Determination of Corn Hardness by the Stenvert Hardness Tester[1]

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ABSTRACT

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Hardness was determined by density and by the Stenvert Hardness Tester (SHT) in three pairs (dent and flint) of isogenic lines. In addition, seven samples (separated according to size and shape from each of three commercial hybrids) were evaluated by density, the SHT, and near-infrared reflectance (NIR) at 1,680 nm. Other determinations made on the fractions separated from the three hybrids included test weight, kernel weight, and moisture, fat, protein, and ash contents. The SHT measured resistance to grinding, height of column of ground corn (as index of packing and fluffiness), and ratio of coarse to fine particles (determined by weight of sieved fractions or estimated by volume of fractions in the receptacle of the tester). The three dent isogenic lines were higher in kernel weight and lower in hardness parameters than their flint counterparts. The three commercial hybrids showed consistent differences in gross composition and hardness. Some consistent differences in composition or hardness were established among the fractions separated according to size and shape (sphericity). Within each fraction separated by size and shape there were consistent differences among the three hybrids in density, fat and protein contents, NIR of ground corn, and the parameters from the SHT. Generally, the round kernels (higher sphericity) were higher in flintlike characteristics than the flat kernels.

Corn hardness determination has been the subject of many investigations, some of which were summarized recently by Pomeranz et al (1984). In that study, breakage susceptibility and kernel hardness as measured by density, near-infrared reflectance (NIR), and average particle size of ground material were determined for four groups of corn samples: isogenic pairs with regard to hardness (dent and flint), commercial dent hybrids, dent corn heat-dried under various conditions, and a group that varied in starch composition (waxy, regular, high amylose) and protein, oil, and ash contents. Density, NIR, and average particle size values were highly, linearly, and positively correlated provided homogeneous groups were analyzed and evaluated. In samples highly susceptible to breakage, correlation coefficients of hardness determination increased when calculations were made on a constant breakage susceptibility basis. The three methods of hardness determination were equally sensitive and useful in routine analyses.

We reported recently on the use of the Culatti Micro Hammer/Cutter Mill (Stenvert Hardness Tester [SHT]) to determine wheat hardness (Lai et al 1983). In that method, the time required to obtain a certain volume of ground grain is determined. Thus, both resistance to grinding (time to grind) and fluffiness-packing (as affected by particle size of ground material and hardness) are measured. We report here on the use of the SHT to determine corn hardness. This study was conducted on three pairs of dent-flint isogenic lines and on a series of seven corn samples, separated by sieving according to kernel size and shape, from each of three commercial corn hybrids. The separated kernels differed in composition (protein, fat, and ash) and NIR at 1,680 nm (as index of hardness). To the best of our knowledge, little is known about the effects of corn kernel size and shape on gross composition and hardness.

MATERIALS AND METHODS

Isogenic Lines

Three pairs of isogenic lines (dent and flint) were obtained from the breeding program of Cargill, Inc., Minneapolis, MN. These pairs were considered to differ primarily in regard to kernel hardness.

Commercial Hybrid Corn

Three yellow dent corn hybrids (Stauffer 8500, Stauffer 8100, and Bo Jac) grown on irrigated fields in Manhattan, KS, in 1983 were combine-harvested at an average moisture of 20.7% (±2.0%). Lots of 2,000 bu of each hybrid were air-dried within four to five days to an average moisture content slightly below 15.5%. After two months of dry storage, about 200 lb from each lot was separated into seven fractions with rotary screens according to the scheme described in Figure 1. In those screens, round holes fractionate the corn according to roundness and slots fractionate it according to thickness. This method of classifying corn is similar to that used by the seed industry.

Separation was according to shape factor (sphericity) and/or kernel volume. Assuming the corn kernel is a triaxial ellipsoid with intercepts a, b, and c and the diameter of the circumscribed sphere is the longest intercept of the ellipsoid, the degree of sphericity can be expressed according to Mohsenin (1970) as

$$\text{sphericity} = \left(\frac{\text{volume of solid}}{\text{volume of circumscribed sphere}}\right)^{1/3} = \frac{(abc)^{1/3}}{a},$$

where a = longest intercept, b = longest intercept normal to a, and c = longest intercept normal to a and b.

