Effects of Storage Temperature and Kernel Physical Condition on Popping Qualities of Popcorn Hybrids

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ABSTRACT

Effect of storage temperature before popping and kernel physical properties on popping characteristics were studied using popcorn (*Zea mays* L.) hybrids harvested in 1997. Popped volume (PV), unpopped kernel ratio (UPK), and popping times were measured from 250 g of moisture-adjusted kernels stored at 30, 1, and –29°C for one month. Maximum popped volume (MPV) and minimum unpopped kernel ratio (MUPK) at the corresponding optimum moisture contents (OMC) were mathematically calculated from PV, UPK, and moisture content values. MPV was significantly affected by storage temperature before popping. Hybrid significantly affected MPV and MUPK. Moisture content, storage temperature, and hybrid significantly varied popping time of the popcorn hybrids, with moisture content being the most important. Correlation results showed that MPV was negatively correlated with unsound kernel ratio, UPK, and popping time. Moisture adjustment of intact kernels should be done at different storage conditions; high temperature storage required higher moisture than low temperature storage to give the best outcome.

Popped volume (PV), popped kernel tenderness, and flavor are important qualities of popcorn (Hoseney et al 1983), with PV generally considered to be the most important factor (Brunson 1937). Popped volume refers to the increase in volume of unpopped corn after it is popped (Eldredge and Thomas 1959). It depends primarily on hybrid, maturity at harvest, popping temperature, and moisture content of the intact kernels (Kandala et al 1994). Moisture content of intact kernels has been emphasized as the most important factor by many researchers. Moisture content not only affects PV, but also other qualities such as unpopped kernel ratio (UPK) (Lin and Anantheswaran 1988) and popping time (Stewart 1923; Huelsen and Bemis 1955). Stewart (1923) reported that dry popcorn pops a little more quickly than moist corn. Similarly, Huelsen and Bemis (1955) reported that popcorn with a higher moisture content required longer popping time but resulted in higher PV. In addition, popping method, popping time, drying conditions of intact corn, kernel physical properties, storage conditions before popping, and salt addition have also been mentioned as important factors affecting the popping qualities (Walton 1968; Haugh et al 1976; White et al 1980; Roshdy et al 1984; Dofing et al 1990; Pordesimo et al 1990; Maga and Blach 1992). Several researchers concluded that storage conditions before popping affects popping qualities in both microwave ovens and conventional oil poppers (Lin and Anantheswaran 1988; Maga and Blach 1992).

A commercial popcorn breeder requested a further investigation to determine whether storage condition actually affects PV. We pointed out that, in previous reports, PV of stored kernels was simply compared with other storage conditions at a fixed moisture content instead of comparing maximum popped volume (MPV) from each storage condition. Thus, in this study, the effect of storage before popping on MPV was investigated further. Moreover, we found no study reporting the effects of storage on popping time. The investigation on popping time would be valuable to commercial poppers in controlling the popping process, especially the continuous popping process. The objectives of this study were to ascertain the effect of hybrids, moisture content, and storage before popping on the PV, MPV, minimum unpopped kernel ratio (MUPK), unpopped kernel ratio (UPK), optimum moisture content (OMC) for MUPK and MPV, and popping times in a conventional oil popper. In addition, relationships between intact kernel physical properties and the popping qualities were established.

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MATERIALS AND METHODS

Moisture Adjustment and Storage Conditions

Six commercial popcorn hybrids grown in Colorado or Nebraska and harvested in 1997 were obtained from the Rocky Mountain Popcorn Company (Fort Collins, CO). The hybrids were A358W, 353W, BKH, 019, 1601 and 5501.

