Measurement of Endosperm Vitreousness of Corn: A Quantitative Method and Its Application to African Cultivars

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ABSTRACT

A quantitative method was developed for determining the vitreousness (vitreousness index [VI]) of corn kernels based on the measurement of the vitreous and the total endosperm areas through a view of sectioned kernels. The VI was highly correlated with the true vitreousness determined by dissection. It is proposed that the VI of African corn could be used to construct an endosperm classification table.

Corn is generally classified into five categories: flint corn, popcorn, flour corn, dent corn, and sweet corn (Watson 1987). Flint corn has a rounded crown and a large, continuous volume of vitreous endosperm. Popcorn is a small flint corn. Flour corn has a rounded or flat crown but contains virtually all floury endosperm. Dent corn, as the name implies, has a depressed crown. Dent corn varieties result from flint-flour crosses (Watson 1987) and can show significant differences in the ratio of vitreous to floury endosperm caused by heritable and environmental influences (Hamilton et al 1951). Furthermore, individual kernels within the same lot differ significantly in the vitreous-to-floury ratio (Paulsen et al 1983, Watson 1987).

Numerous studies on corn (Paulsen et al 1983, Paulsen and Hill 1985, Pomeranz and Czuchajowska 1987, Watson 1987) and sorghum (Maxson et al 1971, Murty et al 1982, Cagampang et al 1982, Scheuring et al 1982, Fliedel et al 1989) showed clear relationships between endosperm texture and kernel qualities for dry milling or specific food uses. But a corn endosperm texture, properly known as endosperm vitreousness, is not well defined, and no official test exists for measuring it. In fact, corn users and breeders usually judge corn vitreousness by considering that a flint grain has a vitreous endosperm and a dent grain has a floury endosperm. Another method for judging vitreousness consists of the visual examination of a sectioned kernel, with the level of vitreousness being proportional to the amount of vitreous endosperm (Paulsen et al 1983). The reliability of this method is largely dependent on the observer's experience. An objective method was proposed by Kirleis et al (1984), who measured with a planimeter the different parts of cross-sectioned sorghum endosperm observed under a light microscope. Gunaserakan et al (1988) suggested the use of an image analyzer for measuring vitreous and floury endosperm areas on corn cross-sections. But its use is limited to laboratories equipped with and financially able to maintain an image analyzer.

A method to quantitatively measure vitreousness was recently developed by Mestres et al (1991). The objectives of the present work are to assess this method and to determine the effect of two levels of kernel moisture content on vitreousness.

MATERIALS AND METHODS

Corn

Nine cultivars of corn and a commercial lot (Table I) harvested in 1988 were used in this study. Grains were cleaned on a Petkus-type apparatus (Röber Saartreiniger, Minden, Germany), and the remaining broken and shriveled kernels were manually removed. Grains were stored at 4°C and brought to 20°C a few days before use.

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Humidification of Corn

After soaking for 1 hr in distilled water at room temperature, grains were brought to 11.5 ± 0.1% or 15.5 ± 0.2% moisture content (wet basis) by storing at 30°C for three to four weeks under partial vacuum (300 mbar) in a hermetic container holding saturated solutions of KBr (at. wt. 0.80) or $SrCl_2$ (at. wt. 0.69), respectively (Brockington et al 1948, Hubbard et al 1957, Multon et al 1981). These humidities correspond to the grain moisture content as generally obtained by traditional drying in tropical and Sahelian zones, respectively, in Africa.

Vitreousness Indexes

Three types of corn kernel sections were made using a razor blade: longitudinal through the center of the germ (Fig. 1A); longitudinal parallel to the germ face, through the center of the largest dimension of the kernel (Fig. 1B); and transverse through the center of the kernel (Fig. 1C).

Sectioned kernels were maintained with the section face up using modeling clay and photographed with a macrolens. The final view was enlarged seven times. The picture was placed on a digitization tablet (Graphic Tablets, Apple Computer, Inc.) and the outlines of vitreous, floury, and total endosperm were drawn by a magnetic pen. The computer (Apple IIe), coupled with the digitization tablet, gave the area of the drawn endosperm. The vitreousness index (VI) was calculated as the percentage of vitreous area relative to total endosperm area. To determine the error due to the VI measurement technique, a single sectioned kernel from each variety of IRAT 148, IRAT 200, and IRAT 102 was measured five times. IRAT 148, IRAT 200, and IRAT 102 were selected to represent a small floury kernel, a large vitreous kernel, and an intermediate kernel with a medium vitreous endosperm area, respectively.