To determine the shape factor, length (including tipcap), width, and thickness were measured with a hand gauge for 50 kernels for each of the seven fractions for each of the three hybrids. These data were then used to calculate the degree of sphericity. Percentages of kernels, kernel weights (average of 200), and shape factors in the seven fractions of the three hybrids are summarized in Table I. Each fraction contained a mixture of kernels, which varied some in shape factor. Almost three-fourths of all kernels were flat. Coefficients of variation (C.V.) within a variety and size for shape factors were 5.4–12.8%. They ranged from 5.6 to 9.7% (av. 7.5%) for Stauffer 8500, from 5.4 to 10.8% (av. 7.4%) for Stauffer 8100, and from 6.0 to 12.8 (av. 8.6%) for Bo Jac. The small kernels (av. 0.667 [Fig. 1]) showed largest variability in shape factor (C.V. = 10.8%). The C.V. in shape factor was 10.2% for the kernels with an average weight of 286 mg and ranged from 6.5 to 7.4% for the kernels with other shape factors and sizes.

Analytical Methods

Corn density was determined by the method described previously by Pomeranz et al (1984). Oil (petroleum ether extract), ash, and protein (N ×6.25) were determined by AACC methods 30-20, 08-01, and 46-10, respectively (AACC 1976). Whole kernels were analyzed for moisture (72 hr at 103° C in a forced-air oven) by ASAE method S352 (ASAE 1978). Test weight, kernel weight, fat, protein, ash, density, NIR, and SHT characteristics were

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determined on samples equilibrated to 12.6% ± 0.8% moisture (Miller et al 1981, 1982). NIR data at 1,680 nm of corn, ground on the modified Weber mill (McGinty et al 1977) at 1-mm mesh setting, were measured with a Technicon Infralyzer. Fat was expressed on a moisture-free basis.

The Stenvert grinding resistance test involves grinding a 20-g sample of grain with a Glen-Creston 14-580 mill (Stenvert 1974, Stenvert and Kingswood 1977); the tester is available from Glen Mills, Inc., Maywood, NJ. A swinging hammer mill with a grooved grinding chamber fitted with a 2-mm aperture screen is used. The SHT specifies a mill speed setting of 3,600 rpm. The time required to collect 17 ml of whole meal is recorded.

The information obtained from testing grain with the SHT includes the time to grind, the total column height of freshly ground grain, and the ratio of coarse to fine particles, determined according to weight of sieved fractions or estimated according to height-volume in the SHT receptacle (Fig. 2). The time to grind is an index of resistance to grinding and the total column height is an index of packing, as the fluffy meal from soft grain occupies more space than the ground vitreous meal from hard grain. The ratio of coarse to fine particles as determined by weight is expressed as Wt C/F, with fraction C (coarse particles) larger than 0.7 mm and smaller than 2.0 mm in diameter and fraction F (fine particles) smaller than 0.5 mm in diameter. The ratio of coarse to fine particles as estimated by volume is expressed as Vol C/F.

All compositional and hardness determinations were made at least in duplicate and all results were averaged. Results were subjected to statistical analyses (ANOVA).

RESULTS AND DISCUSSION

Table II lists the data for average kernel weight, density, and four SHT characteristics for the three pairs of dent and flint isogenic lines, plus the average ratios of those six parameters for the dent and flint hybrids. The flint corn kernels were smaller and had higher density than their dent corn isogenic counterparts.

The times to grind on the SHT were generally smaller and the volumes (total column height) were higher for the floury dent corn than for the vitreous flint corn. Ratios of coarse to fine particles were also consistently higher in the ground flint than in the ground dent isogenic lines. The data were subjected to Student's t test for the pairs of isogenic lines, and except for time to grind and total column height for Dent I:Flint I, the four SHT hardness parameters differed for the three pairs of isogenic lines. The differences were statistically significant at the 0.05 level for Vol C/F in Dent I:Flint I and Dent III:Flint III and at the 0.01 level for the other parameters and isogenic pairs.

