

Effects of Kernel Size and Genotype on Popcorn Popping Volume and Number of Unpopped Kernels

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ABSTRACT

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Four genotypes of commercial yellow popcorn (proprietary hybrids) were screened with 4.36-, 4.76-, 5.16-, 5.56-, and 5.95-mm (11/64-, 12/64-, 13/64-, 14/64-, and 15/64-in.) round-hole sieves to generate five size fractions. The five fractions were conditioned in an environmental chamber at 22.2°C and 70% relative humidity, popped in a Cretors Metric Weight Volume Tester at 243°C (250-g samples), and compared to control samples containing kernels of different sizes in naturally occurring proportions. The 5.16- to 5.56-mm fraction had the highest popping volume and the lowest number of unpopped kernels (UPKs); the 4.36- to 4.75-mm fraction had the lowest popping volume and the greatest number of UPKs. For

one of the varieties studied, the difference between the popping volumes of the size fractions reached as high as 11% (from 40.8 to 45.1 cm³/g). The popping volume of middle-sized kernels of all the varieties studied was 2% higher in general than that of the control samples. The average number of UPKs ranged from 13 to 45. The weight percentage of UPKs varied from 0.62 to 1.56%. The popping volume of the 5.16- to 5.56-mm fraction of different genotypes varied from 45.1 to 47.2 cm³/g, and the number of UPKs ranged from 13 to 23. Statistical analyses indicated that the popcorn genotype and kernel size significantly affected the popping volume and the number of UPKs.

Popcorn has long been a favorite traditional snack food in the United States. Popping volume, defined as volume per unit of weight of a sample, is a primary characteristic of popcorn, since commercial buyers purchase it by weight and sell by bulk volume. Furthermore, popcorn texture (tenderness and crispness) is positively correlated with popping volume (Rooney and Serna-Saldivar 1987).

Factors that affect popping volume are moisture content, popping temperature, kernel size and shape, variety or genotype, kernel density, drying condition, and kernel damage. Moisture content has been considered the most critical factor, because it affects the rate and extent of pressure buildup in starch granules (Eldredge and Lyerly 1943; Hoseney et al 1983). Dexter (1946), Bemis (1959), and Huelsen (1960) reported different values (13.5, 13, and 12.5%, respectively) for the optimum moisture content for maximum expansion. Eldredge and Lyerly (1943) stated that a moisture content between 12 and 13% provided the best popping. However, in a different report, Eldredge and Thomas (1959) claimed that 13-14% was the optimum moisture level. These differences imply that the optimum moisture content for maximum popping volume is dependent on the popcorn tested, popping procedures, and the methods of measuring moisture content. Haugh et al (1976) indicated that the optimum moisture content was different for different hybrids of popcorn. In addition, the method of popping is expected to influence the optimum moisture content. Metzger et al (1989) found that air popping produced a higher volume than oil popping and that a greater moisture content was needed for hot-air popping.

Physical properties of popcorn such as kernel size, shape, and density were found to affect the popping volume (Lyerly 1942; Richardson 1959). The smaller, shorter, and rounder kernels had higher popping volumes. Willier and Brunson (1927) also found that popping volume increased as kernel size decreased. Eldredge and Thomas (1959) reported that popcorn with a higher bulk density yielded a higher popping volume, which they believed was due to denser starch granules in the kernels. Haugh et al (1976), however, found that kernels from the butt location of the ear had the largest popping volume but the lowest specific gravity.

The objectives of this study were to determine the effect of popcorn kernel size on the popping volume and the number of unpopped kernels (UPKs) of selected commercial genotypes.

MATERIALS AND METHODS

Sample Preparation

Four genotypes of commercial yellow popcorn (proprietary hybrids), treated under the same postharvest conditions, were screened in 4.36-, 4.76-, 5.16-, 5.56-, and 5.95-mm (11/64-, 12/64-, 13/64-, 14/64-, and 15/64-in.) round-hole sieves with a Carter-Day Dockage Tester. Materials retained on each sieve were collected separately to generate five fractions identifiable by kernel size. Control samples with a naturally occurring distribution of kernel size were removed before screening.

