Drying of High-Moisture Corn: Changes in Properties and Physical Quality[1]

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ABSTRACT

Corn at 30% moisture was air-dried at 25-100°C. Drying times to 12% final moisture ranged from 1 hr at 100°C to 38 hr at 25°C. Chemical composition was unchanged by drying temperature. Increasing drying temperature decreased test weight, germination, nitrogen solubility index, and it increased kernel breakage susceptibility and percentage of floating kernels. Because breakage susceptibility, but not stress-cracking, increased upon high-temperature drying, some chemical or physical change other than stress-cracking in the kernel cell-wall matrix or in the starch granules may have affected breakage susceptibility. Isoelectric focusing showed decreasing protein bands at pI 4.0-6.6 as corn-drying temperature increased from 70 to 100°C. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis showed that proteins with molecular weights of 21,000-97,000 decreased after treatment at 70°C; they cannot be observed in corn dried at 85-100°C. Prolamin levels also decreased as air-drying temperature increased. Thus, corn density, breakage susceptibility, and germination may change upon drying because of changes in albumins and prolamins. These relationships may provide new or improved methods for identifying grain that is damaged or of lower quality due to high-temperature drying.

Low-temperature drying usually has little effect on corn quality factors such as stress-cracking, density, breakage susceptibility, or germination. The quality of corn dried with heated air can, however, vary greatly. Previous studies examined the effect of heated-air drying on genotype response (Peplinski et al 1989) and protein changes related to reduced quality (Wall et al 1975). Other investigators examined quality variation in corn air-dried at temperatures up to 150°C (Peplinski et al 1975), corn harvested at various moisture levels and dried (Weller et al 1990), and corn dry-milled after being dried at various temperatures (Brekke et al 1973, Peplinski et al 1982). High drying temperatures can decrease protein solubility, protein moisture-binding capacity, and enzymatic activity (Wall et al 1975). Drying grain at elevated temperatures also lowers flaking grit yield in dry milling, makes starch-protein separation more difficult in wet milling, and increases kernel breakage during handling in local and export markets (Hoseney 1986).

To further study these phenomena, we investigated protein extractability and physical characteristics of high-moisture (30%), yellow, dent corn kernels that were air-dried at 25-100°C. Variations in kernel density, breakage, and germination may relate to changes in extractability and compositions of: albumins; water-soluble, alcohol-soluble glutelins (ASG); water-insoluble ASG; and zein proteins. The results may show why overdried or heat-damaged grain has lower quality, and they may also provide better methods for detecting grain-quality damage resulting from overheating.

MATERIALS AND METHODS

Corn Drying

Hybrid, yellow, dent corn was grown in north-central Ohio, picker-sheller harvested at 30% moisture in the fall of 1990, and immediately shipped to the National Center for Agricultural Utilization Research, ARS-USDA, Peoria, IL, to be dried. The hybrid we used had B73 as the maternal parent; the paternal parent is unknown. For each drying temperature (25, 40, 55, 70, 85, and 100°C), 1-kg sublots of 30% moisture corn were placed on a 3.5-mesh U.S. standard sieve between two layers of cheese cloth to restrict air flow. Corn depth was 5.1 cm. Samples were then placed in a Proctor Schwartz forced-air, flow-through tray dryer and periodically removed and weighed until a final precalculated weight of 12% moisture was obtained. In this batch process, heated air was drawn up through the corn and exhausted. Final kernel temperatures were not measured. The sample dried at 25°C served as the control. After the drying process, the warm samples were placed in paper bags and cooled at room temperature (25°C) overnight. Dried, cool samples were then stored at 1°C. Samples were reequilibrated to 25°C before further testing.

Chemical Composition

Nitrogen (Kjeldahl), nitrogen solubility index, ash, and starch contents of whole corn were determined using approved methods of the American Association of Cereal Chemists (AACC 1983). Moisture was determined gravimetrically after drying 10-g samples at 130°C for 60 min in a forced-air oven. The fat content of whole corn was determined by pentane-hexane extraction (AOAC 1990).

