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Popping Properties of Corn Grains of Two Different Varieties at Different Moistures

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ABSTRACT

In this study, the effects of moisture content and corn variety on the physicochemical properties of popcorn were investigated and modeled using response surface methodology. Each of the two corn varieties (Hybrid corn KSC 600 PC and American) was prepared with a range of moisture (six moisture levels ranging from 10 to 20%) and popped by a hot air popper. Variety and moisture content affected the density, air bubble diameter as determined from electron micrographs, textural hardness and color parameters. The lowest densities for American and hybrid corns were obtained at moisture contents of 14 and 18%, respectively. As water content deviated from the optimum levels the popcorn density significantly decreased. For both corn varieties, with increasing water content, the lightness of the samples increased while *b* (yellowness-blueness) values decreased. For American popcorn no significant impact of the moisture content on the hardness was observed, however in hybrid corn, hardness of popcorns significantly decreased with increasing water content, and the lowest density and hardness were observed at moisture content of 18%. Experimental models are presented for the prediction of density, color parameters, air bubble diameter and hardness of popcorns at different moisture contents for American and hybrid corns.

Keywords: Density, Moisture content, Popcorn, Texture.

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INTRODUCTION

Maize or corn (*Zea mays* L.) is the second largest crop produced in the world. Popcorn is one of the most favorite and popular snacks which is consumed widely worldwide. The history of popcorn goes back to many years ago (Hoseney, 1994; Eckhoff and Paulsen, 2003). Popcorn is a form of flint corn and differs from dent and other soft corns in two ways. The first is that it contains almost entirely hard starch. The second is that it has a very hard pericarp and outer layers of endosperm, which permits the internal pressure and temperature to raise high enough to pop upon heating (Cretors, 2001). Popping volume depends on many factors such as moisture content, genotype, physical properties of the kernel, popping method, popping temperature, harvesting and handling practices and grain physical damages. However, among all factors affecting expansion volume, moisture content is one of the most critical factors, because it affects the rate and extent of pressure built up in starch granules (Hoseney *et al*., 1983). To date, a considerable amount of research has been carried out in the area of moisture content and its effects on expansion volume. Studies have shown that maximum popping volume is produced at moistures ranging from 11.0 to 15.5% (Allred-Coyle *et al*., 2000; Metzger *et al*., 1989; Pajic, 1990; Shimoni *et al*., 2002; Song and Eckhoff, 1994). Popping volume of popcorn is affected by water content, and that popping volume increases with an increase in water content up to an optimal value, after which the volume decreases with any additional moisture (Shimoni *et al*., 2002; Wu and Schwartzberg, 1992). The optimum moisture content for maximum popping volume depends

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on the popcorn variety (Haught *et al*., 1976; Lin and Anantheswaran, 1988), popping procedures (Metzger *et al*., 1989), and kernel size (Song and Eckhoff, 1994). Oil popping results in a maximum volume at a moisture content of 13.54%, whereas air popping produces a maximum volume at a moisture content of 14.03% (Metzger *et al*., 1989). Popcorn genotype and kernel size significantly affect the popping volume and the number of unpopped (corn grains that do not expand during popping process) kernels (Song *et al*., 1991). Kernel genotype significantly affects the popping volume, sensory properties, physical and chemical properties of popcorn (Soylu, and Tekkanat, 2007). Texture of popcorn (crispiness and tenderness) is positively correlated with expansion volume (Rooney and Serna-Saldivar, 1987). Due to high growing demand for different varieties of popcorn snacks, maize grains are grown in new agricultural regions around the world to supply the raw material of popcorn industry. Moreover, new maize hybrids are crossed and produced by hybrid maize seed industry. Hybrid corn KSC 600 PC is a maize hybrid produced in Iran Centre for Plant Breeding and Genetics. In this study, the effect of moisture content on physicochemical properties of popcorns produced from corns of two genotypes (American and Hybrid corn KSC 600 PC) is investigated and compared. Materials and methods

MATERIALS AND METHODS

Two corn genotypes were used in this research. Hybrid corn KSC 600 PC was supplied by Iran Center for Plant Breeding and Genetics and American corn was purchased from the local market.

