Article

Standardization of the busted method for the experimental evaluation of popcorn

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Abstract

Mexico is the center of origin of the corn and, therefore, has the vital importance of conserving the germplasm and maintaining the genetic diversity of this crop in the presence of pests and diseases, or of other types of natural phenomena that end with the dominant varieties that they are usually planted in other countries. In Mexico, a great diversity of varieties of this cereal is sown. The popcorn maize is listed as the oldest and is currently in danger of extinction. Popcorn has high fiber, vitamins, minerals, proteins and antioxidants, also help lower cholesterol and control diabetes. Therefore, it is very important to establish a standard busted protocol of popcorn, which allows the evaluation of the genotypes in a consistent manner in the different breeding programs. In this work, the influence of genotype, sample size, time of exposure to microwaves, and moisture of the grain on the busted characteristics of two popcorn maize genotypes, one commercial yellow and one experimental hybrid was evaluated. Significant differences were found in the variables evaluated. The commercial genotype obtained the highest volume of expansion (27.11 cm^3), using 2:45 min in the microwave, and with a humidity of 12%; while in the hybrid genotype it is recommended to use 2:30 min and a humidity of 13%, to obtain the greatest volume of expansion (9.48 cm^3).

Keywords: *Zea mays*, expansion volume, moisture content.

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Introduction

Corn has played a key role in the development of humanity, it was the sustenance of great cultures, such as Olmeca, Tolteca, Maya, Teotihuacana, Zapotec, among others (Vázquez *et al*., 2011). The importance of this cereal goes beyond food because it is part of religious ceremonies, of thought, literature and poetry. It has a long list of centuries-old family dynamics of sowing, harvesting and food preparation, to name a few (De la O *et al*., 2015).

Currently the industry uses corn as fodder in feeding large herds and in obtaining chemical compounds that are marketed as food, medicine and cosmetics, corn syrup, corn sugar, dextrose, corn starch, oils, dyes, alcohol and countless uses (De la O *et al*., 2015).

The ancient indigenous maize races originated in Mexico from their wild relative, the teosinte (*Zea mays* ssp. *parviglumis* IItis & Doebley) and this group is characterized by being a palomero (Romero *et al*., 2006). Romero *et al*. (2006) mention that the popcorn maize race has bursting subraces distributed in the country, to mention a few; the sub-race palomero of Chihuahua, palomero of Jalisco and palomero Poblano.

The corn presents a great diversity of shapes, sizes, colors, textures and adaptations to different environments, although all the maizes belong to the same species, the types or races that differentiate them correspond to an artificial classification, not botanical. There is also a series of genes that modify the chemical composition of the endosperm. The chemical composition of the endosperm configures the physical characteristics that allow to establish enough clear commercial types. From the commercial point of view, the maizes are classified according to the hardness of the grain: jagged, hard, floury, sweet, palomero, ornamental and maize for special uses (ILSI, 2006).

Popcorn maize is the name used for corn that has the ability to pop to produce popcorn or rosettes of corn. Popcorn maize, also known as 'rosero' corn, 'burner' or 'pots busting' has small grains, its endosperm is very hard and its pericarp is thick (Paliwal *et al*., 2001). The name comes from the fact that it explodes when it turns the water of the interior into steam (Soylu and Tekkanat, 2007). Popcorn is grown for human consumption as corn or popcorn rosettes, cookies, sweets, pinole and can also be used to make tortillas (Fernández *et al*., 2013). On the other hand, Amaral *et al*. (2010), mention that the programs of phytogenetics of popcorn are aimed at developing varieties with high volumes of expansion and grain yield. However, it is not easy to obtain varieties with these characteristics, since several authors have pointed out that there is a negative correlation between yield and expansion capacity and its quality (Pereira and Amaral, 2001, Daros *et al*., 2004; Vieira *et al*., 2009).

The popcorn maize ability to burst is conditioned by several factors, such as: genotype, grain size and volume, moisture content of the grain, weight of 1 000 seeds, drying procedure, amount of damage in the pericarp and endosperm, among others (Allred-Coyle *et al*., 2000; Karababa, 2006; Mishra *et al*., 2014). In addition, parameters that include flavor, texture, color and shape are also important to obtain good quality popcorn (Sweley *et al*., 2013). Since, the greater the volume of the grain, it will provide better texture once it has burst. Grains burst when heated around 177 °C (Pajic, 2007).