Samples of each size fraction and the control sample of each genotype were divided into 20 subsamples. A full 4 × 6 × 20 factorial design (four genotypes, five fractions and a control sample, and 20 replicates) was used for testing. A total of 480 samples were conditioned in an environmental chamber at 22.2°C and 70% relative humidity for at least two weeks before popping. The moisture content of 50 g of each sample was measured by a slight variation of the ASAE oven method (103°C for 72 hr) (standard 5352.2, ASAE 1989). The variation consisted of weighing the samples immediately after removal from the oven instead of placing them in a desiccator to cool to room temperature. Taraba (1979) reported that negligible error is introduced if hot samples are not placed in a desiccator.

Popping Method

The popper used was a Cretors Metric Weight Volume Tester (C. Cretors and Co., Chicago, IL) equipped with a graduated cylinder, a motor-driven stirrer, a temperature sensor, and a wattmeter. Both the temperature at which the popcorn is popped and the energy input that controls the heating rate are adjustable. The temperature meter was preset to 243°C, and the wattmeter set to 1,400 W. Before data were recorded, two warm-up samples were popped, to heat the machine and to reduce the variation. The popping procedure consisted of the following steps: pouring 110 ± 5 g of liquid coconut oil into the kettle, heating the oil to the desired temperature (243°C), and then adding 250 ± 0.5 g of popcorn to the kettle and closing the lid. The heating continued until the popping was completed (5 sec after the last kernel popped). The popped corn was gently brushed into the graduated cylinder, and the volume was recorded to the nearest 0.1 cm³/g.

The number of UPKs was determined by transferring the popped corn to a 7.14-mm (18/64-in.) square-hole screen, shaking the screen vigorously, and counting the UPKs underneath it, to the nearest half-kernel; two halves were counted as one UPK.

The shape of the flakes was visually examined while the UPKs were being counted. No attempt was made to describe the shape quantitatively.

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RESULTS AND DISCUSSION

Visual observation indicated that 99% of the flakes were formed in the "butterfly" shape, regardless of the kernel size. Only 1% of the flakes were in the "mushroom" shape. Therefore, in the subsequent analyses the shape of the popped popcorn was not considered an independent factor for comparisons.

Figure 1 shows the average popping volumes of the five size fractions and the control samples of the four genotypes (A, B, C, and D) of popcorn. The popping volume varied with kernel size; the values for the four genotypes were 40.8–45.1, 41.6–46.4, 43.3–45.9, and 43.7–47.2 cm³/g, respectively.

Figure 2 shows the average number of UPKs in 20 replicates of the five size fractions. The average number ranged from 13 to 45 per 250-g sample in the 24 test combinations. The middle-sized fraction (5.16- to 5.56-mm kernels) had the highest popping volume and the lowest number of UPKs. The smallest-sized fraction (4.36- to 4.76-mm kernels) had the lowest popping volume and the greatest number of UPKs. The maximum difference between the popping volumes of the size fractions of genotype A was 11%. In genotype B, the maximum number of UPKs was almost double the minimum number. The popping volumes of the middle-sized fractions were approximately 2% higher than those of the control samples.

The percentage of UPKs in each size fraction by weight is presented in Table I. As mentioned above, the number of UPKs in the different size fractions and genotypes varied in a wide range (from 13 to 45). However, the weight percentage of UPKs varied only from 0.62 to 1.56%. The smallest-sized fraction had the greatest number of UPKs in all genotypes tested, but the largest-sized fraction had the highest percentage in terms of weight, except for genotype B. The middle-sized fraction had the lowest weight percentage of UPKs, except for genotype D.

Since the large kernels are usually found in the butt location on the ear, the test data from this study imply that kernels at the butt are not the best for popping, which is in good agreement with the results given by Lyerly (1942) and Willier and Brunson (1927), but which contradicts the results of Haugh et al (1976).

Comparison between genotypes was also made. Variation in the popping volume of different genotypes was statistically significant. For example, the popping volumes of kernels of the same size (5.16–5.56 mm) but of different genotypes varied from 45.1 to 47.2 cm³/g, and the number of UPKs ranged from 13 to 23. Figure 1 shows that genotype D had the highest popping volume and genotype A had the lowest. Genotype B had the most UPKs overall.

