Physical Testing and Dry Milling of High-Moisture Corn Preserved with Ammonia While Drying with Ambient Air[1]

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ABSTRACT

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Sublots of 20–1,500 bu of high-moisture corn were dried with unheated air, unheated air with intermittent application of anhydrous ammonia gas, and unheated air with intermittent application of anhydrous ammonia gas plus stirring. All lots were stored for eight months. Chemical analysis of whole grain showed little change in major components except for a 14% increase in nitrogen from both of the ammonia-treated sublots. Kernel hardness of all corn was unchanged after dry-down, whereas germination of both ammonia-treated grains was reduced. Stirring of corn increased the number of kernels with stress cracks. Dry milling yielded 60% low-fat prime products from the laboratory control sublot, 59 and 61% from two ammonia-treated grains, and 59% from the field-dried (untreated) control. Fat content of all dry-milled products was only slightly affected by type of grain treatment. Sensory evaluation tests to determine the effect of the treatments on flavor of the dry-milled products indicate that all grits had satisfactory flavors.

Recent shortages and increased cost of petroleum products have spurred the investigation of cheaper and less energy-intensive grain drying methods than the propane-heated air system. Ambient air-drying is the most energy-efficient and least costly post-harvest drying method (Bakker-Arkema et al 1977), but adverse weather conditions in most of the Midwest can result in long drying times and microbiological deterioration of the grain. Procedures that increase the drying rate and thereby help to prevent grain deterioration include the use of alternative systems such as solar, electric resistance, burning of crop residue, or increased air-flow rate through the grain. Another method that warrants serious consideration is the "Trickle Ammonia Process" (TAP) developed by Nofsinger et al (1979). This on-farm system allows high-moisture corn to be dried with unheated air over a period of one to two months, with intermittent application of anhydrous ammonia gas at low levels to suppress microbial deterioration. The process, which has EPA approval for use on corn for feed purposes only, involves the application of 0.05% ammonia to high-moisture corn (based on dry weight of corn) at intervals necessary to suppress or eliminate the growth of molds. Up to 10 applications are permitted

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[3] 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.

as needed.

In this study, high-moisture (26%) corn was dried by the TAP and TAP-plus-stirring procedure. Ammonia was applied to each lot five times, with total NH_3 applied amounting to 0.141% for TAP and 0.154% for TAP with stirring. Each lot was sampled after eight months of storage. Corn was analyzed for physical and chemical properties and then dry-milled to determine the effect of drying treatment on the milling process and final product characteristics.

MATERIALS AND METHODS

Corn and Drying

Field-shelled yellow dent corn harvested at 26–27% moisture in late September, 1978, at Trivoli, IL, was immediately placed in typical galvanized metal storage bins (Table I). A 20-bu sublot (test A) of the wet shelled corn was air-dried by being placed inside the NRRC pilot plant on plastic sheeting. This sublot, used as a control, was turned twice a day by raking. A sublot of 1,400 bu of corn (test B) was placed in a bin with a 2,400-bu capacity, and this served as the large-scale, ambient air-dried control. Two 3,500-bu-capacity bins were filled with 1,500 (test C) and 1,300 bu (test D) of corn, respectively, and dried using the TAP and TAP-plus-stirring procedures. The stirring of the corn was accomplished by the placement of commercially available bin-stirring devices in the particular bin under test. All bins contained perforated metal floors that allowed ambient air or gaseous preservative to be passed upward through the corn. Complete details on rates of drying and amount of gaseous preservation applied were described by Van Cauwenberge et al (1982). At the end of the dry-down (about 45 days) and storage period, the binned corn sublots were probed to obtain representative 150-lb samples to be used in testing. The samples were cleaned with a fanning mill, bagged, and safely stored until they were analyzed and milled.

TABLE I
Corn Storage and Treatment

Test	Corn Used (bu)	Treatment	Percent Moisture Initial	Percent Moisture Final
A	20	Air-dried, 2-in. depth	26.7	12.7
B	1,400	Air-dried in bin	26.7	13.2
C	1,500	Gaseous NH_3, not stirred	26.8	13.8
D	1,300	Gaseous NH_3, stirred	27.5	14.5

TABLE II
Physical Data on Corn After Treatment

Test	Weight Per 100 Kernels (g)[a]	Germination (%)	Kernel Hardness Class: Percent Kernels Floating	Kernel Hardness Class: Hardness[b]	Kernels with Stress Cracks (%)	Stein Breakage (%)
A	33	76	21	VH	48	3
B	33	78	22	VH	31	3
C	33	2	25	VH	23	4
D	33	10	28	VH	43	5

[a] Moisture-free basis.
[b] VH designates very hard.