Dry kernel moisture contents were determined according to standard methods (AOAC 1990). Based on a preliminary study, intact kernel moisture contents of 11.0, 14.0, and 17.0% were studied to determine the popping qualities of the popcorn hybrids at three different storage conditions. Like the method reported by Maga and Blach (1992), for moisture contents lower than the initial kernel moisture content, intact kernels were air-dried in a chamber maintained at 30°C until the desired moisture content was achieved, and was followed by placing 250 g of moisture-adjusted corn into a 385.0- or 475.0-mL glass jar with a metal screw cap. When moisture contents were higher than initial kernel moisture, a calculated amount of water was added to 250 g of kernels in a 385.0- or 475.0-mL glass jar with a metal screw cap. Added water and popcorn kernels were mixed every 2 hr until all water was absorbed into the kernels. The jar was held at 21°C for 10 days, then second or third moisture adjustments were done until the desired moisture contents were achieved. Moisture content for the adjustment of the intact kernels was measured with an electronic moisture tester (Steinlite, Fred Stein Laboratories Inc., Atchison, KS). Moisture-adjusted samples in the tightly sealed jars were stored for one month at 30, 1, or –29°C.

Physical Properties of Unpopped Kernels

Kernel number, kernel weight, kernel volume, and unsound kernel ratio from six replicates of the moisture-adjusted unpopped kernels were evaluated. Methodology reported by Park et al (2000) for determining kernel number, weight, and volume of popcorn hybrids was used. Unsound kernel ratio was reported as the number percent of unsound kernels at each moisture content. The number of unsound kernels was obtained from broken or damaged kernels, diseased kernels, and infested kernels in intact kernels. Kernels slightly stress-cracked on the pericarp or inside the kernels were not separated out as damaged kernels because there were difficulties in differentiating cracks on the pericarp or cracks inside the endosperm.

Popping Kernels

For measuring popping characteristics, 250 g of kernels were popped at 250°C in an oil popper (C. Cretors & Co., Chicago, IL) with 4 g of salt and 100 mL (86.5 g) of sunflower oil obtained from Humko Co. (Memphis, TN). The popper had an automatic temperature regulator and a PV measuring device, which gave PV as cm^3/g of intact corn. The popper was conditioned by two preexperimental popping sessions. The popper then had approximately the same initial temperature for the rest of the popping sessions. Oil and salt were added before turning on the popper. A sample directly from storage was added to the popper at a popper temperature of 250°C. From the moment corn was added to the popper, start time and end time were recorded. The end popping was the moment at which no popping was obvious for at least 3 sec. Popping time was obtained by subtracting start time from end time. After kernel popping, PV was recorded, and unpopped kernels were manually separated and counted. The UPK was calculated from number of the intact kernels for each moisture.

From the PV and UPK of storage temperatures and hybrids, least square equations were calculated by the quadratic regression analysis for each session (SAS Institute, Cary, NC). OMC values for MPV and MUPK for each session and hybrids at different storage temperatures were calculated from first derivatives of the least squares equation calculated to zero using the PV and UPK data. Then MPV and MUPK for each hybrid and each storage condition were calculated by inserting OMC to the least square equation.

Statistical Analysis

Effects of experiment session, hybrid, moisture, storage temperature, and the interactions on PV, UPK, and popping time were analyzed by three-way completely randomized split-block factorial analysis using SAS/STAT. Popping was done in three sessions (total of 324 observations: 6 hybrids × 3 storage temperatures × 3 moisture contents × 3 sessions × 2 replicates) for three days every two months. The popping session was the block effect. Storage temperature was assigned in each of three days. Two replicates of six hybrids and three moisture contents were completely randomized within a storage temperature.

At the first popping session (block), all moisture-adjusted popcorn samples from 30°C storage were popped on the first day, samples from –29°C storage were popped on the second day, and samples from 1°C storage were popped on the third day. At the second popping session, samples were popped by order of samples from 1, 30, and –29°C. Finally, popcorn samples from –29°C were popped on the first day, followed by samples from 1 and 30°C at the third popping session.

Effects of hybrid, storage, and hybrid × storage on the OMC, MPV, and MUPK were also evaluated statistically. Multiple comparisons of the data were done by the Student Newman Keuls (SNK) method at $P < 0.05$. The Pearson's correlation coefficient using the data from the preliminary and the storage studies evaluated the relationships among kernel physical characteristics, MPV, UPK, and popping time.