For each section type, three kernels from Plata, Katsaka Akondo, Local, DEA, IRAT 45, IRAT 100, IRAT 148, IRAT 170, and IRAT 275 (Table I) were cut and photographed, and the VI was calculated. The procedure was duplicated for IRAT 148. These varieties were chosen with the aim of having, a priori, a wide range of vitreousness. In addition, after soaking in distilled

TABLE I
Characteristics of Corn Samples

Corn Lot	Type	Origin	Kernel Color	Kernel Texture
IRAT 81	Topcross hybrid	Ivory Coast	White	Dent
IRAT 200	Variety	Ivory Coast	Yellow	Dent
IRAT 100	Intervarietal hybrid	Burkina Faso	Yellow	Semident
IRAT 39	Intervarietal hybrid	Benin	White	Semident
IRAT 102	Intervarietal hybrid	Burkina Faso	White	Semident
IRAT 275	Composite	Ivory Coast	Yellow	Flint
IRAT 148	Single hybrid	Ivory Coast	White	Dent
Local	Ecotype	Togo	White	Dent
Katsaka Akondo	Ecotype	Congo Republic	White	Dent
Plate	Ecotype	Argentina	Yellow	Flint
DEA	Commercial lot	France	Yellow	Flint

water for 20–30 min, these same kernels were peeled to remove the pericarp, degermed, and separated into vitreous and floury endosperm by hand using a scalpel (Robutti et al 1974). The different endosperm parts were dried at 130°C for 2 hr and weighed. Weighed VI was calculated as the percentage of vitreous relative to total endosperm dry weights.

RESULTS AND DISCUSSION

Reliability of VI Measurement

Coefficients of variability for total, floury, and vitreous endosperm areas were less than 1% (Table II). Errors in VI due to measurement technique were much smaller than the VI itself. Therefore, the measurement technique is highly reliable and offers results similar to those observed by Kirleis et al (1984) for sorghum cross-sections. Consequently, measurements were made in duplicate.

Choice of Cross-Section

Significant correlations (at $P < 0.01$) were found between weighed VI and VI were 0.78, 0.75, and 0.82 for sections A, B, and C, respectively (Fig. 2). The coefficients of correlation and regression were not significantly different. Cut C was easiest to obtain since it required less mechanical manipulation during cutting. Consequently, VI estimated from cut C offers the best combination of accuracy and simplicity. As further evidence of

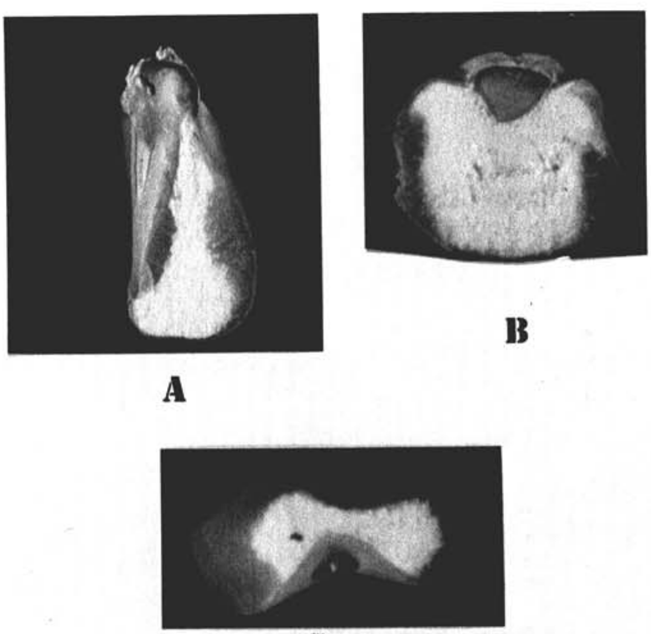

Fig. 1. Section types of corn kernels. **A**, longitudinal section through the germ; **B**, longitudinal section parallel to the germ face through the largest dimension of the kernel; **C**, transverse section through the median of the longest dimension of the kernel.