Analytical Methods

Weight per 100 kernels was determined for three 100-g lots of undamaged, whole, moisture-equilibrated kernels. Percentage germination was determined for 400 undamaged kernels in accordance with the rules for seed-testing adopted by the Association of Official Seed Analysts (AOSA 1970). Kernel-hardness index, expressed as degree of hardness, was determined on 100-g samples by the "floaters' test" described by Wichser (1961). Stress-crack counts were obtained on samples of approximately 50 g by the method of Thompson and Foster (1963) under threefold magnification. Breakage tests were run with the Stein Grain Breakage Tester, model CK2, on whole kernels that had been equilibrated at 10–11% moisture by holding for two weeks at 25°C and 50% relative humidity. Portions of 100 g each were placed in the tester pan, and the kernels were under impact for 2 min; breakage was determined as percentage of the ground sample passing through a 12/64-in. round-hole perforated sieve.

Chemical composition of whole corn was determined by AACC (1962) approved methods for ash, starch, fiber, nitrogen, and nitrogen solubility index (NSI). For NSI, the method was modified by adjusting the extraction water from a sample ground to minus 100 mesh to pH 7.2. Fat contents of whole corn and germ fractions were obtained by pentane-hexane extraction, using the Butt procedure (AOCS 1970), whereas fat contents of other roller-milled fractions were assayed by the gas-liquid chromatography procedure of Black et al (1967), as modified by Nielsen et al (1979). Available lysine values were determined by the method of Rao et al (1963). Determination of soluble solids was made using Corn Industries Research Foundation method G 26 (CIRF 1965). Fat-acidity values were obtained by an AOAC method (AOAC 1960). Linoleic acid content of pentane-hexane extracted fats was determined by gas-liquid chromatography (Black et al 1967). Odor and flavor comparisons were evaluated by a trained 12-member panel experienced in taste and odor testing of cereal products, with the scalar scoring and descriptive test methods following the procedure outlined by Baker et al (1979).

Degerming and Milling Corn

Cleaned, blended corn (9.1 kg) was tempered by water addition to 16% moisture, then blended and held 16 hr; more water was added to 21% moisture, while holding for 1.75 hr. To help increase hull release and make the corn germ more pliable and resistant to breakage, a final temper to 24% moisture was performed 15 min before degerming. Corn was tempered and blended in a room with a controlled temperature of 25°C and 50% relative humidity. After the final water addition, corn was fed into a horizontal rotor degermer (HRD) operating at 1,750 rpm, and a constant net motor load of 0.26 kW was kept as the corn was processed; details on the use of the HRD were published previously (Brekke et al 1972). After degerming, product throughput was dried with 100°F air in a forced-air flow-through tray dryer to 17 ± 1% moisture and roller-milled by the dry-milling flow system described by Brekke et al (1972). All data on degermed and roller-milled corn and fractions are results of replicate tests.

TABLE III
Chemical Composition[a] of Whole Corn After Treatment

Test	Nitrogen (%)	Fat (%)	Ash (%)	Starch (%)	Fiber (%)	Available Lysine	Soluble Solids (%)	Fat Acidity[b]	Nitrogen Solubility Index (%)	Linoleic Acid[c]
A	1.4	4.0	1.3	75	1.9	3.2	7.1	27	16	59
B	1.4	4.1	1.2	73	2.0	2.9	6.8	71	17	58
C	1.6	4.0	1.3	74	1.5	2.7	7.8	49	27	58
D	1.6	4.0	1.2	73	1.9	2.9	8.5	31	29	58

[a] All values on moisture-free basis.
[b] Milligrams KOH per 100 g of dry matter.
[c] As percent of extracted fat.

TABLE IV
Yield[a] of Roller-Milled Products from Treated Corn

Test	Grits[b]	Low-Fat Meal	Low-Fat Flour	Prime Product Mix	High-Fat Meal and Flour	Degermer Fines	Bran Meal	Hull	Germ
A	45	9	6	60	12	3	5	8	12
B	46	9	5	60	12	3	5	8	12
C	47	9	5	61	12	3	5	7	12
D	44	10	5	59	12	4	5	7	13
Least significant difference[c]	3.9	4.6	4.6	6.2	1.5	1.7	2.1	2.1	3.5

[a] Percent, as is.
[b] First-, second-, and third-break grits combined.
[c] $P<0.05$.