Composition and physical properties of the commercial corn hybrids by hybrids across shape factors are summarized in Table III. The average kernel size of Bo Jac was smaller than that of the two Stauffer hybrids. Differences in ash content among the three hybrids were small. Stauffer 8500 was highest and Bo Jac was

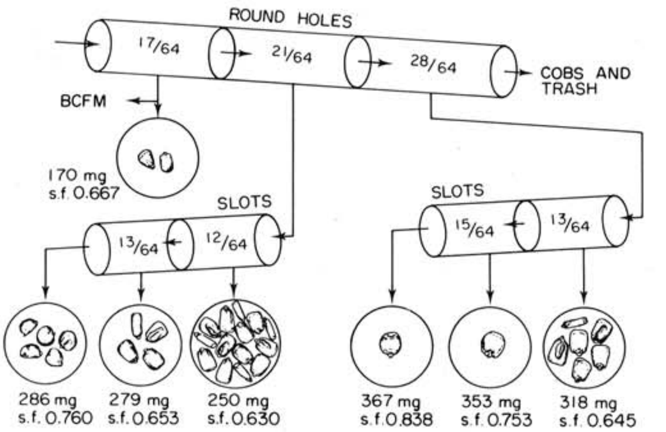

Fig. 1. Classification of corn with rotary screens. Numbers of corn kernels correspond to approximate percentages in fractions separated in three hybrids. Below each drawing are the average kernel weight in milligrams and the shape factor. Dimensions of holes and slots are in inches; BCFM = broken corn and foreign material.

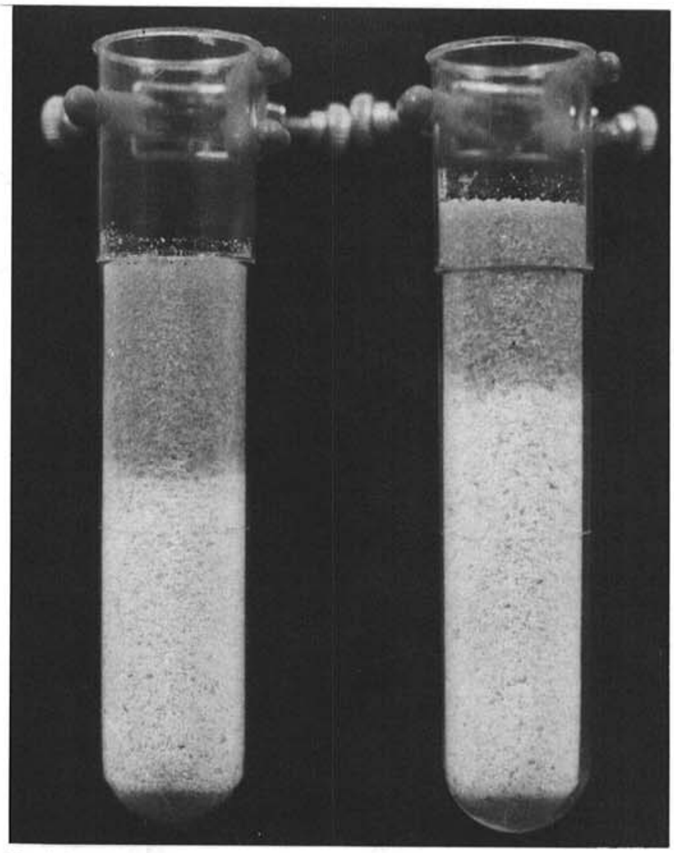

Fig. 2. Ground corn from (left) Stauffer 8500 and (right) Bo Jac in Stenvert Hardness Tester receptacles (125 mm long, 25 mm diam lower part), showing coarse (dark) material at top and fine (light) material at bottom.

TABLE I
Percentage of Total Grain, Average Kernel Weight, and Shape Factors of Three Corn Hybrids

Sieve Characteristics[a]		Percentage of Total Grain			Average Kernel Weight (mg)			Shape Factors		
Holes	Slots	Stauffer 8500	Stauffer 8100	Bo Jac	Stauffer 8500	Stauffer 8100	Bo Jac	Stauffer 8500	Stauffer 8100	Bo Jac
28/64 T	15/64 O	3.0	4.0	2.2	371.3	373.0	356.0	0.853	0.843	0.817
21/64 T	13/64 O	19.0	13.4	11.3	283.9	291.0	282.3	0.775	0.789	0.716
28/64 T	15/64 T	4.1	5.2	3.2	358.2	359.5	342.5	0.741	0.768	0.750
21/64 T	13/64 T	18.4	6.4	15.8	288.0	281.2	268.0	0.662	0.651	0.641
28/64 T	13/64 T	11.8	24.8	18.2	324.3	320.1	309.9	0.652	0.659	0.624
21/64 T	12/64 T	39.2	38.6	43.4	251.8	250.5	247.6	0.654	0.628	0.607
17/64 T		4.5	7.6	5.9	169.6	171.2	168.2	0.674	0.662	0.664

