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Investigation note

Hectoliter weight and seed weight predict popping volume in amaranth

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Abstract

Studies associated with the popping volume of amaranth (*Amaranthus hypochondriacus* L.) are practically nonexistent. The objective was to evaluate the relationship between characteristics of plant and raw grain with the popping volume of the popped grain. Between 2014 and 2015 2018-2019, five trials were established in Puebla, Mexico to evaluate the varieties Nutrisol, Revancha, Gabriela, Laura, Diego, Areli and PQ2 and three local populations. Characteristics of plant, raw and popped grain were measured. Positive and statistically significant (*p*# 0.01) correlations were observed between popping volume (PPVL) with hectoliter weight (HLW) (r= 0.56**) and weight of one thousand seeds (WTS) (r= 0.3**). It was also found that WTS and geometric seed diameter positively correlated with popped grain volume with size of 2.38 and 2 mm. Therefore, HLW and WTS could be used to help predict the behavior of popping volume in amaranth genotypes.

Keywords:

Amaranthus hypochondriacus, expansion volume, grain weight, hectoliter weight.

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Amaranth in Mexico is consumed mainly as expanded or popped grains (Escobedo-López *et al*., 2012). Popping is the increase in the volume of the grain when subjected to high temperatures (Castro-Giráldez *et al*., 2012), which gives it better flavor, color, aroma and increases the quality of the protein (Morales *et al*., 2014). In products made for sale by volume, it is important to obtain the maximum volume of popped grain to increase economic gains, having more product to market.

However, little attention has been paid to understanding the characteristics of the seed and the popping process that influence the obtaining of higher popping volumes in amaranth. It is known that several variables influence the volume of expansion and the size of the popped grain obtained in amaranth. Among the factors are the following: the production environment, genotype (Ortiz-Torres *et al*., 2018), physical characteristics of the grain (Mishra *et al*., 2015), chemical composition of the grain (Castro-Giráldez *et al*., 2012; Mishra *et al*., 2014) and popping method (Mishra *et al*., 2014; Ramírez-Pérez *et al*., 2018).

Knowing the degree of association between popping volume with different types of raw grain and plant could help identify properties highly related to each other. Characteristics such as grain dimensions, grain weight, plant precocity or plant height would be easier to measure in plant or raw grain and would allow rapid evaluation of a large number of genotypes. This increases the probability of selecting genotypes with characteristics of high popping volume.

For this reason, the objective of the study was to evaluate the relationship of the characteristics of the plant in the field and raw grain with the expansion volume and size of the popped grain of amaranth. The following materials were evaluated: the improved varieties Nutrisol, Revancha, Gabriela, Laura, Diego, Areli and PQ2 and the populations C30 and C2 from the zone of Tochimilco, Puebla, Mexico, and the population of the local producer (CrPr), at whose site each experiment was established.

The five evaluation sites were Santiago Tochimizolco (18° 51’ 49.91” north latitude, 98° 37’ 17.87” west longitude, 2 273 masl), San Jerónimo Tecuanipan (19° 0’ 19.17” north latitude, 98°25’ 24.21” west longitude, 2 167 masl), San Andrés Calpan (19° 6’ 44.6”, 98° 24’ 12.82” west longitude, 2 260 masl), San Lorenzo Chiautzingo (19° 13’ 0.7” north latitude, 98° 27’ 21.37” west longitude, 2 344 masl) and Ciudad Serdán (19° 00’ 07.451” north latitude, 97° 27’ 51.689” west longitude, 2 520 masl). All in the state of Puebla, Mexico. At all sites, the climate is temperate subhumid with rains in summer (INEGI, 2017).

The experimental plot consisted of two furrows of 5 m and 0.8 m between furrows. The experimental design was randomized blocks with three repetitions. In 2014-2015, the establishment of the crop was carried out on June 3, 6 and 23 in Tochimizolco, Tecuanipan and Calpan, respectively. In 2015-2016, the sowing was on May 27 and June 3 in Ciudad Serdán and Chiautzingo, respectively. The population density was 125 000 plants ha^{-1}. The fertilization formula used was 80N-40P-00K and urea and diammonium phosphate as sources.

The fertilization was carried out at the first hoeing, this was 30-35 days after sowing. The second hoeing was carried out 40-45 days after sowing. All trials were under rainfed conditions. In the field, the variables that were measured were: grain yield (YIE), which was the weight of clean grain at 10% moisture, and it was expressed in kg ha^{-1}; days to male flowering (DMF), they were the number of days between sowing and when 50% of the population presented anthesis. In five plants of each plot, plant height (PTH) was determined, which was the distance in centimeters from the soil to the tip of the inflorescence.