TABLE V
Fat Content[a] of Roller-Milled Products from Treated Corn

Test	Grits[b]	Low-Fat Meal	Low-Fat Flour	Prime Product Mix	High-Fat Meal and Flour	Degermer Fines	Bran Meal	Hull	Germ	Recoverable Oil (lb/cwt corn)
A	0.7	0.7	0.9	0.7	1.6	1.9	3.5	2.2	26	2.5
B	0.6	0.6	1.0	0.7	1.7	2.0	4.6	2.7	27	2.5
C	0.7	0.6	0.9	0.7	1.5	1.7	3.5	1.6	27	2.7
D	0.7	0.6	0.9	0.7	1.4	1.5	3.1	2.0	25	2.6
Least significant difference[c]	0.1	0.20	0.15	0.15	0.60	0.15	1.3	1.6	2.2	0.32

[a] Percent, moisture-free basis.
[b] First-, second-, and third-break grits combined.
[c] $P<0.05$.

TABLE VI
Flavor Scores and Descriptions of Grits from Milling of Treated Corn

Test	Total Flavor Score[a]	Taste Description[b]				
		Corn	Cereal/ Grain	Farina	Musty/ Stale	Other "Off" Flavors[c]
A	7.9	0.9	0.5	0.4	...	0.2
B	8.3	0.8	0.2	0.5	...	0.1
C	7.5	0.9	0.5	0.4	...	0.5
D	6.6	0.8	0.9	0.4	0.5	0.6

[a] Ten = highest (best quality), 0 = lowest score.
[b] Three = strongest, 0 = weakest.
[c] "Off" flavors include bitter, astringent, and cardboard.

RESULTS AND DISCUSSION

Physical Testing of Stored Corn

Data obtained from physical examination of the stored corn are presented in Table II.

Ammonia treatments lowered kernel germination to 10% or less. Kernel weight and hardness were unchanged, regardless of type of treatment of the grain, whereas breakage of ammonia-treated corn was significantly increased. Percentage of stress-cracked kernels was increased significantly in the air-dried pilot plant control and in corn that was ammonia-treated with stirring. The NRRC air-dried corn that had been handled and dried with the most care contained the greatest number of stress-cracked kernels. Studies by Westerman et al (1973) have shown that relative humidity of drying air must be kept at or above 50% to minimize formation of stress cracks in corn. The NRRC air-dried corn was placed in a heated pilot plant under conditions such that relative humidity was probably lower than 50% during the two-week drying period of this sublot. In contrast, all Trivoli bins had outside air passing through the grain bed from late September into November, and relative humidity never ranged lower than 50% during this time. Ammonia-treated corn with stirring (test D) contained about twice the number of stress cracks (43%) as the unstirred ammonia-treated (test C) grain (23%). The probable cause of this increase of kernels with stress cracks in test D may be attributed to the continuous stirring of the grain for 45 days. Israel (1979) disclosed that generation of fines by breakage is not a problem caused by stirring, but he did not indicate its effect on formation of stress cracks.

Chemical Composition

Chemical composition of corn (Table III) was changed little by variations in drying methods or preservative used. Nitrogen, nitrogen solubility index, and soluble solids were greatly increased in the two ammonia-treated corns, as might be expected; nitrogen content of treatments C and D was increased by 14%. Fat, ash, starch, and fiber were unchanged for all corn sublots. Fat acidity, an indicator of fatty-acid deterioration in the oil, was highest in the air-dried, untreated Trivoli control corn, indicating that the preservative treatments prevented bacterial growth and subsequent oil quality loss in the corn at the elevated storage moistures. Lysine, measured as available lysine, and linoleic acid, both essential components for human nutrition, were unaffected by the drying or preservative treatment.

Roller-Milling of Degermed Corn

Typical yields (Table IV) of degermed, roller-milled grits and of low-fat meal and flour (low-fat fractions called the prime product mix) were produced from all corn sublots, ranging from 59 to 61%. Yields of high-fat fractions, consisting of high-fat meal and flour, degermer fines, bran meal, hull, and germ, were unaffected by drying or preservative treatment. Peplinski et al (1982) have shown that high (≥82°C) air-drying temperatures have significantly reduced roller-milled grit yields.

Fat content of prime product mix (Table V) was unchanged at 0.7% for all sublots. Fat content of high-fat fractions and germ recoverable oil yield showed no significant variation according to corn treatment.

Sensory Evaluation of Grits

Flavor scores based on odor and taste of second and third break grits (Table VI) from both air-dried control corn sublots are characterized as having satisfactory flavors typical of good-quality products. Grits from ammonia-treated corn that had not been stirred also had the very acceptable flavor score of 7.5. Grits from corn ammonia-treated with stirring gave a slightly less desirable flavor, but not at a level that would make the products unsatisfactory. No grits from any treated corn gave a flavor description attributable to residual odor or taste of ammonia.

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