[1]The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

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Physical Properties

Test weights were measured according to U.S. Official Grain Standards (USDA 1977). Kernel weights were determined for 100 whole, sound kernels. Stress-crack counts (total of single, multiple, and checked kernels) were made using 3× magnification on 50-g samples of unbroken corn according to the method of Thompson and Foster (1963). Kernel breakage susceptibility was measured with a Stein CK2 breakage tester by impacting 100-g portions of corn for 2 min. Breakage was the percentage of impacted sample passing through a 4.76-mm (12/64 in.) round-hole sieve. The percentage of floating kernels was determined on 100-g samples with the Wichser (1961) floaters test, which was modified by using a sodium nitrate solution of 1.107 specific gravity. Germination on 100 seeds was determined by the method of the Association of Official Seed Analysts (AOSA 1970). All physical tests were on corn equilibrated to 9 ± 0.5% moisture using whole, sound kernels that were apparently free of chips and other obvious surface defects. Chemical analyses and physical tests were replicated two or more times for each sample. General linear models statistical analysis was used to determine least significant difference for all test values.

Albumin Isolation

Water-soluble proteins and nonprotein nitrogen were extracted from 0.1 g of ground, whole corn for 2 hr with 2 ml of cold water on a Buchler Vortex-Evaporator shaker and centrifuged at 20,000 rpm for 10 min with a Beckman L8-70M centrifuge. The milky extract was filtered through a 0.45-μm BioRad Prep-Disc filter to obtain a clear extract. Protein amounts were determined by a bicinchoninic acid protein assay (Pierce Chemical Co., Rockford, IL) and calibrated with a bovine serum albumin standard. Aliquots (0.1 ml) of samples, standards, and blank were mixed with 2 ml of a solution of 50 parts reagent A (containing sodium bicarbonate, sodium carbonate, bicinchoninic acid detection reagent, and sodium tartrate in 0.2*N* sodium hydroxide) and 1 part reagent B (4% copper sulfate). After the solution was added, the sample, standards, and blank were placed in a 37°C water bath for 30 min. They were then cooled to room temperature in 10 min. Absorbance at 562 nm was determined using a Beckman DU-40 spectrophotometer.

Gel Electrophoresis

Sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) of albumin extracts (45 μl) was done on 12% mini-PROTEAN II Ready gels (Bio-Rad) for 70 min. Proteins were detected with Silver Stain Plus (Bio-Rad). Gels were fixed with fixative enhancer solution (50% methanol, 10% acetic acid, 35% deionized water, and 5% fixative enhancer concentrate) for 20 min and rinsed twice for 10 min with deionized water. Gels were then developed for 20 min in staining solution until the desired intensity was reached. The staining solution was 35% deionized water, 5% silver complex solution (ammonium nitrate and silver nitrate), 5% reduction moderator solution (tungstosilicic acid), 5% image development reagent (formaldehyde), and 50% development accelerator reagent (5% sodium carbonate). The reaction was stopped by shaking the gel gently in 5% acetic acid solution for 10 min.

Isoelectric focusing (IEF) was done on the PhastGel system as directed in the 1986 Phastsystem owner's manual (Pharmacia AB, Uppsala, Sweden). Gel pI ranges used were 4–6.5, 5–8, and 3–9. Proteins were detected from 5-μl albumin extracts with silver stain using the PhastGel system as directed in the 1987 PhastGel Silver Kit instruction manual (Pharmacia AB).

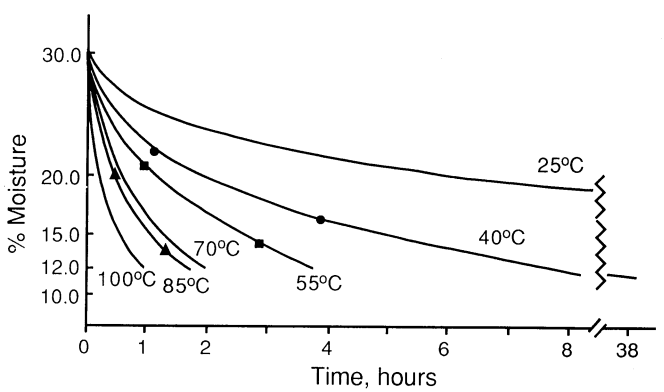

Fig. 1. Changes in corn drying rate as affected by air temperatures of 25–100°C.