[a]See Figure 1. T = throughs, O = overs.

lowest in fat and protein contents. Similarly, Stauffer 8500 was hardest and Bo Jac was softest, as determined by density, NIR at 1,680 nm, Stenvert time, height of ground corn column, and Wt C/F and Vol C/F. Weighted average shape factors (sphericities) were 0.689, 0.678, and 0.640 for Stauffer 8500, Stauffer 8100, and Bo Jac, respectively. Those weighted shape factors were positively related to all hardness parameters of maize:density, NIR at 1,680 nm, and the four indices from the SHT (Table III).

Some differences were established for the corn hybrids separated by shape factor (sphericity) when averaged across hybrids (Table IV). The round kernels were higher in test weight, protein content, and SHT time to grind than the flat kernels. Among the round kernels, density and NIR at 1,680 nm decreased as sphericity decreased. Among the flat kernels, test weight, fat content, and NIR at 1,680 nm decreased as sphericity decreased. The dividing line between round kernels (sphericity of 0.753 or higher) and flat kernels (sphericity of 0.653 or lower) is, of course, arbitrary.

Simple correlations between and among composition and physical properties are given in Table V; correlation coefficients were calculated for individual hybrids and for all samples. Partial correlations, with several factors held constant (shape factor, kernel weight, fat, protein, and ash), for individual hybrids and for all samples are given in Table VI. Only a few simple correlation coefficients were significant for individual hybrids and none was significant for all three (Table V). For the combined hybrids, fat and protein were each correlated with NIR at 1,680 nm and the three interrelated parameters from the SHT (time to grind, Wt C/F, and Vol C/F). Similarly, there were significant correlations between NIR and each of the SHT parameters or between pairs of parameters from the tester. Partial correlations for individual hybrids and combined samples were significant primarily for the hardness parameters (NIR and SHT) rather than for the compositional parameters (Table VI).

Even though flint kernels were smaller than dent kernels (Table II), there were no highly significant correlations between kernel weight and hardness parameters of dent corn (Table V). However, kernel weight was highly correlated with hardness (NIR at 1,680 nm, SHT time, and Wt C/F or Vol C/F) when protein or ash was held constant (Table VI). Generally, there was a significant correlation between fat and protein, NIR, or SHT parameters when shape factor, kernel weight, or ash was held constant. There were simple significant correlations between protein contents and hardness parameters (Table V) and partial correlations between protein contents and hardness parameters (Table VI) when shape factor or kernel weight was held constant. Simple correlations among hardness parameters (Table V) were also significant when shape factor, kernel weight, ash, or protein was held constant (Table VI).

Consistent trends were determined for the three hybrids within each shape factor group. Results for shape factors 0.838, 0.760, and 0.753, all basically round and with average kernel weight ranging from 285.7 to 366.8 mg, are summarized in Table VII; results for shape factors 0.653, 0.645, and 0.630, with increasing degrees of flatness and with average kernel weight ranging from 250.0 to 318.1 mg, are summarized in Table VIII. In practically all shape factor groups (including the mixture of small flat and round kernels,

TABLE II
Kernel Weight, Density, and Stenvert Hardness Tester Characteristics of Isogenic Pairs of Corn

Characteristics	Dent I	Flint I	Dent II	Flint II	Dent III	Flint III	Average Dent:Flint Ratio
Corn							
Average kernel weight (mg)	315.9	267.9	313.6	256.5	325.6	269.4	1.203
Density (g/cc)	1.306	1.318	1.280	1.324	1.302	1.345	0.975
Stenvert Hardness Tester							
Time (sec)	14.6	14.5	13.8	15.9	14.4	17.5	0.894
Total column height[a]	173	170	178	169	179	168	1.045
Wt C/F	1.30	1.70	1.19	1.79	1.29	1.83	0.711
Vol C/F	0.67	0.99	0.56	1.01	0.86	1.21	0.651

[a]Arbitrary divisions.