Sample Preparation

The kernels were equilibrated to five moisture levels (10, 12, 14, 16, 18, and 20%) by either drying at 60˚C in an air-assisted oven (Isuzu Seisakusho Ltd. Model KM23S, Tokyo, Japan) or water spraying followed by equilibration in closed jars at 4˚C for 50 hours before popping. Initial moisture content of American corn and Hybrid corn were 12 and 16%, respectively, as determined by AACC method (2000).

Chemical Composition

Chemical composition of the corn grains and the popped samples was determined according to the AACC methods (AACC, 2000).

Popping Method

Corn grains were popped using a hot-air popper (Hinari Domestic, Model No: PC330, UK, 1100-1200W, 230- 240V, 50Hz, Capacity: 1/2 Cup maximum) set at 180˚C.

Density Evaluation

Density and volume of popcorns were measured by rapeseed displacement method (Farahnaky and Majzoobi, 2008). A container with a known volume and weight was used. Some popcorn was placed in the container and the empty void was filled with rapeseeds. Knowing the volume of the container, the density of rapeseed and the weight of the popcorn, the volume and density of popcorn were then calculated.

Electron Micrographs

To study the microstructure of the popcorn samples, a scanning electron microscope (SEM) (Model 5526, Cambridge, UK) was used. The samples were prepared by slicing the corn grains or popped popcorn, using a sharp razor and sputter coated with gold. Each sample was then transferred to the microscope where it was observed at 20kV.

Measurement of Air Bubble Diameters

Captured electron micrographs were then analyzed using the image analyzing software, ImageJ 1.43r (Rasband, W. National institutes of health, USA) (Sandhu *et al.*, 2004; Parker *et al.*, 1999) and air bubble diameters were determined.

Texture Evaluation of Corn Grains and Popcorn Samples

Texture of popcorn samples was measured using a Texture Analyzer (TA-XT2i, Stable Micro Systems, Surry, UK) using puncture test (Test speed 1 mm s^{-1}, Pretest speed 1 mm s^{-1}, Post test speed 10 mm s^{-1}, Trigger Force 5 g, probe diameter 2 mm, penetration depth 4 mm) equipped with a 30 kg load cell (Bourne, 2002). The data were analyzed by the Exponent Lite software developed by the equipment manufacture and gradient of force-distance curve was taken as an indication of the hardness of the samples (Bourne, 2002).

Color Evaluation

Color values of popcorn samples were evaluated by measuring the *L*, *a* and *b* values using digital imaging followed by image analysis by Photoshop software 8 in the "Lab" mode (Afshari-Joybari and Farahnaky, 2011). A Fujifilm digital camera (A202, FinePix, China) installed at a 30 cm constant distance from the sample surface was used for taking digital images. The lamp and the camera were placed in a box (50×50×60 cm) with interior white walls. The angle between the axis of the camera lens and the sample surface was 90º. The angle between sample surface and light source was 45º. Illumination was achieved using a 40 Watt fluorescent light lamp (Natural Daylight, Cixing, China).

Data Modeling

Six popcorn samples with different moisture levels (10, 12, 14, 16, 18, and 20%) were produced and data were then analyzed. Software of Design-Expert 6.0.2: D-Optimal Response Surface mode was used in order to model and estimate any nonlinearity in the relationships between the parameters under study. The resultant data were analyzed using the Design-Expert 6.0.2 and the best models were obtained (Farahnaky and Hill 2007).

RESULTS AND DISCUSSION

Chemical Composition of Samples

Chemical composition of American corn and hybrid KS 600 corn are shown in Table 1. There are significant differences between the American and hybrid KS 600 in terms of lipid, moisture and total carbohydrae contents. These results are in agreement with the previous studies of Smith *et al.* (2004), who reported that the protein, lipid, ash, fiber and starch contents of corn kernels were 10, 3.5-4.5, 1.5-2, 1.5-2.1 and 65-70%, respectively. Park *et al.* (2000) reported 8.1-10.5, 3.8-4.6 and 61-67.9% for protein, lipid and starch contents, respectively. Percentage of corn chemical components in particular protein and lipid vary among different genotypes of corn.

Density of Popcorn

Significant effects of moisture content and

Table 1. Chemical composition (%) of American and hybrid corn KS 600 kernels [a].

