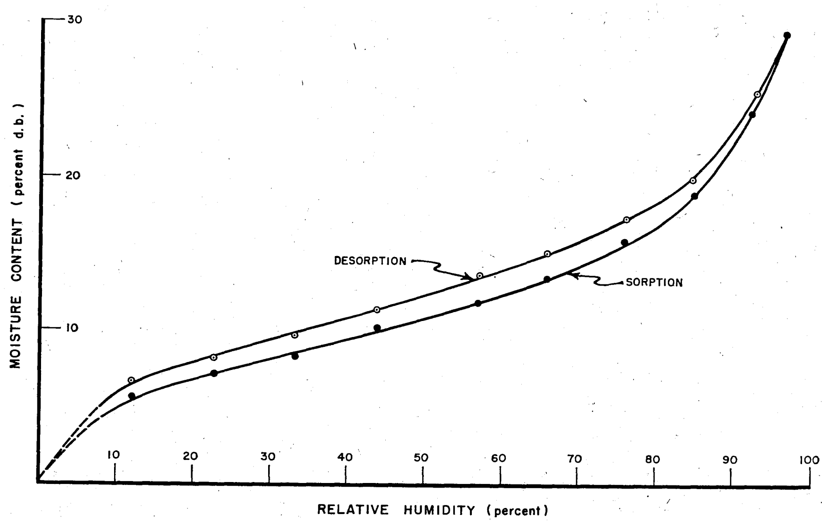

Fig. 1. Sorption-desorption isotherms for whole corn kernel at 74°F.

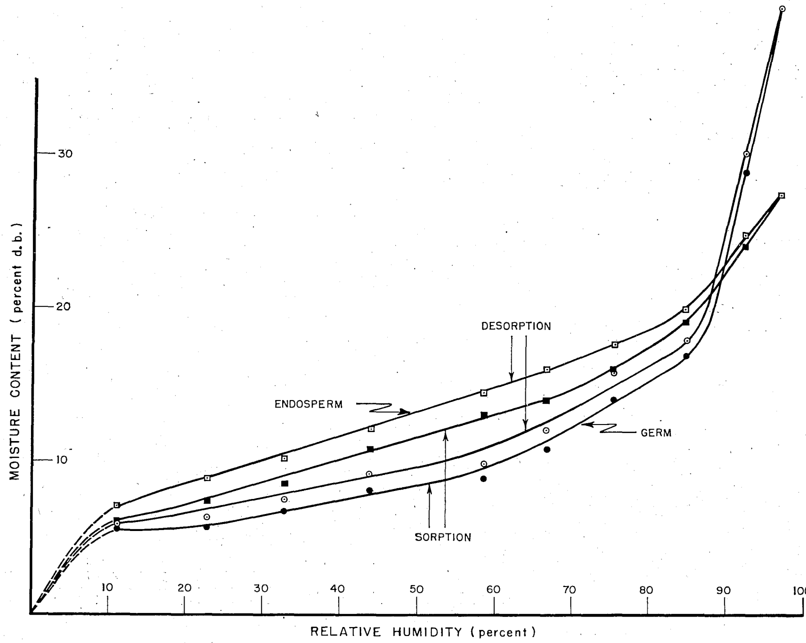

Fig. 2. Sorption-desorption isotherms for corn germ and endosperm at 74°F.

TABLE II

HYGROSCOPIC MOISTURE IN GERM, ENDOSPERM, AND WHOLE CORN KERNEL AT 74°F.

Relative Humidity	Moisture Content: Desorption			Moisture Content: Sorption			Difference (Desorption — Sorption)		
	Germ	Endo-sperm	Whole Kernel	Germ	Endo-sperm	Whole Kernel	Germ	Endo-sperm	Whole Kernel
%	*% d.b.*	*% d.b.*	*% d.b.*	*% d.b.*	*% d.b.*	*% d.b.*	*% d.b.*	*% d.b.*	*% d.b.*
11.1	5.95	7.15	6.62	5.58	6.07	5.67	0.37	1.08	0.95
22.9	6.29	8.90	8.05	5.72	7.46	7.07	0.57	1.44	0.98
32.9	7.50	10.20	9.55	6.80	8.54	8.00	0.70	1.66	1.55
43.9	9.22	12.15	11.40	8.10	10.85	10.15	1.12	1.30	1.25
58.7	9.80	14.50	13.59	8.98	13.07	11.83	0.82	1.43	1.76
66.7	12.12	16.00	15.12	10.78	14.00	13.40	1.34	2.00	1.72
75.5	15.85	17.70	17.55	14.10	16.10	15.80	1.75	1.60	1.75
84.8	17.90	19.90	19.80	16.95	19.20	18.90	0.95	0.70	0.90
92.5	30.20	24.75	25.50	28.85	24.05	24.25	1.35	0.70	1.25
97.0	39.60	27.40	29.30						

hysteresis effect was generally more pronounced in the endosperm than in the germ (Table II).