The standard NMX-FF-034/2-SCFI-2003 mentions that the classification of maize can be done with different moisture levels; however, it is considered that the adequate moisture content to allow handling, conservation and storage is 14%. The greater influence of moisture and time of busted could be related to the composition of the pericarp (hemicellulose, cellulose and lignin), which fulfills the function of preventing moisture from escaping from the grain, thus achieving a vapor pressure increase to such a degree that it allows the busted for the formation of the rosette or popcorn.

The palomero Toluqueño race is commonly used in the Mesa Central. Because this race of corn is grown to a large extent in the Toluca Valley, it was given the name of palomero Toluqueño (Gamez *et al*., 2014). The use of conventional varieties of popcorn maize such as Toluqueño may be limited in some regions, since only plantations above 2 000 meters above sea level have been located (Romero *et al*., 2006).

There are several factors for which the pigeon pea are of great importance: a) they are cataloged from the oldest ones, because one of the first ways in which the consumption of corn began was to burst their grains in the heat of the fire; b) popcorn is a 100% Mexican food; c) at present, the Mexican popcorn maize are in serious danger of extinction, due to the fact that there are few farmers who grow popcorn in our country; d) the SIAP-SAGARPA (2017), published that Mexico has to import approximately 80 000 tons of popcorn from countries such as the United States of America and Argentina, this causes the enormous need to promote national programs to perform the rescue of this crop; e) popcorn contains very high levels of polyphenols, which are antioxidants that prevent cell damage and can help fight cardiovascular diseases and cancer problems; and f) they have high fiber content, vitamin B complex, vitamin E, provide minerals and proteins, lower cholesterol and help control diabetes (Arendt and Zannini, 2013, Paraginski *et al*., 2016).

Due to the great importance of popcorn maize in our country, the objectives in the present study were: a) to determine the causal relationship between the moisture content of the seed of popcorn maize and its surrounding atmosphere modified by different concentrations of saline solutions and b) establish a standard popcorn busted protocol, which allows the evaluation of the genotypes in a consistent manner in the different breeding programs, optimizing the expansion of the grain by manipulating the main factors that affect the bursting of it.

Materials and methods

Genetic material

Two genotypes of popcorn maize, one commercial yellow of the North American Yellow Pearl race and one experimental hybrid were used as a result of a cross between a line of North American Yellow Pearl by a line of a population of the native race palomero Toluqueño, resulting in the next genealogy: NAYPP-II × MEX5-77 (Figure 1).

Figure 1. On the left, the genotype NAYPP-II × MEX5-77, on the right commercial popcorn maize of the North American Yellow Pearl race.

Humidity balance of the seed under modified atmospheres with saline solutions of different concentration

In order to know the concentration of sodium chloride (common salt), to be used to create an atmosphere for the seed to enter hygroscopic equilibrium with the surrounding environment in order to reach the desired moisture content, a test was carried out, based on the proposal of Brenes (2007), using solutions of different concentrations of common salt to modify the surrounding atmosphere, taking as a base the concentration of 175 g of sodium chloride dissolved in one liter of water (Table 1), under the premise that a higher salt concentration would generate a low relative humidity, placing 1 kg of grain in storage in blanket bags in hermetically sealed containers for 7 days. A wooden structure with wire mesh was introduced into the plastic containers above the saline solution, keeping the sample out of contact with the solution; fans were placed to homogenize the environment and a HOBO data recorder was placed inside each container to monitor the relative humidity and temperature at regular intervals. The assembly described above is shown in Figure 2.

Table 1. Induction of different relative humidity in popcorn maize through atmospheres modified with common salt.

Ambient	Concentration (g NaCl L^{-1} of water)
1	186.1
2	238
3	292.7

Figure 2. Airtight structure to generate the modified atmospheres and obtain different equilibrium humidities in the popcorn grain.

The moisture content of the grain was determined under the different atmospheres modified using the oven drying method at 103 °C, for 17 h according to the protocols described by the ISTA (1996) in four repetitions per treatment.