Hectoliter weight (HLW), it was determined with an Ohaus YS601 digital scale, with precision of 0.1 g, the grain, which was placed to the flush in a metal container (100 ml) previously weighed, was weighed and it was recorded in kg hl^{-1}. Weight of one thousand seeds (WTS), reported in grams, for which an analytical scale with an accuracy of 0.1 mg (Shimadzu model AUW220) was used. In grain, the diameter and sphericity were determined. Ten grains were randomly chosen from each sample, and each was fixed to a slide with transparent liquid silicone, visualized with

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a phase-contrast optical microscope (Motic, BA410E) and photographs were taken with a digital camera (Jenoptik ProgRes C14 plus).

Each photograph was then analyzed with the Progres Grypahx program (version 1.1.10.6 Jenoptik Optical Systems) to determine seed height (SHG), seed width (SWD) and seed thickness (STH), all expressed in mm. These variables were used to define the geometric diameter (Dg), which was calculated with the following expression Dg: $(SHG*SWD*STH)^{1/3}$, in mm. Finally, the seed sphericity (SPHE) was calculated by dividing Dg by SHG. The result is a dimensionless measure (Arapa and Padrón-Pereida, 2014).

Popping was carried out on a sample of seeds weighing 15 g and was carried out in duplicate. First, the moisture content of the grain was adjusted to 12% (Ramírez-Pérez *et al*., 2018). Subsequently, the sample was subjected to high temperatures to obtain the popping, by means of a fluidized bed dryer (Amaranth seed popping module, model REVCP-1, College of Postgraduates) with hot air at 232 °C (Argumedo-Macias, 2019). The samples from 2014 were popped in February 2015 and those from 2015 in February 2016. The tests were carried out in the laboratory of the Puebla *Campus* of the College of Postgraduates located in Cholula, Puebla, Mexico.

The popped grain obtained was passed through the physical test sieve number 16 with opening of 1.19 mm (Montinox, Mexico) and the following variables were determined: non-popped grain weight (NPPW) it is the weight (grams) of the popped and non-popped grain that passed through sieve 16, popped grain volume (PPVL) it is the volume (ml) of the popped grain that remained on sieve 16. To determine the size of the popped grain (known in Mexico as ‘palomita’), the sample was passed through physical test sieves (Montinox, Mexico) number 8, 10 and 16, which have an opening of 2.38, 2 and 1.19 mm, respectively.

With which the following variables were obtained: volume of popped grain of sieve 8 (VLS8), volume of popped grain of sieve 10 (VLS10) and volume of popped grain of sieve 16 (VLS16), which are the volumes (ml) of the popped grain that remained on sieves 8, 10 and 16, respectively. To determine the degree of association between the variables of raw grain, popped and agronomic grain, the Pearson correlation coefficient (r) was calculated. The program SAS version 9.0 (SAS Institute, 2004) was used in the analysis.

The results of the analysis of correlation between the variables evaluated are shown in Table 1. It is observed that the PPVL correlated positively and statistically significantly ($p\leq$ 0.01) with agronomic variables, such as DMF ($r= 0.56^{**}$), HLW ($r= 0.56^{**}$) and WTS ($r= 0.3^{**}$). This means that later varieties, with high HLW and WTS, presented a greater volume of expansion. In popcorn (Pordesimo *et al*., 1990) and sorghum (Mishra *et al*., 2015), it has been reported that heavier grains produce greater volumes of expansion. Due to their association with the expansion volume of popped grain (r= 0.56 and 0.3), the variables HLW and WTS could be a way to evaluate the popping potential of amaranth genotypes indirectly.

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Table 1. Coefficients of linear correlation between the variables evaluated.