	Lipid	Ash	Protein[b]	Moisture	Total carbohydrate
Hybrid	4.63^{a} ±0.3^{c}	1.94^{a} ±0.2	12.48^{a} ±0.5	16^{a} ±0.1	64.95^{a} ±0.9
American	2.95^{b} ±0.3	1.57^{a} ±0.1	11.41^{a} ±0.4	12^{b} ±0.1	72.07^{b} ±0.8

[a] Average±Standard deviation, [b] Protein factor= N×6.25, [c] Different letters in each column indicate statistically significant difference.

kernel genotype on popcorn density were observed (Figure 1). The lowest density and the maximum popping volume were obtained at the moisture contents of 14 and 18% for American and hybrid corn, respectively. The lowest density for the American popcorn was about 0.05 g cm^{-3} while this value for the hybrid genotype was about 0.07 g cm^{-3}. As moisture content deviated from the optimum moisture level, the popcorn density increased significantly. The results for American corn were in agreement with the previous studies of Pajic (1990) and Metzger *et al.* (1989), who reported that the optimum moisture content for maximum expansion volume was 14%. At moisture contents lower than 18%, the density of popcorn produced from the hybrid corn was much greater than that of American corn.

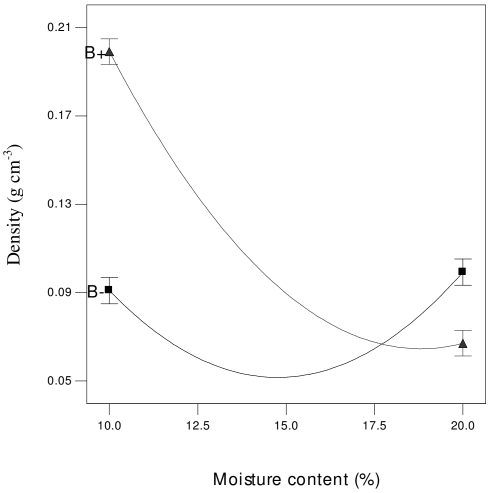

Figure 1. Effect of Moisture content and corn grain genotype on density of the popcorn obtained by experimental modeling from the Design Expert. (Squares B-: American grain, Triangles B+: Hybrid grain)

In order to calculate the density of popcorns from American or hybrid corn grains with different moisture contents, quadratic models were obtained using response surface methodology [Equations (1) and (2), Table 2] with regression coefficient of 0.90. The effect of grain moisture on the density of hybrid KS 600 popcorns was much greater than that on the American popcorns. Popcorn volume may be regarded as the result of two mechanisms, expansion and shrinkage of popped corns. Decrease in the popping volume beyond the critical moisture content can be explained by the rupture of the pericarp at a temperature when the pressure inside the kernel is too low. As moisture content of kernel increases, the melting temperature of the pericarp decreases, thus when the water

Table 2. Equations obtained in the D-Optimal mode of Response Surface Methodology (given by Design Expert software) in terms of actual factors: effect of grain moisture content on each measured parameter. Regression coefficients between the actual and predicted values are given (R^2).

Parameter	Grain type	Equations in terms of actual factors	R^2 coefficient of Determination
Density (g cm^{-3})	American-Equation (1)	$0.430-0.051\times MC\ (\%)+1.736E-003\times MC^{a}\ (\%)^{2}$	0.90
	Hybrid-Equation (2)	$0.678-0.065\times MC(\%)+1.736E-003\times MC\ (\%)^{2}$	0.90
Bubble diameter (µm)	American-Equation (3)	$32.109+2.999\times MC\ (\%)-0.101\times MC\ (\%)^{2}$	0.70
	Hybrid-Equation (4)	$6.420+4.146\times MC\ (\%)\ -0.101\times MC\ (\%)^{2}$	0.70
Lightness (*L* value)	American-Equation (5)	$+85.111+0.720\times MC\ (\%)-0.019\times MC\ (\%)^{2}$	0.88
	Hybrid-Equation (6)	$+65.106+2.650\times MC\ (\%)-0.0682\times MC\ (\%)^{2}$	0.88
b value	American-Equation (7)	$+25.164-0.520\times MC\ (\%)$	0.64
	Hybrid-Equation (8)	$+33.424\ -0.707\times MC\ (\%)$	0.64
Texture: Gradient (N mm^{-1})	American-Equation (9)	$+1.516+0.285\times MC\ (\%)-0.012\times MC\ (\%)^{2}$	0.75
	Hybrid-Equation (10)	$+40.792-4.147\times MC\ (\%)+0.112\times MC\ (\%)^{2}$	0.75

[a] Moisture Content (%).