Reversed-Phase High-Performance Liquid Chromatography

Zein plus ASG were simultaneously extracted from ground corn with 70% ethanol containing 0.5% sodium acetate plus 0.2% dithiothreitol (Paulis and Bietz 1986). Proteins were then fractionated by reversed-phase high-performance liquid chromatography (RP-HPLC) on a C18 column using an aqueous acetonitrile gradient in the presence of 0.1% trifluoroacetic acid (Paulis and Bietz 1986). Proteins were detected by absorbance at 210 nm (0.1 absorbance units full scale). At this wavelength, absorbance relates closely to protein quantity (Buck et al 1989). Data were stored in a ModComp computer for subsequent plotting, integration, and statistical evaluation. Early eluting peaks contained water-soluble and water-insoluble ASG; later peaks contained monomeric α-zein (Paulis and Bietz 1986).

RESULTS

Corn Drying and Chemical Composition

Corn drying time varied inversely with the drying temperature. It took from 1 hr at 100°C to 38 hr at 25°C to reduce each sublot from 30 to 12% moisture (Fig. 1). After each sublot had reached 12% moisture, as measured by weight loss, it was placed in a paper bag with the top closed and cooled at 25°C overnight. Standardizing dried sublots at 12% final moisture and slowly cooling dried grain overnight at 25°C helped minimize subsequent quality changes.

Air-drying temperatures of 25–100°C had little or no statistically significant effect on kernel nitrogen, fat, starch, or ash (Table I). Chemical composition ranges were: 1.3–1.4% nitrogen, 3.8–4.0% fat, 74–78% starch, and 1.3–1.4% ash. Water-soluble nitrogen (nitrogen solubility index), however, decreased from 15% in corn dried at 25°C to 8% in corn dried at 100°C. The largest decrease in nitrogen solubility index was when drying temperature exceeded 70°C (Table I). Peplinski et al (1975) also noted that the corn nitrogen solubility index decreased from 12 to 6% as air-drying temperature increased from 21°C (70°F) to 149°C (300°F).

Physical Properties of Corn Dried at Various Temperatures

As air-drying temperatures increased from 25 to 100°C, kernel test weight and germination decreased, kernel breakage susceptibility and percentage of floating kernels increased, and 100-kernel weight and stress-cracked kernels were unchanged (Table II). The ranges (at 25–100°C, respectively) were: 48.2–51.1 lb/bu test weight, 0–90% germination, 27–67% breakage susceptibility, 17–80% floating kernels, 16.6–17.2 g 100-kernel weight, and 78–86% stress-cracking. Values of breakage susceptibility and germination changed most as drying temperature increased from

TABLE I
Chemical Composition of Corn Dried at Various Temperatures[a]

Drying Temperature (°C)	Nitrogen (%)	Nitrogen Solubility Index	Fat (%)	Starch (%)	Ash (%)
25	1.4	15	4.0	74	1.3
40	1.3	14	3.8	77	1.4
55	1.4	13	3.8	78	1.4
70	1.3	12	3.9	78	1.4
85	1.4	9	3.9	77	1.3
100	1.3	8	3.8	77	1.4
LSD[b]	0.04	4	0.1	1	0.1

[a]Moisture-free basis.
[b]Least significant difference at $P \leq 0.05$.

TABLE II
Physical Properties of Corn Dried at Various Temperatures[a]

Drying Temperature (°C)	Test Weight (lb/bu)	100-Kernel Weight (g)	Stress Cracks (%)	Stein Breakage[b] (%)	Floaters[c] (%)	Germination[d] (%)
25	50.0	16.8	78	27	17	86
40	51.1	16.6	81	34	19	90
55	50.5	16.6	80	52	42	29
70	49.7	16.6	80	57	53	0
85	48.7	17.2	86	67	80	0
100	48.2	17.0	84	63	79	0
LSD[e]	1.2	1.3	6	4	5	3

[a] 9 ± 0.5% moisture basis.
[b] Through 12/64 in.
[c] 1.107 specific gravity.
[d] At 72 hr.
[e] Least significant difference at $P \leq 0.05$.