RESULTS AND DISCUSSION

Kernel Physical Properties

The initial moisture content of the popcorn hybrids was 12.3–14.4% (Table I). Mean kernel number of popcorn hybrids over moisture treatments were 1,455–2,219. Unsound kernel ratio of hybrid BKH was significantly lower than that of hybrid A358W, 019 and 1601. Generally, lower moisture content of the intact kernel resulted in higher number of kernels, lower kernel weight and volume, but not unsound kernel ratio (data not shown). In a previous report by Mohamed et al (1993), kernel volume was 0.093–0.129 cm^3, which was converted from thousand-kernel weight. Also, Haugh et al (1976) reported that 12 popcorn hybrids at 15.0% moisture had popcorn kernel weights of 109.4–198.7 mg and measured 0.083–0.149 cm^3. Therefore, from this study and former studies, it can be inferred that physical characteristics of popcorn hybrids vary from hybrid to hybrid and moisture content to moisture content.

Popped Volume (PV)

Moisture content, storage temperature, and hybrid affected the PV of popcorn hybrids. As in reports by Dofing et al (1990), Song et al (1991), and Hoseney et al (1983), popcorn hybrid and moisture content were very important factors affecting PV. Generally, PV at 14% moisture was the highest and PV at 11% moisture was the lowest (Fig. 1). At 11% moisture, storage temperature did not affect PV. However, storage temperature at the 14% moisture was significant for PV, where the frozen storage resulted in lower values. At 17% moisture, PV from frozen storage (–29°C) was lower than from refrigerated storage (1°C) and warm storage (30°C). PV of refrigerated popcorn was lower than that of popcorn stored at higher temperatures. PV of hybrid BKH at 30°C storage was the highest (38.1 cm^3/g) among hybrids and storage conditions, while PV of hybrid 5501 at frozen storage (–29°C) was the lowest (29.6 cm^3/g).

MPV at Optimum Moisture Content (OMC)

Optimum moisture content of popcorn hybrids was 14.4–15.0%, while that of storage temperatures was 14.5–14.9% (Table II). OMC of 30°C storage was significantly higher than storage temperatures of

TABLE I
Intact Kernel Characteristics of Hybrid Samples[a]

Hybrid	Moisture Content (% ± SEM)	Total Kernel Number (no/250g ± SEM)	Unsound Kernel Ratio (% ± SEM)	Kernel Weight (mg ± SEM)	Kernel Volume (cm^3 ± SEM)
A358W	12.3f ± 0.09	2,206c ± 17.7	1.5cd ± 0.1	113g ± 1	0.135g ± 0.00
353W	12.7e ± 0.02	2,219c ± 18.4	0.9cde ± 0.1	113g ± 1	0.131g ± 0.00
BKH	13.7d ± 0.01	1,810d ± 12.7	0.8e ± 0.1	138f ± 1	0.161f ± 0.00
019	13.7d ± 0.02	1,753e ± 13.1	1.1cde ± 0.1	143e ± 1	0.169e ± 0.00
1601	14.4c ± 0.04	1,455g ± 16.0	1.3cde ± 0.1	172c ± 2	0.202c ± 0.00
5501	12.3f ± 0.03	1,600f ± 13.0	1.0cde ± 0.1	156d ± 1	0.183d ± 0.00

[a] Values ± standard error of the mean (SEM). Mean values of kernel characteristics from three moisture treatments. Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE II
Optimum Moisture Content (% ± SEM) for Maximum Popped Volume of Hybrids and Storage Temperatures[a]