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content is high, the pressure in the kernel at popping moment is lower, causing less expansion and lower final popped volume (Shimoni *et al*., 2002). Volume decrease at high moisture levels may also be due to the shrinkage of the popped samples in the presence of extra water pushing the system into the rubbery (soft) state. At low moisture contents, the pressure inside the kernel is too low and this pressure is not sufficient to break the pericarp well resulting in decreased final popped volume (Hoseney, 1994). The density data clearly indicated that in different maize genotypes the optimum moisture level could be rather different.

Electron Microscopy Images of Corn Grains and Popcorns

The SEM images (Figure 2) show opaque and translucent parts of cross section of American and hybrid KS 600. It is revealed that in the opaque parts of both corn grains starch granules of about 15 µm in diameter are spread and no polygonal structural units are observed. Some free volume is also present between the starch granules. On the other hand, on SEM images of translucent parts of both corn genotypes polygonal (pentagonal or hexagonal) unit structures are observed. These polygonal structures were closely packed with no obvious free volume between them. Similar findings were

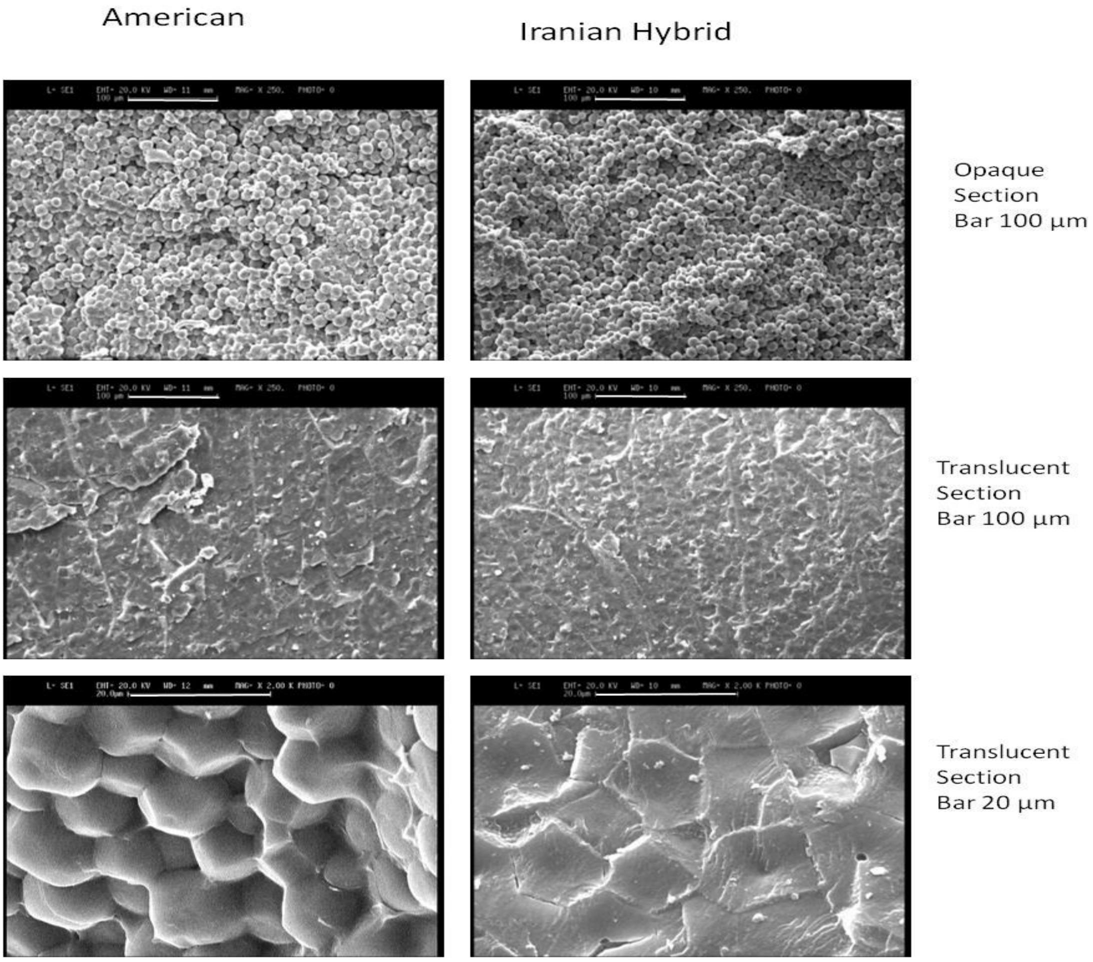

Figure 2. Electron microscopy images of opaque and translucent parts of cross section of American and Iranian hybrid corn grains.