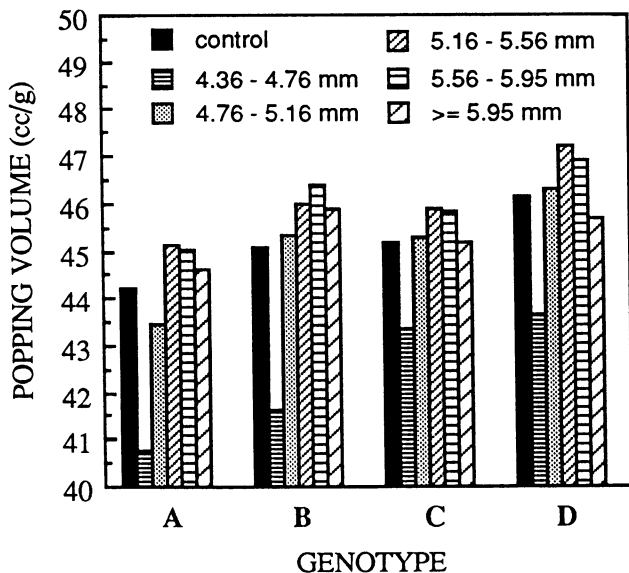


Fig. 1. Mean popping volumes of 20 replicates of five size fractions and a control sample of four popcorn genotypes.

Figure 3 shows that the number of UPKs decreased as the popping volume increased. There is an indication that increases in pop volume above about 44 cm³/g may have been due to more complete popping rather than a continued decrease in the number of UPKs, because the number of UPKs leveled off (especially in genotypes A, B, and D).

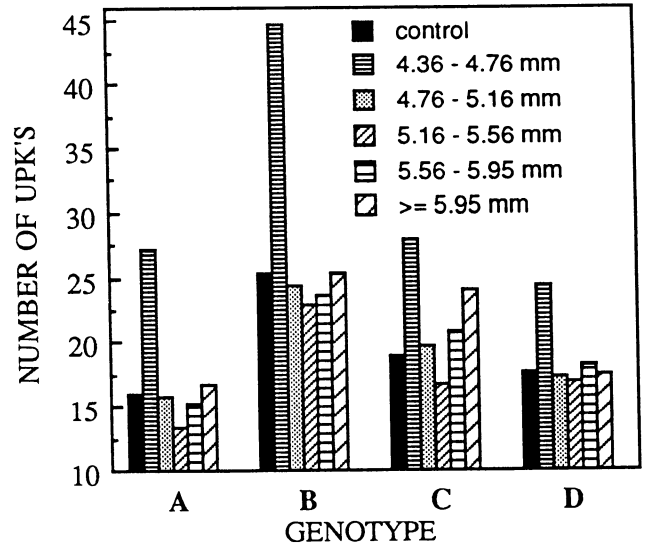


Fig. 2. Mean number of unpopped kernels (UPKs) in 20 replicates of five size fractions and a control sample of four popcorn genotypes.

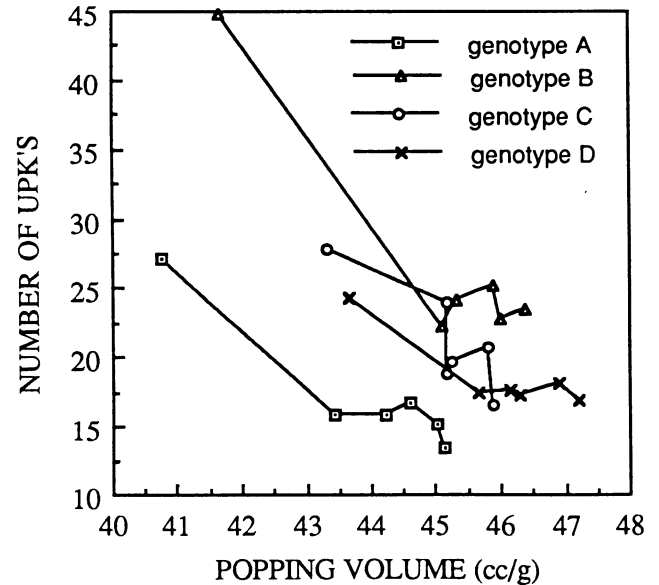


Fig. 3. Mean number of unpopped kernels (UPKs) in 20 replicates vs. average popping volume of four popcorn genotypes.