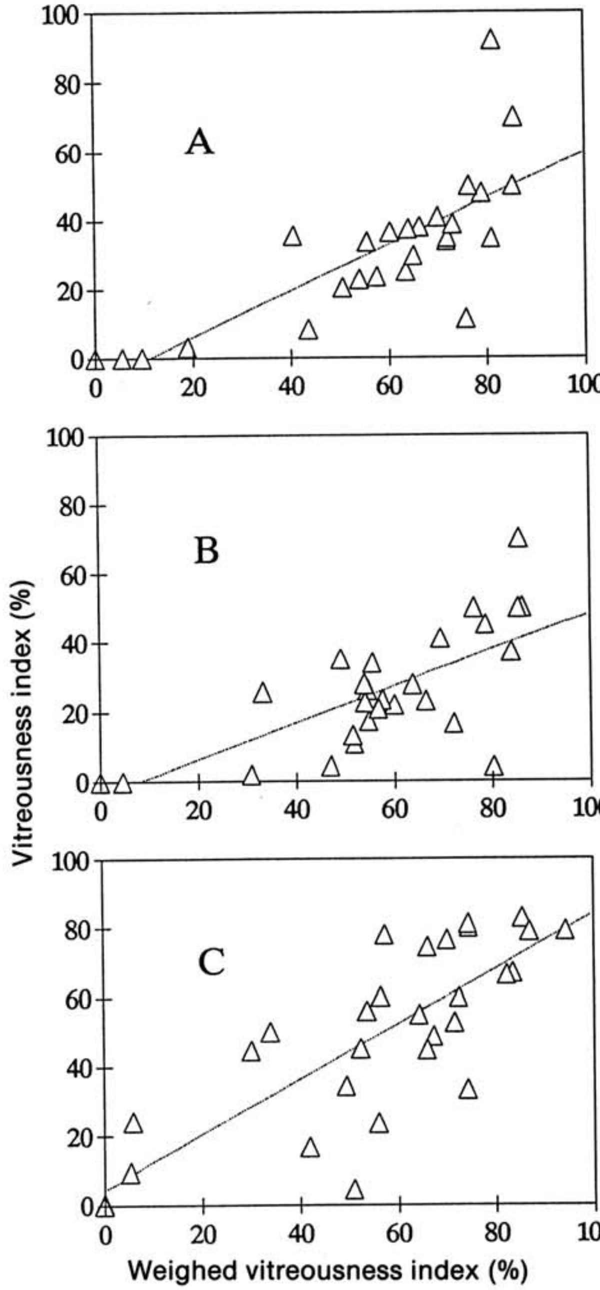

Fig. 2. Regressions between weighed vitreousness index and vitreousness index observed for the three section types of corn kernels. **A**, longitudinal section through the germ ($y = -7.48 + 0.67x$, $r = 0.78$); **B**, longitudinal section parallel to the germ face through the largest dimension of the kernel ($y = -4.26 + 0.52x$, $r = 0.75$; **C**, transverse section through the median of the longest dimension of the kernel ($y = 4.34 + 0.8x$, $r = 0.82$).

TABLE II
Measurements of Endosperm Areas and Vitreousness for Three Corn Cultivars

Cultivar	Endosperm Area (mm²)[a] Total	Floury	Vitreous	Vitreousness Index (%)
IRAT 148	1,031 ± 4	640 ± 2	392 ± 6	38.0 ± 1.0
IRAT 102	1,701 ± 8	799 ± 3	901 ± 9	53.0 ± 0.5
IRAT 200	2,013 ± 11	350 ± 4	1,663 ± 6	82.6 ± 0.4
Overall standard deviation	8.5	3	7.3	0.5
Coefficient of variability, %	0.5	0.5	0.7	0.9

[a]Mean ± SD of five measurements of a sectioned kernel.

TABLE III
Vitreousness Index for Seven African Corn Cultivars at Two Levels of Moisture Content

Cultivar	Kernel Moisture Content[a] 11.5%	15.5%	Mean[b]
IRAT 81	78.9 ± 2.5	77.8 ± 2.3	78.4 a
IRAT 200	72.8 ± 3.3	81.3 ± 2.0	77.1 a
IRAT 100	62.6 ± 2.5	64.7 ± 2.4	63.6 b
IRAT 39	62.9 ± 2.6	60.1 ± 2.8	61.5 b
IRAT 102	47.6 ± 3.1	50.7 ± 3.2	49.1 c
IRAT 275	42.7 ± 2.7	46.7 ± 3.1	44.7 cd
IRAT 148	42.3 ± 3.0	37.7 ± 2.8	40.0 d

[a]Means of 50 observations ± SD.
[b]Different letters denote statistically significant differences (at $P = 0.05$) using Student-Neuman-Keuls test.