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reported by Reeve and Walker (1969).

In Figure 3, SEM images of popcorn samples of American and hybrid KS 600 as a function of grain moisture (10-20%) are presented. Three dimensional structures consisting of polygonal interconnected open units for all popcorn samples are observed. It seems that change of grain moisture affects the size of air bubbles generated during popping. For hybrid KS 600 the presence of highest moisture (i.e. 20%) generated the largest air bubble with thin walls, while for the American corn grains the largest air bubbles are seen at lower moisture level of about 14%. Thin walls of popcorn networks seem to be responsible for the soft and crispy texture of this product.

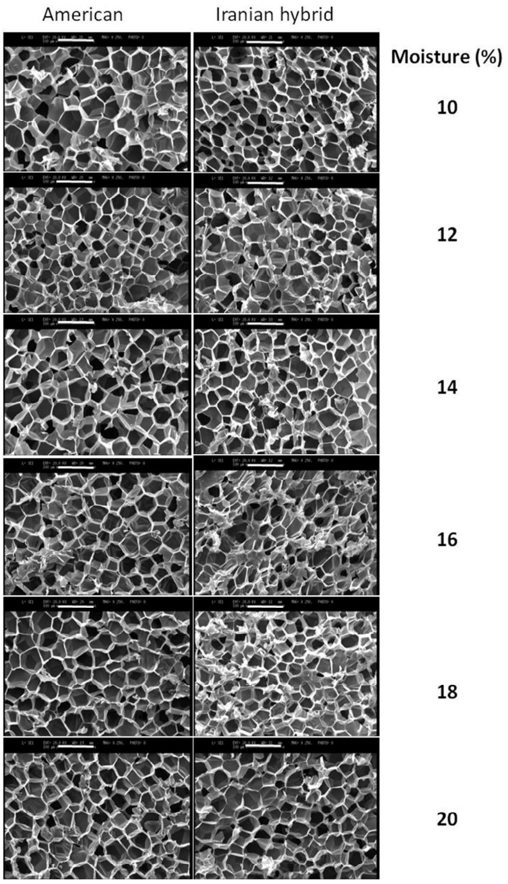

Figure 3. Electron microscopy images of cross section of popcorn produced from American and Iranian hybrid corn grains at different grain moisture levels.

Air Bubble Diameter

The air bubble diameter from SEM images of popcorn samples as a function of moisture content and corn grain genotype were determined and the data were modeled using response surface methodology (Figure 4). The air bubble diameter of popcorns from hybrid KS 600 increased from about 37 to 48 μm with increase of grain moisture from 10 to 20% [Equation (3), Table 2]. The air bubble size of American popcorns changed from 52 to 55 μm. In this case the maximum air bubble diameter was observed at grain moisture of 14.5%. The effect of grain moisture on air bubble diameter was more profound for hybrid KS 600 popcorns (Figure 4). These results were similar to the changes of density and popping volume. A quadratic experimental model [Equations (3) and (4)] with R^2 of 0.704 was obtained for the calculation of popcorn air bubble diameters of popped grains produced at different moisture contents and popping temperatures.