Up to 88% r.h. the equilibrium moisture of the germ was lower than that of the endosperm. At this point, both reached a level of 21%, and above this level the germ took up water much more rapidly. The moisture content of the germ at 97% r.h. was nearly 40%, 12%

higher than that of the endosperm. Similar behavior was found by Sprague (12) when corn kernels were stored in a saturated atmosphere.

Since respiration of the living germ might have influenced results in the high relative humidities, a similar sorption experiment was run with dead-germ kernels. The moisture content of the dead germs at relative humidities above 85% was a little lower than that of the living germs, but the general pattern of the germ isotherm was maintained.

Henderson (9) found that equilibrium moisture content curves for a number of materials can be described by the following equation:

$$1 - \mathrm{rh} = e^{-k' M^{n}}$$

in which rh = equilibrium relative humidity expressed as a decimal;
M = equilibrium moisture content, percent dry basis;
k′ = factor varying with material and temperature;
n = exponent, varying with material.

It seemed worth while to check the applicability of this equation for the germ and the endosperm in addition to the whole kernel.

For each of the three desorption isotherms two points on the curve, at 25 and 75% equilibrium r.h., were selected and the values of k′ and n were computed (see table below).

	k′	*n*
Germ	4.82×10^{-3}	2.12
Endosperm	1.42×10^{-3}	2.40
Whole kernel	2.48×10^{-3}	2.22

These values were then used for calculating additional points.

Observed and calculated moisture content values for the germ, endosperm, and whole kernel are shown in Table III. The best coin-

TABLE III

Observed and Calculated Moisture Content Values for Germ, Endosperm, and Whole Kernel

Relative Humidity	Moisture Content					
	Germ		Endosperm		Whole Kernel	
	Observed	Calculated	Observed	Calculated	Observed	Calculated
%	% *d.b.*	% *d.b.*	% *d.b.*	% *d.b.*	% *d.b.*	% *d.b.*
10	5.7	4.3	6.8	6.0	5.8	5.4
20	6.5	6.1	8.5	8.6	7.7	7.6
30	7.7	7.6	10.0	10.0	9.2	9.4
40	8.3	9.0	11.5	11.5	10.8	11.0
50	9.5	10.4	13.2	13.2	12.3	12.2
60	10.7	11.9	14.7	14.8	14.1	14.4
70	13.1	13.5	16.6	16.6	16.1	16.3
80	16.2	15.5	18.6	18.7	18.5	18.5
90	25.7	18.4	22.8	21.8	23.5	21.8
95	35.0	20.9	26.0	24.3	28.0	24.6

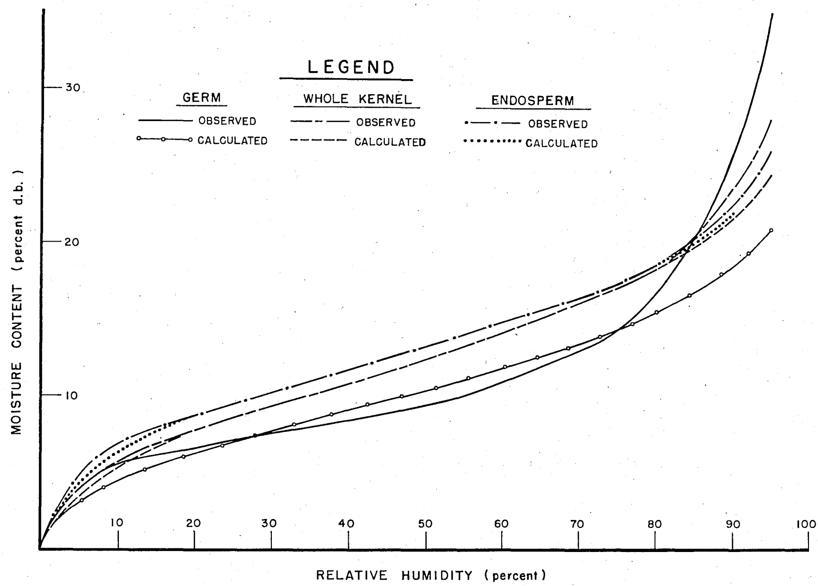

Fig. 3. Observed and calculated desorption isotherms for the germ, endosperm, and whole corn kernel.

cidence of the observed and calculated points was in the endosperm (Fig. 3), where deviations at very low and very high relative humidities were small. No coincidence was found in the germ. This explains the lack of agreement between the observed and calculated moisture content values for the whole kernel at high relative humidity.

It might therefore be concluded that the oil-free material agreed best with Henderson's equation. Such results were predicted by Henderson from data for flaxseed and soybeans.

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