	Storage Temperature (°C)			
Hybrid	30	1	–29	Mean
A358W	14.8 ± 0.1	14.4 ± 0.0	14.4 ± 0.1	14.5cd ± 0.1
353W	15.2 ± 0.0	15.0 ± 0.0	14.9 ± 0.1	15.0a ± 0.1
BKH	14.7 ± 0.1	14.3 ± 0.0	14.2 ± 0.0	14.4d ± 0.1
019	14.9 ± 0.1	14.5 ± 0.0	14.5 ± 0.1	14.6c ± 0.1
1601	14.7 ± 0.0	14.5 ± 0.1	14.5 ± 0.1	14.6c ± 0.0
5501	15.0 ± 0.1	14.8 ± 0.0	14.9 ± 0.1	14.9b ± 0.0
Mean	14.9c ± 0.1	14.6d ± 0.1	14.5d ± 0.1	

[a] Values ± standard error of the mean (SEM). Mean values followed by the same letter in the same column or in the same row are not significantly different ($P < 0.05$).

1 and –29°C, but OMC at 1 and –29°C storage were not significantly different each other. Unlike previous studies, OMC of popcorn hybrids had a much narrower range (14.4–15.0%). Eldredge and Thomas (1959) reported that OMC for MPV was 13.0–14.0%. Haugh et al (1976) reported that OMC was 12.5–15.5%; Maga and Blach (1992) reported 12.5–13.5%; Song and Eckhoff (1994) reported 12.9–13.6%.

The MPV of popcorn hybrids was affected by storage condition ($P = 0.0005$) and hybrids ($P = 0.0001$), where hybrid was a much more significant factor affecting MPV. Mean MPV of hybrid BKH over all storage conditions was the highest (42.8 cm^3/g), while that of the hybrid 5501 was the lowest (Table III). Mean MPV at 30°C storage was significantly higher than those at 1 and –29°C, however, mean MPV at 1 and –29°C were not significantly different each other. This opposed results reported by Maga and Blach (1992) and Lin and Anantheswaran (1988), where PV was higher after low temperature storage than after high temperature storage. The discrepancy with the previous studies may have resulted from the simple comparison of PV of the storage condition at one moisture content. In this study, the comparison was done with MPV. Lin and Anantheswaran (1988) compared PV of storage conditions only with 14% moisture-adjusted popcorn from one hybrid. Also, in the former studies, PV may have been compared at lower moisture content levels than OMC of hybrids, thus, the low temperature storage resulted in higher PV. OMC of the high temperature storage was higher than that of the low temperature storage as confirmed by the current study. Therefore, the experimental moisture contents in the studies by Lin and Anantheswaran (1988) and Maga and Blach (1992) may be closer to the OMC of low temperature storage, but far from the OMC of high temperature storage.

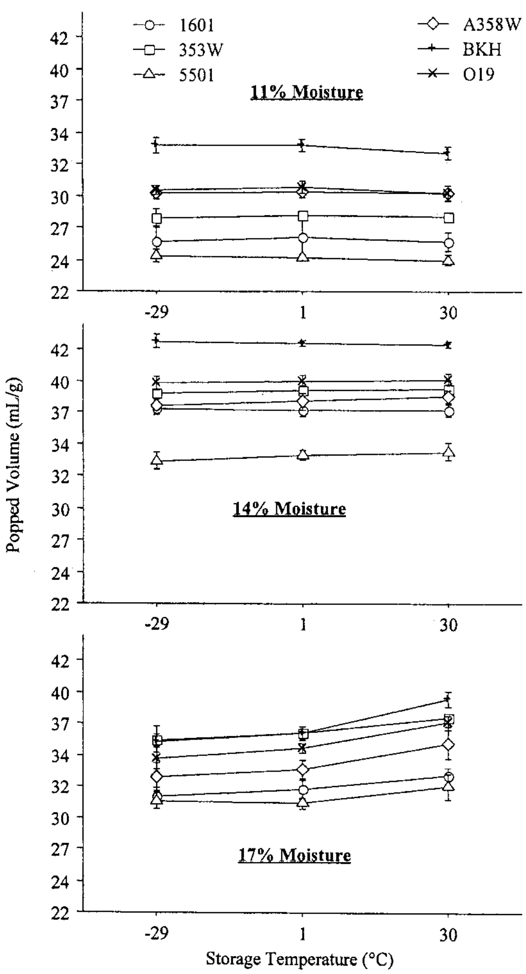

Fig. 1. Popped volume of moisture contents, hybrids and storage temperatures.