	NPPW	VLS8	VLS10	VLS16	Dg	SPHE	DMF	PTH	HLW	WTS	YIE
PPVL	-0.58**	0.48**	0.78**	-0.35**	0.21*	-0.05	0.56**	0.2*	0.56**	0.3**	0.21**
NPPW	1	-0.15	-0.35**	0.01	-0.01	-0.1	-0.56**	-0.17*	-0.78**	-0.19*	-0.29**
VLS8		1	0.46**	-0.72**	0.55**	-0.05	-0.08	0.12	0.16	0.666**	-0.176*
VLS10			1	-0.76**	0.53**	-0.11	0.42**	0.1	0.42**	0.66**	0.06
VLS16				1	-0.75**	0.11	0.04	-0.02	-0.11	-0.89**	0.21*
Dg					1	-0.01	-0.06	-0.12	0.01	0.8**	-0.28**
SPHE						1	0.19*	0.08	-0.11	0	0.14
DMF							1	-0.2*	0.55**	0.02	0.13
PTH								1	0.02	-0.05	0.74**
HLW									1	0.16*	0.15
WTS										1	-0.25**

**= significant at 0.01 probability; *=significant at 0.05 probability; PPVL= popped grain volume; NPPW= non-popped grain weight; VLS8= volume of popped grain retained in sieve 8; VLS10= volume of popped grain retained in sieve 10; VLS16= volume of popped grain retained in sieve 16; Dg= geometric diameter; SPHE= seed sphericity; DMF= days to medium male flowering; PTH= plant height; HLW= hectoliter weight; WTS= weight of one thousand seeds; YIE= grain yield.

PPVL negatively correlated (r= -0.58**) with NPPW. This relationship is explained by the fact that the maximum popping volumes were obtained from samples with a greater number of popped grains and therefore, a lower percentage of non-popped grains. This same behavior has also been reported in popcorn (Dofing *et al*., 1990; Soylu and Tekkanut, 2007). Likewise, PPVL correlated positively with VLS8 (r= 0.45**), VLS10 (r= 0.78**) and negatively with VLS16 (r= -0.35*), so a high value in expansion volume was associated with higher quantities of medium and large popped grain. The same has been observed in popcorn by Dofing *et al*. (1990); Soylu and Tekkanut (2007).

Regarding the variables of popped grain size and agronomic variables, it is observed (Table 1) that HLW positively correlated with VLS10 (r= 0.42**) and negatively correlated with NPPW (r= -078**). This means that, in varieties with high HLW, there are more grains that popped in medium size of popped grain and less of small size, therefore, they show a greater volume of popped grain.

The agronomic variable DMF correlated positively with VLS10 (r= 0.42**) and negatively with NPPW (r= -0.56**), which shows that later varieties presented more grains that pop and greater volume of popped grain of medium size. DMF also correlated with HLW (r= 0.55**). This behavior is explained by the fact that later plants have larger and heavier grains, because they had more leaves and time for grain filling compared to earlier plants, as shown in corn by Capristo *et al*. (2007).

The variable that was best related to the volume of the different sizes of popped grain was WTS, because WTS correlated positively and statistically significantly ($p \leq 0.01$) with VLS8 (r= 0.67**) and VLS10 (r= 0.66**) and negatively and significantly with VLS16 (r= -0.89**). This behavior means that, with heavier grain, higher yields of medium and large expanded grain were obtained. Something similar has been found in popcorn by Dofing *et al*. (1990); Pordesimo *et al*. (1990); Song and Eckhoff (1994).

However, Dofing *et al*. (1990) highlight that there is not always an increase in the volume of expansion in large grains because they observed a decrease in the number of raw grains in the same weight. They then conclude that grain size *per se* is not the only factor associated with a high volume of expansion. Nevertheless, WTS can be an indirect way to evaluate the quality of

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popped grain in different amaranth genotypes, this is because the larger raw grain provides a high proportion of large, popped grains.

On the other hand, WTS presented a positive and statistically significant (*p*# 0.01) correlation index with Dg (r= 0.8**). At the same time, the variable Dg correlated positively and significantly ($p \leq 0.01$) with VLS8 (r= 0.55**) and VLS10 (r= 0.53**) and negatively and significantly (*p*# 0.01) with VLS16 (r= -0.75**). Based on the above, another indirect way to predict the size of the popped grain to be obtained can be the measurement of any of the dimensions of the grain, because they show a good relationship with the size of the 'palomita' obtained.

In corn, it has been reported that seed sphericity influences expansion volume (Pordesimo *et al*., 1990). However, in this work no correlation was observed between sphericity and expansion volume. This behavior may be due to the fact that the shape of the amaranth seed is more spherical than the corn kernel and there are not many differences between varieties.

Conclusions

The characteristics of the seed that were associated with popping volume and specifically with the size of the popped grain were geometric diameter and weight of one thousand seeds. The agronomic characteristics related to the popping volume were hectoliter weight and days to male flowering. Hectoliter weight and weight of one thousand seeds can be used to predict the behavior of the expansion volume in amaranth genotypes, since at higher seed weight and hectoliter weight, there is a better popping volume.

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