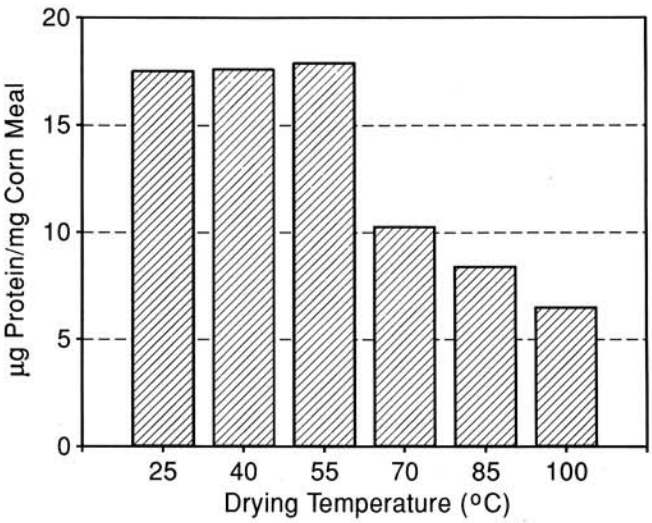

Fig. 2. Changes in solubility of albumins in corn dried at various temperatures.

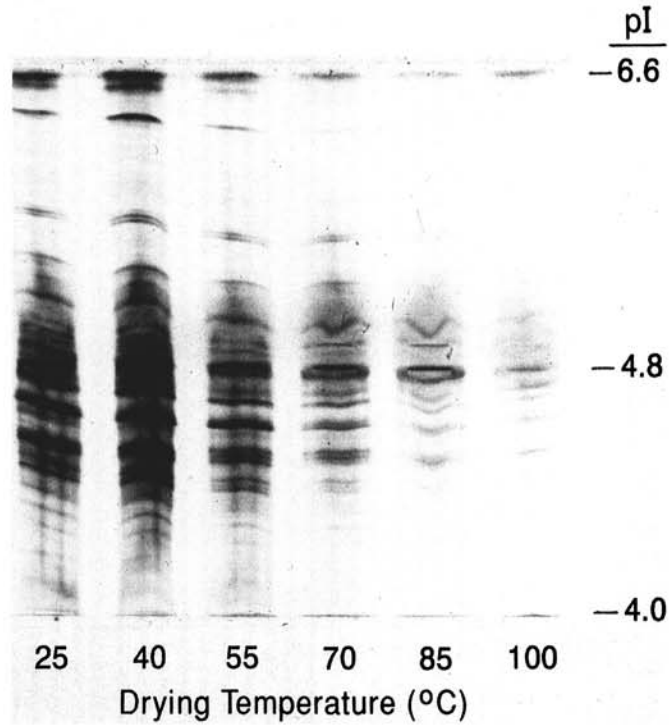

Fig. 3. Isoelectric focusing patterns of albumins extracted from equivalent amounts of corn meal dried at various temperatures. Isoelectric points of standard proteins are shown on the right.

40 to 55°C. Test weight, though low for a yellow dent corn, reached a maximum of 51 lb/bu at 40°C; this decreased to 48 lb/bu for corn dried at 100°C. Kernel weight (17.0–17.2 g per 100 kernels), stress-cracking (84–86%), breakage susceptibility (63–67%), and percentage of floating kernels (79–80%) were largest with 85–100°C drying temperatures. Corn dried at 55°C was only 29% viable; grain dried above 55°C did not germinate.

High harvest moisture of the grain, combined with mechanical damage from less-than-optimal condition of harvest equipment, caused 78% kernel stress-cracking. Drying increased stress-cracking to a maximum of only 86% at 85°C. This small increase in stress-cracking upon drying prevented us from showing any statistically significant relationship between stress-cracking and breakage susceptibility, as shown previously (Peplinski et al 1975, 1992; Paulsen and Hill 1985; Weller et al 1990). Because breakage susceptibility, but not stress-cracking, increased upon high-temperature drying in this study, some chemical or physical change in the cell-wall matrix or in the starch granules may have occurred upon drying, which affected breakage susceptibility.

Albumins

The amount of water-extractable protein remained constant in grain dried at 25–55°C, but it rapidly decreased as air-drying temperature increased to 100°C (Fig. 2). Compared to corn dried at 25°C, the percentage of albumins decreased by 43% at 70°C and 63% at 100°C. Wall et al (1975) previously showed that the amount of albumins decreased as corn-drying temperature increased from 15 to 143°C, while McGuire and Earle (1958) showed that water-extractable nitrogen decreased from 17 to 12% as drying temperature increased from 49 to 93°C. Decreases in water-extractable nitrogen mainly represent decreased protein nitrogen.

Changes in some corn albumins upon heating were also apparent upon IEF. Bands of pI 4.0–6.6 decreased in corn dried at 70–100°C, suggesting that albumins in such corn are less soluble than those in corn dried at 25–55°C (Fig. 3). Proteins at pI 4.8 were evident at all drying temperatures, but bands at pI 4.0 and 6.6 disappeared as drying temperature increased from 70 to 100°C.