TABLE III
Average Composition and Physical Properties of Corn by Hybrids Across Shape Factors

Composition or Physical Property	Stauffer 8500 Mean[a]	C.V.[b]	Stauffer 8100 Mean	C.V.	Bo Jac Mean	C.V.
Weighted average shape factor	0.689	···	0.678	···	0.640	···
Test wt (lb/bu)	60.2	1.17	60.6	1.56	58.0	2.24
Kernel wt (mg)	292.4	23.52	292.4	23.51	282.1	22.54
Density (g/cc)	1.34	0.40	1.32	1.07	1.28	1.39
Fat (%)	4.71 a	3.06	4.27 b	3.23	4.17 c	3.35
Protein (%)	9.02 a	2.54	8.44 b	3.21	8.41 b	2.08
Ash (%)	1.26 a	1.92	1.21 c	4.02	1.25 b	1.93
NIR at 1,680 nm	352 a	7.8	340 b	6.0	292 c	6.8
Stenvert time (sec)	16.6 a	5.26	13.3 b	11.1	12.0 c	9.98
Wt C/F	1.41 a	3.89	1.19 b	8.91	1.02 c	7.27
Vol. C/F	0.89 a	7.62	0.57 b	10.91	0.54 c	17.70
Height of ground corn column[c]	179.4 c	0.49	185.7 b	0.54	191.8 a	0.72

[a]Different letters denote statistically significant differences at the 0.05 level.
[b]Coefficient of variation.
[c]Arbitrary divisions.

TABLE IV
Average Composition and Physical Properties of Corn by Shape Factors Across Hybrids

Composition or Physical Property	Round 0.838	Round 0.760	Round 0.753	Flat 0.653	Flat 0.645	Flat 0.630	Small Variable 0.667
	Shape Factors[a]						
Test wt (lb/bu)	60.40	60.80	60.20	59.75	58.85	58.70	58.70
Kernel wt (mg)	366.8	285.7	353.4	279.1	318.1	250.0	169.7
Density (g/cc)	1.32	1.32	1.30	1.31	1.31	1.31	1.32
Fat (%)	4.36 e	4.46 b	4.39 cd	4.51 a	4.40 c	4.38 d	4.19 f
Protein (%)	8.98 a	8.61 c	8.71 b	8.58 cd	8.48 e	8.49 e	8.53 cde
Ash (%)	1.23 d	1.27 a	1.24 bcd	1.25 bc	1.22 e	1.24 cd	1.25 b
NIR at 1,680 nm	357 a	339 b	330 d	335 c	329 d	309 e	301 f
Stenvert time (sec)	14.7 a	14.8 a	14.4 a	13.7 bc	12.6 d	13.5 c	14.1 ab
Wt C/F	1.22 ab	1.24 a	1.20 bc	1.21 bc	1.12 d	1.19 c	1.24 a
Vol C/F	0.69 a	0.68 a	0.71 a	0.68 a	0.61 b	0.68 a	0.62 b
Height of ground corn column[b]	182.9 e	184.8 cd	185.3 cd	184.2 d	189.2 a	185.7 bc	186.9 b

[a]Different letters denote statistically significant differences at the 0.05 level.
[b]Arbitrary divisions.

TABLE V
Significant (at the 0.01 Level) Simple Correlation Coefficients

	Shape Factor	Kernel Weight	Fat	Protein	Ash	NIR	Stenvert Time	Wt C/F	Vol C/F
				Individual Hybrids[a]					
Shape factor				(A)			(C)	(C)	
Kernel weight	0.620					(C)			
Fat									
Protein			0.682						
Ash									
NIR			0.675	0.608					
Stenvert time			0.790	0.747		0.654			
Wt C/F			0.815	0.655		0.679	0.941		
Vol C/F			0.898	0.710		0.546	0.866	0.862	
				Combined					

[a](A) = Stauffer 8100, (B) = Stauffer 8500, (C) = Bo Jac.