TABLE I
Average Weight Percentage of Unpopped Kernels in Five Size Fractions and a Control Sample of Four Popcorn Genotypes^a

Kernel Size (mm)	Genotype			
	A	B	C	D
4.36-4.76	0.96	1.56	1.00	0.85
4.76-5.16	0.65	1.00	0.86	0.74
5.16-5.56	0.62	1.05	0.82	0.82
5.56-5.95	0.79	1.18	1.15	1.01
≥ 5.95	1.00	1.43	1.50	1.08
Control	0.73	1.19	0.97	0.83

^a Average of 20 replications.

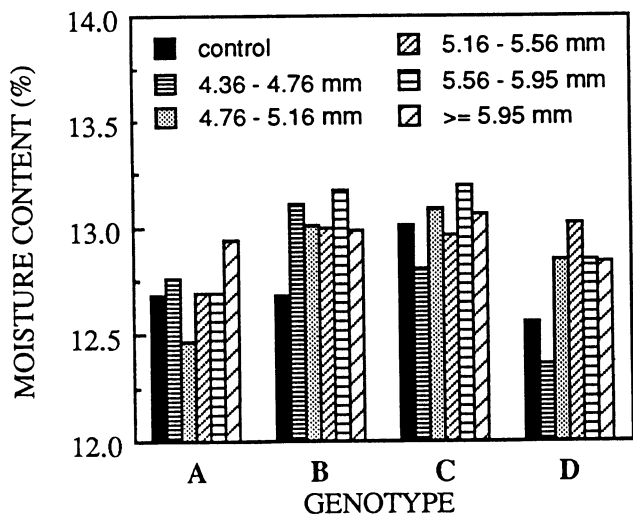


Fig. 4. Mean moisture content of 20 replicates of five size fractions and a control sample of four popcorn genotypes.

TABLE II
Pairwise Comparisons of Popping Volume and Number of Unpopped Kernels of Size Fractions of Popcorn Genotype A

Kernel Size (mm)	Mean Popping Volume (cm ³ /g) ^a	Mean Number of Unpopped Kernels
4.36-4.76	40.8 a	27.2 a
4.76-5.16	43.4 b	15.9 bc
5.16-5.56	45.1 c	13.5 b
5.56-5.95	45.0 c	15.3 bc
≥ 5.95	44.6 d	16.7 c
Control	44.2 e	16.0 bc

^aMeans with the same grouping letter in the same column are not significantly different at the 5% level, by Duncan's multiple range test.

TABLE III
Pairwise Comparisons of Popping Volume and Number of Unpopped Kernels of the Smallest-Sized Fraction of Four Popcorn Genotypes

Genotype	Mean Popping Volume (cm ³ /g) ^a	Mean Number of Unpopped Kernels
A	40.8 a	27.2 a
B	41.6 b	44.8 b
C	43.3 c	27.9 a
D	43.7 d	24.4 a

^aMeans with the same grouping letter in the same column are not significantly different at the 5% level, by Duncan's multiple range test.

Statistical analysis of variance (ANOVA) using SAS software (SAS 1985) showed that both the popcorn genotype and the kernel size and also the interaction of these variables significantly affected the popping volume and the number of UPKs at the 0.01% level. Duncan's multiple range test was used to make pairwise comparisons between different fractions of the same genotype and between the same fractions of different genotypes. Table II presents the results of Duncan's test, showing the order of popping volumes of the size fractions and the numbers of UPKs in genotype A. The popping volumes of the 5.16- to 5.56-mm and the 5.56- to 5.95-mm fractions were statistically the same but different from those of the control samples and the other size fractions. The number of UPKs in the fraction containing the smallest kernels significantly differed from that of the rest of the groups, as previously mentioned.