SDS-PAGE also showed selective loss of albumins as corn-drying temperature increased (Fig. 4). Albumins from corn dried at 25–55°C have major 25,000–70,000 mol. wt. bands, but these become fainter at 70°C and are almost nonexistent in corn dried at 85–100°C. These proteins make up part of the saline-soluble proteins and may be most susceptible to heat denaturation. High-temperature drying may cause their aggregation and insolubilization, preventing them from migrating into the gel.

Prolamins

IEF and SDS-PAGE did not reveal noticeable changes in extractability of prolamins from corn dried at elevated temperatures. This suggests that corn prolamins may not be as readily heat-

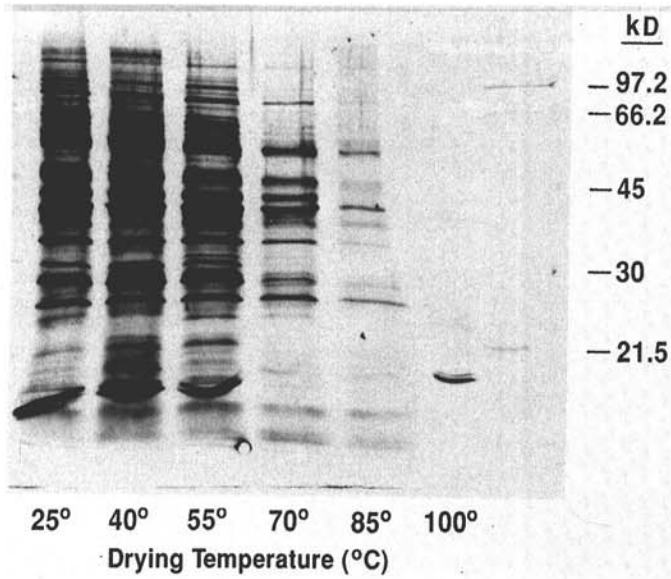

Fig. 4. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis patterns of albumins extracted from equivalent amounts of corn meal dried at various temperatures. Apparent molecular weights, determined from mobilities of standard proteins, are shown on the right. kD = molecular weight bands.

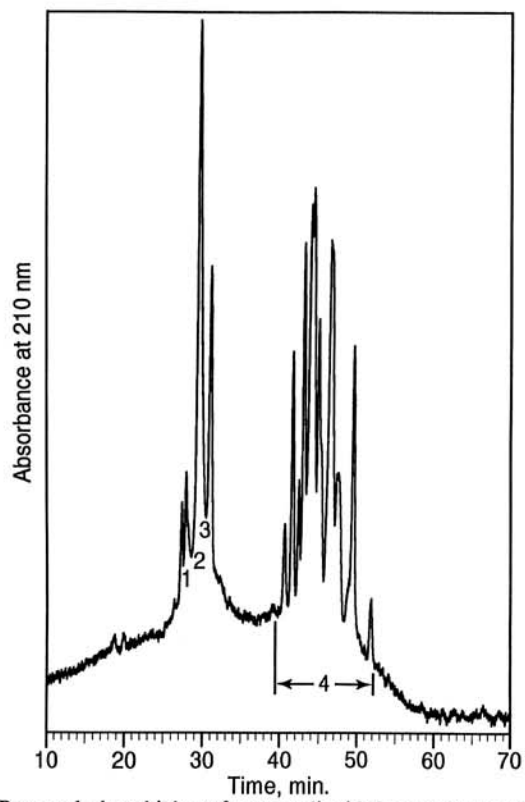

Fig. 5. Reversed-phase high-performance liquid chromatogram of alcohol-soluble proteins extracted from corn dried at 25°C. Peak 1, high-methionine water-insoluble alcohol-soluble glutelin, 15,000 mol. wt. Peak 2, high-proline water-soluble alcohol-soluble glutelin, 26,000 mol. wt. Peak 3, high-proline water-insoluble alcohol-soluble glutelin, 15,500 mol. wt. Peak area 4, α-zein, 22,000–24,000 mol. wt.

denatured as are albumins. RP-HPLC, however, which has superior quantitative capabilities, showed that specific ASG subunits (Fig. 5, peaks 1–3) decreased by 35, 11, and 12%, respectively, as drying temperature increased from 25 to 100°C (Fig. 6). Monomeric α-zeins (Fig. 5, peak area 4) decreased by only 11% (Fig. 6). Glutelins, containing ASG subunits, must be more sensitive to insolubilization upon heating than are low molecular weight monomeric zeins.