Unpopped Kernel Ratio (UPK)

As in the results reported by Maga and Blach (1992), the UPK of popcorn hybrids was significantly affected by the moisture, storage temperature, and hybrid. For most hybrids and storage temperatures, 14% moisture showed the lowest UPK. However, UPK of the 11 and 17% moisture levels were more or less dependent on hybrid and storage condition. Hybrid 5501 showed the highest mean UPK (6.7%), while hybrid BKH showed the lowest (1.5%).

TABLE III
Maximum Popped Volume (cm^3/g ± SEM) of Hybrids and Storage Temperatures[a]

	Storage Temperature (°C)			
Hybrid	30	1	–29	Mean
A358W	38.7 ± 0.2	38.0 ± 0.4	37.7 ± 0.2	38.1c ± 0.2
353W	39.8 ± 0.2	39.4 ± 0.1	39.1 ± 0.2	39.4b ± 0.1
BKH	42.8 ± 0.1	42.7 ± 0.1	42.7 ± 0.3	42.7a ± 0.1
019	40.2 ± 0.1	39.7 ± 0.2	39.5 ± 0.3	39.8b ± 0.1
1601	37.6 ± 0.3	37.4 ± 0.2	37.4 ± 0.2	37.5d ± 0.1
5501	34.6 ± 0.4	34.0 ± 0.2	33.6 ± 0.3	34.0e ± 0.2
Mean	38.9c ± 0.6	38.5d ± 0.6	38.3d ± 0.7	

[a] Values ± standard error of the mean (SEM). Mean values of kernel characteristics from three moisture treatments. Values followed by the same letter are not significantly different ($P < 0.05$).

TABLE IV
Minimum Unpopped Kernel Ratio (MUPK) and Optimum Moisture Content (OMC) for MUPK of Hybrids[a]

Hybrid	MUPK (% ± SEM)	OMC for MUPK (% ± SEM)
A358W	1.9f ± 0.1	13.8e ± 0.2
353W	1.2g ± 0.0	15.2c ± 0.1
BKH	1.3g ± 0.0	14.5d ± 0.3
019	3.1e ± 0.1	14.3d ± 0.1
1601	4.4d ± 0.2	14.4d ± 0.1
5501	5.1c ± 0.2	14.8cd ± 0.2

[a] Values ± standard error of the mean (SEM). Mean values from three storage conditions and moisture treatments. Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE V
Mean Popping Time (sec ± SEM) of Popcorn Hybrids and Storage Temperatures[a]

	Storage Temperature (°C)		
Hybrid	30	1	–29
A358W	84.7dBC ± 5.1	87.9dC ± 4.8	87.7dA ± 5.0
353W	86.8eB ± 5.9	91.7dAB ± 5.5	93.3dA ± 5.4
BKH	78.2eD ± 4.8	79.4dE ± 5.0	81.1dC ± 4.6
019	93.6dA ± 6.2	94.1dA ± 5.8	95.2dA ± 6.2
1601	86.9dB ± 5.6	89.8dBC ± 5.8	87.6dB ± 5.6
5501	83.3dC ± 5.5	82.9dD ± 5.0	85.1dB ± 5.2

[a] Values ± standard error of the mean (SEM). Mean values from three moisture treatments. Values in the same row with the same small letter or in the same column with the same capital letter are not significantly different ($P < 0.05$).

TABLE VI
Correlation Between Kernel Physical Properties and Popping Characteristics[a,b]

Trait	KVOL	USK	MPV	UPK
USK	0.30			
MPV	–0.19	–0.53*		
UPK	0.44	0.54*	–0.83***	
PT	–0.37	0.00	–0.57*	0.39

[a] KVOL = kernel volume, USK = unsound kernel ratio, MPV = maximum popped volume, UPK = unpopped kernel ratio, PT = popping time.
[b] * and *** = significant at $P < 0.05$ and 0.001.