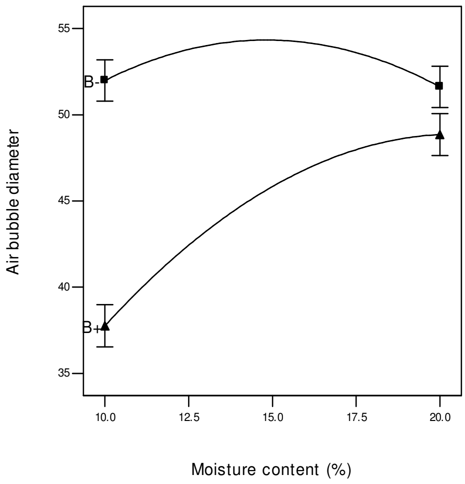

Figure 4. Effect of moisture content and corn grain genotype on air bubble diameter (μm) of the popcorns obtained by experimental modeling from the Design Expert. (SquaresB-: American grain, Triangles B+: Hybrid grain)

Color

For both corn genotypes, *L* values of popcorns increased with increasing moisture content (Figure 5). In hybrid popcorn *L* value range change (84.5-90) was higher than American popcorn and this may be explained by higher changes of density range in hybrid popcorn. *L* values of American popcorn (90-92) were higher than those of hybrid popcorn.

Quadratic equations [Equations (5) and (6)] obtained from the Design Expert for *L* with R^2 of 0.88, can be used for the prediction of this parameter as the grain moisture is altered. For both corn genotypes, with increasing moisture content of corn grains, *b* value or yellowness decreased [Figure 6, linear Equations (7) and (8)]. The slopes of *b* color value versus grain moisture were 0.520 and 0.707 for American and hybrid corns [Equations (7) and (8)], respectively. In American popcorn, *b* values were lower than that of hybrid popcorn, which might be explained by lower density of the American popcorn. Color of starch based toasted snacks with volume change has been studied by Farahnaky *et al.* (2009a). They reported that color of puffed samples is affected largely by the volume and material density. Higher volumes will result in the inclusion of more air bubbles and reducing the percentage of sample surface covered by dry substance. This is the case for popcorns produced from American and hybrid corn grains at different moisture levels. Popping temperature also could have significant effects on popcorn color, the higher the popping temperature, the greater the total color and the lower the lightness.

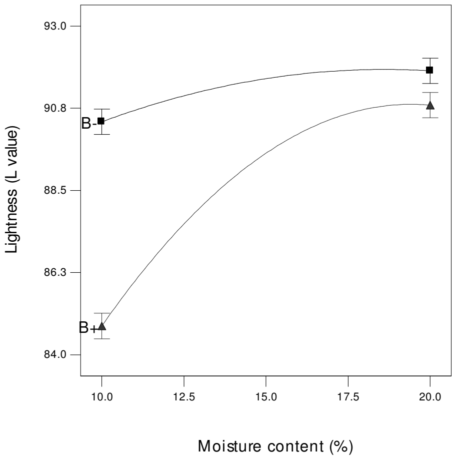

Figure 5. Effect of moisture content and corn grain genotype on the lightness of the popcorn obtained by experimental modeling from the Design Expert. (Squares B- : American grain, Triangles B+: Hybrid grain)

Texture

Texture changes of American popcorn were much limited compared to the hybrid popcorn (Figure 7). Changing moisture content of American grains from 10 to 20% caused a slight but significant decrease in the slope of force-deformation of textural tests. However, moisture change of hybrid corns from 10 to 20% reduced the gradient from about 11 to 3 (N mm^{-1}). This may be expalined by higher changes of popcorn density range for the hybrid popcorn than

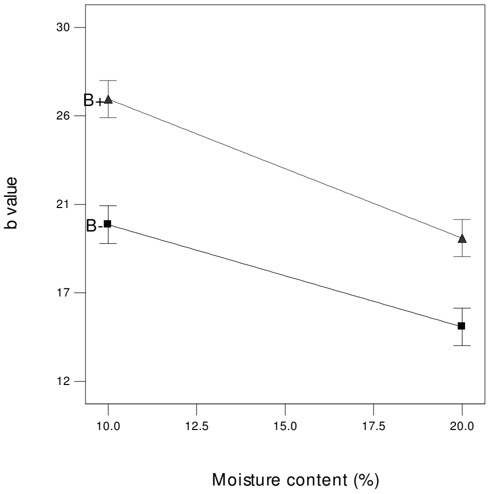

Figure 6. Effect of moisture content and corn grain genotype on the b value of the popcorns obtained by experimental modeling from the Design Expert. (Squares B-: American grain, Triangles B+ : Hybrid grain).