Variation factors used to evaluate the busted method in popcorn

For the busted tests, a Daewoo brand microwave oven, Model KOR-164H with the specifications indicated in Table 2 was used, adjusting the oven power to 70%.

Table 2. Specifications of the microwave oven used for the busted tests.

Microwave Daewoo KOR-164H		Specifications
Power supply		127 V~/60Hz. Simple phase with earth
Parameters	Consumption	1 400 W
	Microwave output power	1 000 W
	Microwave frequency	2 450 MHz
External dimensions (width × height × depth)		589 × 339 × 486 mm
Dimensions of the cavity (width × height × depth)		399 × 263 × 426 mm
Net weight		Approximately 18.5 kg
Chronometer		99 min 99 s
Power levels		10 levels

Using a microwave oven with the specifications described above, the influence of the following variation factors on the busted characteristics was evaluated.

Genotypes: North American Yellow Pearl and NAYPP-II × MEX5-77.
Time of exposure to microwaves: times of 2:15, 2:30, 2:45 and 3:00 min was evaluated.

Grain moisture: grains with different moisture contents generated by modified atmospheres were used (12, 13, 14 and 15%).
Sample size: samples of corn weighing 20, 30 and 40 g were taken.

With the study factors, 96 treatments were generated, which were analyzed under a completely randomized experimental design with a factorial arrangement of 2 × 4 × 4 × 3, with 4 repetitions.

The statistical analysis was carried out with the statistical package SAS (Statistical Analysis System) version 9.0 SAS (2002), by means of a factor variance analysis ($p \leq 0.05$) and Tukey's mean comparison test ($p \leq 0.05$; Steel and Torrie, 1996).

The response variables that were evaluated in the genotypes North American Yellow Pearl and NAYPP-II × MEX5-77 were: volume of expansion in cm^3 (VE); type of rosette (TR), where the value of 1 corresponds to the type 'butterfly' and the value of 5 corresponds to the type 'fungus'; pulverized pericarp (P), where the value of 1 corresponds to a completely pulverized pericarp and percentage of non-burst grains (GNR).

Results and discussion

Causality relationship between the moisture content of the seed of popcorn maize and its surrounding modified atmosphere

With the results obtained from the different concentrations of common salt that were used in this study, to modify the surrounding atmosphere; a regression equation was generated and a curve was constructed where the different salt concentrations and their corresponding moisture contents of the grain are represented in a range between 10.5 and 16.5% (Figure 3).

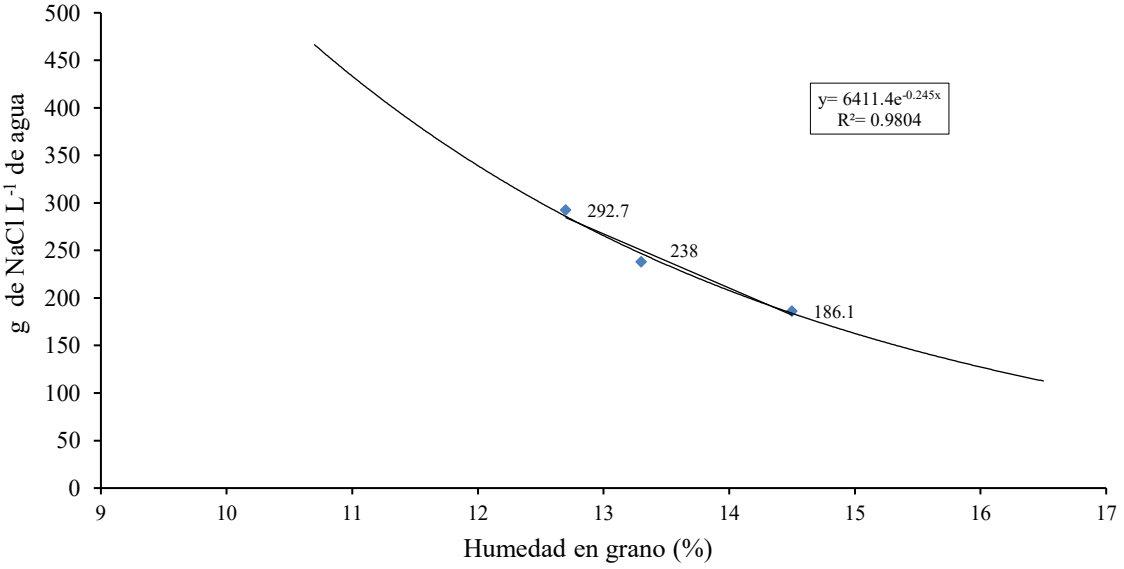

Figure 3. Curve for the percentage of moisture in grain depending on different salt concentrations.