TABLE VI
Significant (at the 0.01 Level) Partial Correlation Coefficients[a]

	Shape Factor	Kernel Weight	Fat	Protein	Ash	NIR	Stenvert Time	Wt C/F	Vol C/F
				Individual Hybrids[b]					
Shape factor						M(A),F(C), P(C),M(C)	P(C)		
Kernel weight	F			F(A),K(C)				S(A),F(C)	
Fat	M	M				P(C),M(A)		P(C)	
Protein		F	S,K			F(A)	K(C)	M(C),K(C)	
Ash						K(A)			
NIR		M	S,K,M	S			P(C),F(C)	P(C)	
Stenvert time		P,M	S,K,M	S,K		S, K,M		K(A),S(A), F(C)	
Wt C/F		P,M	K,M	S,K		S,K,M	S,K,F,P,M		S(C) P(A)
Vol C/F		P,M	S,K,M	K			S,K,P,M	S,K, P,M	
				Combined					

[a]Factors kept constant: S = shape factor, K = kernel weight, F = fat, P = protein, M = ash (minerals).
[b](A) = Stauffer 8100, (B) = Stauffer 8500, (C) = Bo Jac.

TABLE VII
Composition and Physical Properties of Corn by Variety and Shape Factor

Composition or Physical Property	Shape Factor, Average Kernel Weight, and Variety								
	0.838 (366.8 mg)			0.760 (285.7 mg)			0.753 (353.4 mg)		
	8500	8100	Bo Jac	8500	8100	Bo Jac	8500	8100	Bo Jac
Density (g/cc)	1.33	1.32	1.30	1.33	1.34	1.29	1.34	1.31	1.29
Fat (%)	4.70	4.20	4.17	4.75	4.40	4.24	4.85	4.20	4.12
Protein (%)	9.41	8.88	8.65	8.72	8.66	8.45	9.21	8.50	8.42
NIR at 1,680 nm	402	353	315	357	367	293	339	338	312
Stenvert time (sec)	15.3	14.6	14.3	18.1	14.7	11.5	16.6	13.7	12.9
Wt C/F	1.30	1.22	1.15	1.44	1.25	1.04	1.42	1.12	1.07
Vol C/F	0.86	0.56	0.65	0.92	0.63	0.49	1.01	0.60	0.52

TABLE VIII
Composition and Physical Properties of Corn by Variety and Shape Factor

Composition or Physical Property	Shape Factor, Average Kernel Weight, and Variety											
	0.653 (279.1 mg)			0.645 (318.1 mg)			0.630 (250.0 mg)			Small Variable 0.667 (169.7 mg)		
	8500	8100	Bo Jac	8500	8100	Bo Jac	8500	8100	Bo Jac	8500	8100	Bo Jac
Density (g/cc)	1.34	1.33	1.28	1.33	1.30	1.29	1.34	1.31	1.28	1.34	1.33	1.28
Fat (%)	4.84	4.48	4.22	4.81	4.07	4.32	4.59	4.31	4.25	4.46	4.23	3.89
Protein (%)	8.98	8.49	8.26	8.98	8.28	8.17	8.99	8.15	8.34	8.84	8.15	8.61
NIR at 1,680 nm	353	362	293	370	321	296	328	320	279	325	321	257
Stenvert time (sec)	16.7	13.1	11.4	16.8	10.3	10.8	15.9	13.0	11.5	16.8	13.8	11.8
Wt C/F	1.43	1.22	0.99	1.38	0.99	0.98	1.41	1.19	0.97	1.47	1.32	0.93
Vol C/F	0.92	0.53	0.60	0.80	0.45	0.58	0.84	0.60	0.59	0.89	0.61	0.36

average kernel weight of 169.7 mg), density, fat and protein contents, NIR, and three parameters of the SHT (resistance to grinding, Wt C/F, and Vol C/F) were highest in Stauffer 8500, lowest in Bo Jac, and intermediate in Stauffer 8100. These findings confirm and extend those in Table III and show that varietal differences were consistent, irrespective of kernel size and shape. Varietal differences are less pronounced when averages for shape factors across hybrids are calculated, as in Table IV.

Our study was limited to three commercial corn hybrids. In those hybrids, the various hardness parameters (NIR and results of measurements by the SHT) were highly and consistently correlated and useful in determining corn hardness. Establishing the effects of kernel weight and shape factor on composition and physical properties would require more extensive research on a broader selection of hybrids and additional evaluation methods.

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