TABLE IV
Two-Way Analysis of Variance of Cultivars and Kernel Moisture Effects on Vitreousness Index

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio	H_o Probability	Standard Deviation	Coefficient of Variability (%)
Total	403,305	699	577	...	...	...	...
Cultivar	139,237	6	23,206	61.0	<0.0001	...	...
Kernel moisture	302	1	302	0.80	0.38	...	...
Cultivar × kernel moisture	298	6	497	1.31	0.25	...	...
Residual	260,785	686	380	...	...	19.5	32.9

TABLE V
Classification Table for Texture of African Corn Endosperm[a]

Class	Texture Classification	Vitreousness Index	Number of Cultivars[b]
1	Very vitreous	>70	6
2	Vitreous	69–60	5
3	Medium vitreous	59–50	6
4	Poorly vitreous	49–40	5
5	Floury	<39	3

[a]These guidelines are based on the means of the vitreousness indexes obtained at 11.5 and 15.5% kernel moisture content and are tentatively assigned for the endosperm texture categories of the African corn cultivars.

[b]For each class of cumulative data from the present study and previous work (Mestres et al 1990).

its usefulness, this section was used by Gunaserakan et al (1988) and Mestres et al (1991).

Influence of Cultivar and Kernel Moisture on VI

Using section C, VI was determined for seven African corn cultivars at two levels of kernel moisture (Table III) on 50 kernels. As analysis of variance did not reveal significant interaction between cultivar and kernel moisture (Table IV), the main effects were studied. For the kernel-moisture parameter, probability of verification of the null hypothesis (defined as the equality of samples mean) was greatly superior to 0.05 (Table IV). This indicates that within the experimental conditions, kernel moisture content did not influence VI. On the contrary, the cultivar effect was highly significant ($P < 0.01$), and according to a Student-Newman-Keuls test, four homogeneous groups ($P = 0.05$) were obtained for the seven African cultivars (Table III).

Within each cultivar, the standard deviations (SDs) of the mean of VI calculated for 50 kernels at 11.5 and 15.5% moisture content were 2.0–3.3 (Table III). The SD seemed to increase when the VI average value decreased. Kirleis et al (1984) also observed this phenomenon, which was attributed to difficulty in distinguishing between vitreous and floury endosperm parts for the most floury cultivars.

Since no effect was found for the humidity parameter (Table IV), the two sets of measurements (11.5 and 15.5% moisture content) can be considered as duplicates. For all the cultivars except IRAT 200, the VI at 11.5% moisture content was within the confidence interval (defined as the mean value of VI plus or minus two SDs) of the VI at 15.5% moisture content. Therefore, the method studied has repeatability, and determination of VI using 50 kernels seems to be a good compromise. The method appears to be a useful research tool for measuring the vitreousness of corn grain endosperm and is more objective and less expensive than methods previously used (Paulsen et al 1983, Gunaserakan et al 1988).

For African corn, guidelines for classification on the basis of the VI may be established (Table V). The figures are based on the result of multiple comparisons of means (Table III) (Williams and Sobering 1986). This classification agrees with previous multiple comparisons of means of vitreouness calculated by the proposed method on 18 African corn samples (Mestres et al 1991). However, it would be advisable to test the proposed classification with additional cultivars.

CONCLUSION

The VI was estimated on kernel cross-sections as the ratio of the measured vitreous endosperm area to the measured total endosperm area. Good correlation was observed between true vitreousness (estimated as the percentage of vitreous relative to total endosperm dry weights) and the VI. VI can be measured at levels of kernel moisture content of 11.5–15.5%. Estimation of VI was precise and repeatable when determined on 50 kernels. The method studied may be regarded as satisfactory for routine testing of corn for endosperm texture.

Among seven cultivars, four homogeneous groups were distinguished that showed VIs of 40–80. An enlarged classification table is proposed for the description of African cultivars.

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