The moisture content of the seed and its physiological quality are jointly influenced by the species and the warehouse environment (Brenes, 2007). The humidity of the seed increases significantly if the storage environment is warm and humid, which is why, at a higher concentration of salt used in this experiment, it generated a lower relative humidity and, therefore, a lower equilibrium moisture content in the seed.

In Figure 3 it can be seen that using a concentration of 186.1 g of NaCl L^{-1} of water, a moisture content of 14.5% of the grain was generated, the concentration of 238 g of NaCl produced a moisture content of 13.3%, while the concentration of 292.7 g of NaCl generated a grain moisture of 12.7%.

Genotypes

In the Table 3 shows the means of the variables evaluated by genotype, where it can be seen that the commercial genotype of the North American Yellow Pearl race showed a greater volume of expansion (23.15 cm^3) and a lower percentage of non-burst grains (40%), which demonstrates, on the one hand, the long history of genetic improvement in popcorn maize in North America, as mentioned by Ziegler (2003) and, on the other hand, the lack of attention in the popcorn maize races native to Mexico.

Table 3. Comparison of means by genotype for the response variables of popcorn maize.

Genotype	VE	GNR	TR	P
Commercial	23.15 a*	40.14 b	2.42 b	2.85 b
Hybrid	9.2 b	57.24 a	3.45 a	4.96 a

VE= expansion volume in cm^3; GNR= percentage of unprocessed grain; TR= type of rosette; P= pulverized pericarp. *= means with the same letter in the columns are statistically equal (Tukey, α= 0.05).

Regarding the type of rosette, the commercial genotype showed a popcorn shape that approximates the 'butterfly' type, while the hybrid presented a form that approximates the type 'fungus' as shown in Figure 4. And in the variable pericarp sprayed, the commercial genotype exhibited a pericarp that fragmented, while the hybrid presented a pericarp whole and stuck to the popcorn.

Figure 4. Rosette shape obtained in the busted tests. a) rosettes of experimental hybrid corn and b) rosettes of commercial corn of the North American Yellow Pearl race.

The importance of the genotype in the VE and in the GNR is widely known and mentioned by several authors (Gökmen, 2004; Soylu and Tekkanat, 2007; Ertaş *et al*., 2009). These results coincide with those previously published by Gökmen (2004), where it mentions that commercial varieties of popcorn maize produce a higher VE and lower GNR, than the creole varieties; and that this may be due to the fact that the landraces have large grains but they are not uniform.

Exposure time to microwaves

The comparison of means for the times of exposure to microwaves is presented in Table 4. In which it is observed that as the time increases, the volume of expansion increases and the percentage of non-burst grain decreases.

Table 4. Comparison of means in the time factor of exposure to microwaves for the evaluated variables of popcorn maize.

Time (min)	VE	GNR	TR	P
2:15	15.43 b*	54.06 a	2.94 b	3.95 a
2:30	15.28 b	53.54 a	2.9 c	3.89 c
2:45	16.82 a	44.15 b	2.97 a	3.88 c
3:00	17.2 a	43.01 b	2.94 b	3.92 b

VE= expansion volume in cm^3; GNR= percentage of unprocessed grain; TR= type of rosette; P= pulverized pericarp. *= means with the same letter in the columns are statistically equal (Tukey, α= 0.05).

In this study, it is important to point out that when the time of 3:00 min was used in the microwave, there were burns in the popcorn, such as those observed in Figure 5. Therefore, it is not advisable to use this time exposition.

Figure 5. Popcorn produced at a time of exposure to microwaves at 3:00 min.

There are very few studies where different exposure times to microwaves are tested. For its part, Gökmen (2004) evaluated the VE and GNR of different popcorn maize genotypes using a microwave of 230 V and 1200 W and used between 2.5 and 3 min of exposure to microwaves.