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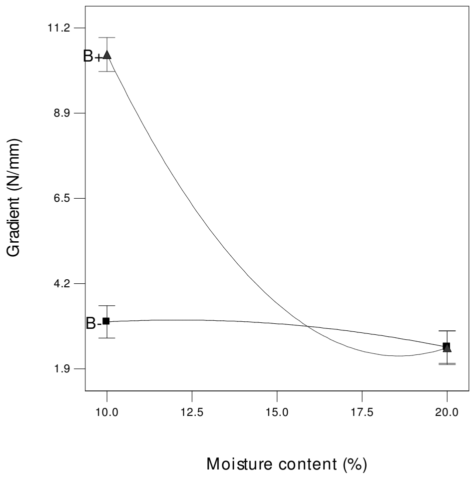

Figure 7. Effect of moisture content and corn grain genotype on textural hardness (gradient of Force –Deformation curve) of the popcorn obtained by experimental modeling from the Design Expert. (Squares B-: American grain, Triangles B+: Hybrid grain)

the American popcorn. These results were similar to findings of Rooney and Serna-Saldivar (1987). For hybrid popcorn the lowest density and hardness were observed at the moisture content of 18%. Expeimental models [Equations (9) and (10)] with the regression coefficient of 0.75 are presented for the estimation of textural hardness of popcorns. Generally, the reproducibility of texture tests of glassy materials is low and rather low regression coefficient of 0.75 obtained for popcorn is likely to be due to this reason.

CONCLUSIONS

The effect of moisture content of corn kernels on physichochemical properties of popcron was investigated. Significant effects of moisture level on the density, SEM images, bubble diameter, colorimetric parameters and textural hardness of popcorns were found. The lowest density and maximum popping volume were obtained at moisture contents of 14 and 18% for American and hybrid KS 600 corns, respectively. Overall, the popcorn produced from the American genotype had a lower density over the moisture range under study, and hybrid KS 600 corn was able to compete only at moisture levels above 18%. Physical state of starch component can have important effects on popping properties (Farahnaky *et al.,* 2009b). Hybrid KS 600 can be used for popcorn production if production parameters such as moisture and process temperature are adequately monitored and controlled.

According to the findings of this study it is concluded that, i. corn grain conditioning to regulate grain moisture (to reduce or increase moisture level, depending on the initial grain moisture) is a must in unit operation of popcorn production line and ii. the optimum moisture of different corn genotypes can be rather different with great impacts on quality attributes of the final popcorns.

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خواص انبساطی دانه دو واریته ذرت در رطوبت های مختلف

ع. فرحناکی، م. علی پور، و م. مجذوبی

چکیده

در این تحقیق با استفاده از روش سطح پاسخ تاثیر میزان رطوبت و نوع واریته ذرت روی ویژگی‌های فیزیکوشیمیایی پاپ کورن‌های تولیدی بررسی و مدل گردید. از هر یک از واریته‌های ذرت آمریکایی و هیبرید ایرانی (KSC 600 PC) در دامنه رطوبتی ۱۰ تا ۲۰ درصد (۶ سطح) با استفاده از هوای داغ پاپ کورن تهیه گردید. واریته و میزان رطوبت روی دانسیته پاپ کورن، قطر حباب‌های هوا (اندازه گیری شده با تصاویر میکروسکوپ الکترونی)، سفتی بافت و پارامترهای رنگی موثر بود. کمترین دانسیته پاپ کورن برای هر یک از واریته‌های ذرت آمریکایی و هیبربد ایرانی (KSC 600 PC) به ترتیب در رطوبت ۱۴ و ۱۸٪ به دست آمد. در هر دو واریته با کاهش یا افزایش رطوبت دانه ذرت از میزان اپتیمم، دانسیته پاپ کورن به طور معنی داری افزایش یافت. در هر دو واریته با افزایش رطوبت دانه ذرت روشنایی نمونه‌ها کاهش و پارامتر رنگی b کاهش یافت. در مورد واریته آمریکایی میزان رطوبت دانه ذرت تاثیر معنی داری روی سفتی پاپ کورن تولیدی نداشت، اما در مورد هیبربد ایرانی افزایش رطوبت باعث کاهش سفتی گردید و حداکثر آن در ۱۸٪ مشاهده شد. مدل‌های تجربی برای پیشگویی و تخمین دانسیته، رنگ، قطر حباب های هوا و سفتی پاپ کورن در رطوبت های مختلف ارایه شدند.

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