The varietal effect on the popping volume and the number of UPKs is illustrated in Table III for the fraction containing the smallest kernels (4.36-4.76 mm). The popping volumes of the different genotypes were significantly different from one another. However, genotypes A, C, and D had the same number

of UPKs, and only genotype B had a significantly different number.

The reasons for differences in the popping volume and the number of UPKs in different genotypes and kernel sizes are not fully understood. Previous researchers (Eldredge and Lyerly 1943; Crumbaker et al 1949; Eldredge and Thomas 1959) believed that popcorn of hard flinty structure with very little soft starch pops best. Different genotypes and kernel sizes may have different ratios of soft and hard endosperm or different starch structures, which directly affect the popping volume. In addition, the differences in chemical composition and structure may be partially reflected as differences in equilibrium moisture content. Attempts were made to explore the variation in the moisture content of different popcorn genotypes and kernel sizes and possibly to tie the variation in pop volume and UPKs to it. In Figure 4 the average moisture content is plotted against the variety for popcorn of different sizes. Although all the 480 samples were placed in the same environmental chamber, the equilibrium moisture content varied in kernels of different sizes and genotypes. However, the moisture content pattern with respect to size did not correlate well with the popping volume and UPK patterns.

CONCLUSIONS

Popcorn genotypes and kernel sizes significantly affect the popping volume and the number of UPKs. The middle-sized fractions (5.16- to 5.56-mm and 5.56- to 5.95-mm kernels) had the highest popping volume and the lowest number of UPKs, and the smallest-sized fraction (4.36- to 4.76-mm kernels) had the lowest popping volume and the greatest number of UPKs, in all the varieties. The average popping volume ranged from 40.8 to 47.2 cm³/g. The number of UPKs ranged from 13 to 45. The weight percentage of UPKs varied from 0.62 to 1.56%. The highest weight percentage of UPKs occurred in the largest kernels in three of the four genotypes tested. The difference in the popping volumes of fractions of the same genotype reached as high as 11% (the difference between the middle-sized and the smallest-sized fractions). The largest kernels were not the best in terms of popping volume and weight percentage of UPKs, which agrees well with results reported by Willier and Brunson (1927).

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LITERATURE CITED

- AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS. 1989. ASAE Standards. The Society: St. Joseph, MI.
- BEMIS, W. P. 1959. Popcorn-harvesting and conditioning for maximum popping. Univ. Ill. Res. 1(1):10.
- CRUMBAKER, D. E., JOHNSON, I. J., and ELDRIDGE, J. C. 1949. Inheritance of popping volume and associated characters in crosses between popcorn and dent corn. Agron. J. 41:207.
- DEXTER, S. T. 1946. Conditioning popcorn to the proper moisture content for best popping. Mich. Agric. Exp. Stn. Q. Bull. 29:64.
- ELDRIDGE, J. C., and LYERLY, P. J. 1943. Popcorn in Iowa. Iowa Agric. Exp. Stn. Bull. 54:753.
- ELDRIDGE, J. C., and THOMAS, W. I. 1959. Popcorn—Its production, processing and utilization. Iowa Agric. Exp. Stn. Bull. P127:1.
- HAUGH, C. G., LIEN, R. M., HANES, R. E., and ASHMAN, R. B. 1976. Physical properties of popcorn. Trans Am. Soc. Agric. Eng. 19(1):168.
- HOSENEY, R. C., ZELEZNAK, K., and ABDELRAHMAN, A. 1983. Mechanism of popcorn popping. J. Cereal Sci. 1:43.
- HUELSEN, W. A. 1960. Searching for reasons why some popcorn doesn't pop well. Univ. Ill. Res. 2(4):12.
- LYERLY, P. J. 1942. Some genetic and morphologic characters affecting the popping expansion of popcorn. J Am. Soc. Agron. 34(1):986.
- METZGER, D. D., HSU, K. H., ZIEGLER, K. E., and BERN, C. J. 1989. Effect of moisture content on popcorn popping volume for oil and hot-air popping. Cereal Chem. 66:247.
- RICHARDSON, D. L. 1959. Effect of certain endosperm genes on