Grain humidity

In Table 5 it can be seen that a greater volume of expansion is obtained at a moisture 12% in grain and with that same humidity the lowest percentage of non-burst grain was shown. Most authors agree that the range of 11% to 15.5% moisture in the grain produces the greatest volume of expansion (Allred-Coyle *et al*., 2000; Shimoni *et al*., 2002; Gökmen 2004; Ertaş *et al*., 2009); however, the optimum content depends on the variety of corn, the method of busted and the size of the grain (Vázquez *et al*., 2011).

Table 5. Comparison of means in the grain moisture factor for the evaluated variables of popcorn maize.

Humidity (%)	VE	GNR	TR	P
12	16.62 a*	47.04 b	2.97 c	3.78 c
13	15.95 b	47.28 b	3.16 a	4 a
14	16.2 ab	51.32 a	3.05 b	3.8 b
15	15.97 b	49.12 ba	2.56 d	4 a

VE= expansion volume in cm^3; GNR= percentage of unprocessed grain; TR= type of rosette; P= pulverized pericarp; *= means with the same letter in the columns are statistically equal (Tukey, α= 0.05).

Sample size

In the comparison of means by sample size (Table 6), it can be perceived that the greater the sample size, the greater the percentage of non-burst grains, and presents a type of rosette that is closer to the 'butterfly' type.

Table 6. Comparison of means by sample size for the evaluated variables of popcorn maize.

Sample (g)	GNR	TR	P
20	45.58 b*	3.01 a	3.98 a
30	46.62 b	2.96 b	2.83 c
40	53.86 a	2.84 c	3.91 b

GNR= percentage of grain not burst; TR= type of rosette; P= pulverized pericarp; *= means with the same letter in the columns are statistically equal (Tukey, α= 0.05).

Considering that the primary objective of the study is the standardization of a busted method to optimize grain expansion by manipulating the main factors such as moisture in grain, time of exposure to microwaves, sample size and genotype, which affect the bursting of the same, it is necessary to take into account the individual observations resulting from the combinations of the different levels and factors involved; thus, in Tables 7 and 8, the comparison of the means of expansion volume of popcorn maize is presented, simultaneously considering the variation factors: genotype∗humidity∗time, using a standard sample size of 30 g.

Table 7. Comparison of means of expansion volume of corn (cm^3), using a sample size of 30 g in the commercial genotype.

Humidity (%)	Time (min)			
	2:15	2:30	2:45	3:00
12	24.12	23.96	27.11	25.96
13	22.45	23.47	25.47	26.62
14	24.10	22.77	24.79	28.42
15	21.29	21.95	26.11	24.78

Table 8. Comparison of means of expansion volume of corn (cm^3), using a sample size of 30 g in the hybrid genotype.

Humidity (%)	Time (min)			
	2:15	2:30	2:45	3:00
12	8.97	9.31	9.14	8.81
13	8.65	9.48	8.98	8.65
14	8.64	8.12	8.64	8.29
15	8.98	9.15	8.65	8.65

Analyzing the information in Tables 7 and 8, it is considered convenient to provide specific recommendations for each genotype, so it is considered that the best combination to obtain a greater expansion volume in the commercial genotype is exposing the popcorn maize to 2:45 min in the microwave and containing a humidity of 12%, considering a sample size of 30 g. And for the hybrid genotype, the best results were observed, when using the time of 2:30 min, with a humidity of 13%, considering the same sample size.

Conclusions

In the causal relationship between the moisture content of the seed of popcorn maize and its modified surrounding atmosphere, a moisture content of 12.7% was obtained when the highest concentration of NaCl L^{-1} was used in this study (292.7 g).

The commercial genotype of the North American Yellow Pearl race showed a greater volume of expansion, a popcorn shape that is closer to the butterfly type and a lower percentage of non-burst grain, compared to the experimental hybrid evaluated.

The highest volume of expansion in the commercial genotype was obtained using 2:45 min in the microwave, and with a humidity of 12%, while in the hybrid genotype it is recommended to use 2:30 min and a humidity 13%, to obtain the highest volume, taking into account a sample of 30 g.

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