Minimum Unpopped Kernel Ratio (MUPK) at OMC

Only hybrid significantly affected MUPK of popcorn. Hybrid 5501 showed the highest MUPK, while hybrid 353W showed the lowest (Table IV). Also, OMC for MUPK was significantly affected only by hybrid. OMC for MUPK of hybrid A358W was the lowest (13.8%), while that of hybrid 353W was the highest.

Lin and Anantheswaran (1988) reported that OMC for MPV was 12.5–13.5%, while OMC for MUPK was 10.0–10.9%. The present study revealed that OMC for MPV was 14.4–15.0% and OMC for MUPK was 13.8–15.2%. Mean OMC for MPV across hybrids and storage temperatures was 14.67% and mean OMC for MUPK was 14.48%. As in results by Lin and Anantheswaran (1988), OMC for MUPK was significantly lower than OMC for MPV by the paired *t*-test ($P = 0.0266$) using SAS StatView.

However, unlike results by Lin and Anantheswaran (1988), both OMC values were higher, and differences between OMC for MUPK and OMC for MPV were much smaller. In addition, OMC for MUPK was highly positively correlated with OMC for MPV ($R = 0.80$) by the Pearson's correlation coefficient test using SAS. Popcorn hybrids with higher OMC for MPV had higher OMC for MUPK.

Popping Time

Storage effect on popping time depended on popcorn hybrids (Table V). At all three storage conditions, popping time of hybrid 019 was the longest, while that of the hybrid BKH was the shortest. The 11% moisture treatment showed shorter popping time than did 14 and 17% moisture, and the 14% moisture showed shorter popping time than did 17%. As in the current study, Stewart (1923) reported that popcorn with a higher moisture content required longer popping time. Also, Huelsen and Bemis (1955) reported that popcorn with a low moisture content started to pop later and showed a shorter total popping period. In addition, start and end times of popcorn hybrids were different for moisture content, storage temperature, and hybrid (data not shown). Storage temperature was most important to start time, while moisture was most important to end time. Lower storage temperature resulted in later start time than higher storage temperature. Higher moisture resulted in later end time. The detailed results for start and end popping times of popcorn hybrids are available in the report by Park (1998).

Relationship Between Kernel Physical Characteristics and Popping Characteristics

Unlike the results reported by Lin and Anantheswaran (1988), Pordesimo et al (1990), and Song et al (1991), kernel volume (kernel size) was not correlated with any popping characteristics (Table VI). Lin and Anantheswaran (1988) reported that kernel size was positively correlated with PV but not correlated with UPK. Pordesimo et al (1990) and Song et al (1991) reported that PV of medium-sized kernels was the highest. However, as in this study, Dofing et al (1990) reported that kernel size was not a significant factor affecting PV. Unsound kernel ratio was negatively correlated with MPV and positively correlated with UPK. Pericarp participates directly in the popping action and appears to serve as a pressure vessel (Grinnell 1976). Pericarp damage and stress cracks may reduce popped volume of popcorn (Eldredge and Thomas 1959; White et al 1980; Hoseney et al 1983; Lin and Anantheswaran 1988). Thus, pericarp damage on unsound kernel resulted in lower PV and higher UPK. MPV was negatively correlated with UPK and popping time. The popcorn with shorter popping time gave higher MPV.

CONCLUSIONS

Storage conditions before popping was a very important factor affecting the OMC for MPV and popping start time. Popcorn kernels stored at low temperature needed less moisture for MPV. However, storage temperature did not significantly affect MUPK ($P = 0.27$) and OMC for MUPK ($P = 0.09$). MPV of popcorn stored at high temperature was higher. Also, correlation coefficients ascertained that kernel size was not correlated with MPV, UPK, or popping time.

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