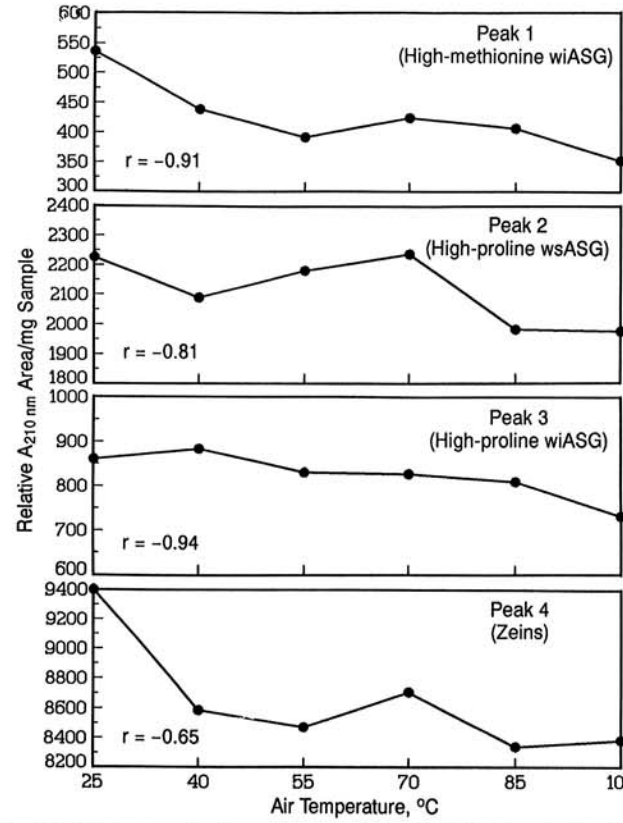

Fig. 6. Relative amounts of protein extracted with 70% ethanol plus 0.5% sodium acetate plus 0.2% dithiothreitol from meals of corn dried at different temperatures. Quantitation was by integration of areas (monitored at 210 nm) resulting from analysis of extracts by reversed-phase high-performance liquid chromatography. wiASG = water-insoluble alcohol-soluble glutelin, wsASG = water-soluble alcohol-soluble glutelin.

SUMMARY AND CONCLUSIONS

Our studies show that density, germination, and water-soluble nitrogen (nitrogen solubility index) of corn decrease at elevated drying temperatures. The flotation test differentiates density changes caused by drying better than do test weight measurements. Most changes in kernel physical properties became evident only in corn dried above 40°C. At 55°C, kernel breakage, percentage of floating kernels, and germination showed appreciable changes compared to those of corn dried at 25–40°C. Proximate analyses showed no major change in chemical composition of corn dried from 25 to 100°C.

From these data, we suspect that kernel stress cracks produced by field, weather, or handling conditions may differ from stress cracks caused by heated-air drying. About 80% of the kernels were stress-cracked in all six dried-corn sublots; breakage susceptibility ranged from 27 to 67% as drying temperature increased from 25 to 100°C. Thus, an effect other than heat-induced internal stress-cracking may influence corn breakage susceptibility. Some unknown chemical or physical change may occur in the endosperm cell matrix or in the starch granules upon heated-air drying.

The modifications in physical properties of kernels upon heating closely parallel changes in protein solubilities. Drying at or above 70°C decreased albumin solubility, as shown by SDS-PAGE and IEF. ASG subunits also decreased significantly with increased drying temperature, as revealed by RP-HPLC. Solubility of monomeric zeins changed less. Apparently, heating aggregates albumins and further polymerizes glutelins, decreasing their solubilities. Our tests show that rapid tests, such as albumin solubility (Fig. 2), can quantify corn proteins and thus assess corn quality by examining protein heat denaturation (Fig. 2).

Our studies, both of kernel physical characteristics and of protein composition and extractability, suggest that corn is damaged upon drying and decreases in quality only when dried at temper-

atures of 55°C or higher. Air-drying at temperatures of 25–55°C produces little if any change in kernel chemical and physical properties.

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