Article

Effect of Xenia on popping characteristics in popcorn

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Abstract

In the process of genetic fertilization of corn (*Zea mays* L.), pollen exerts a direct and immediate effect on the properties of the resulting caryopsis known as Xenia. This situation is of great importance in popcorn, since the popping capacity depends directly on the characteristics of the endosperm, so it is necessary to study the magnitude of Xenia in popcorns to give appropriate recommendations for the production and conservation of this genetic resource. The present study was carried out in 2018, the effect of Xenia of corn varieties of different endosperm constitution was evaluated on physical and popping characteristics of the caryopsis of two genotypes of popcorn. The experiment was conducted in two localities, Montecillo, State of Mexico and Santa María Zacatepec, municipality of Juan C. Bonilla, Puebla, using a randomized complete block experimental design. The varieties of popcorn Compuesto Amarillo and North American Yellow Pearl Popcorn were used as female parents, while the same materials, CML-349 of semicrystalline endosperm and a population of the Cacahuacintle race of mealy endosperm were used as male parents. The results showed that Compuesto Amarillo had a decrease in the dimensions of the caryopsis from 0.17 to 13%, while in NAYPP, the effect resulted in an increase, from 2.27 to 18%. The popping volume showed the greatest effect of Xenia, since in Compuesto Amarillo, it decreased from 25 to 49% when pollinated with non-popcorns, while in NAYPP the decrease was 59%. According to the results, there was an effect of Xenia on the popcorn evaluated, which was greater on the volume of expansion, while in the physical characteristics of the caryopsis, this effect was less pronounced.

Keywords: *Zea mays*, endosperm, pollination, popcorn, varieties, Xenia.

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Introduction

Gene flow is the natural movement of genes between organisms, through a process of migration and subsequent sexual recombination or hybridization between the migrant and recipient populations. In plants, this process occurs when pollen successfully pollinates and fertilizes another plant (Guzmán *et al*., 2008). In the process of genetic fertilization of corn (*Zea mays* L.), pollen exerts a direct and immediate effect on the properties of the resulting caryopsis known as Xenia, this effect can be defined as the action of pollen genes on the development of the fruit or seeds (Bulant *et al*., 2000).

In corn, an increase of 10.1% in caryopsis weight has been reported in the case of cross-fertilization, compared to self-fertilization (Villarreal *et al*., 2010), since, from the genetic point of view, the advantage of cross-fertilization or Xenia effect can be interpreted in terms of the complementation between the genes of the male and female, which modifies some enzymatic systems and thereby causing heterosis, which can be noticed mainly at the end of the metabolic pathway, as in the case of starch (Bulant *et al*., 2000).

The fraction of corn that is most related to its uses as food is the endosperm, whose composition occupies about two-thirds of the volume of the fruit and constitutes approximately 86% of its dry weight, a trait that is usually controlled by one or a few genes of simple inheritance. Based on its type of endosperm, corn is classified into sweet, toothed, mealy, crystalline and popcorn (Figueroa *et al*., 2013). According to this classification, there are caryopses with different endosperm constitution, as is the case of mealy corn, which, as its name implies, is constituted by an endosperm of disaggregated structure (meal), and lacks a crystalline endosperm, unlike popcorn which is constituted very predominantly by a very hard crystalline endosperm and that only has a small portion of mealy endosperm (Estrada *et al*., 1999).

The popcorn from Mexico is represented by several races, and most of them are in danger of extinction due to their low productivity and undesirable traits related to nixtamalization and even their use in popped corn making (De la O *et al*., 2015). Corn generally does not manifest incompatibility between different races and is easily pollinated through the action of the wind, in addition to the fact that Mexican farmers often exchange seeds, and their sowing generates mixtures from different sources, which results in recombination and loss of specific characteristics of the original race (SCCA, 2004).

In popcorn, the usable portion and desirable characteristic is the endosperm of the caryopsis, a portion that in the presence of heat and moisture expands to produce popped corn and the endosperm tissue is triploid, with two portions of genetic information provided by the mother plant and a portion contributed by the male parent through pollen.

Popcorn has a precise balance in the expression of anatomical characteristics of the caryopsis in terms of pericarp thickness, proportion and distribution pattern of crystalline and mealy endosperm, and germ size, all of them with a wide genetic control, in addition to intrinsic genes for capacity and characteristics of popping, which must be preserved so that the caryopsis does not lose its qualities. Therefore, based on the type of fertilization that corn has and the ease of crossing with each other that the different existing populations have, it is important to know the immediate effects that the pollen of corns of different endosperm constitution will have on the characteristics of the caryopsis of popcorn and therefore, the effect on popping, which has implications for the management of production plots and on the conservation of popcorn genetic resources.

Therefore, the objectives set for this research were: 1) to evaluate the direct and immediate effect of pollen of corn varieties of different endosperm constitution on the physical characteristics of the caryopsis of popcorn; and 2) to evaluate the effect of Xenia of pollen of corn varieties of different endosperm constitution on the popping volume of popcorn and on the characteristics of the popped corn obtained.

Materials and methods

Genetic material

In this work, two populations of popcorn were used as females, one was Compuesto Amarillo (CA), which comes from a stabilized population formed from a hybrid of the Palomero Toluqueño race (Mex-5) × Yellow Pearl of the United States of America, from which yellow caryopses were selected and after a genetic recombination between them, the CA population originated.

The other population was the North American Yellow Pearl Popcorn (NAYPP) race, which corresponds to the type of corn most commonly grown commercially in the corn belt of the United States. The males used were the two previous materials, the inbred line CML-349, with semicrystalline endosperm, white caryopsis and early maturity adapted to highlands and a population of landrace corn of the Cacahuacintle (CAC) race of mealy endosperm, native to the Texcoco Valley and characteristic of the High Valleys of central Mexico.

Experimental sites

The pollination experiments were established during the spring-summer cycle of 2018 in two environments of the Central High Valleys, one was the locality of Montecillo, municipality of Texcoco, State of Mexico (19° 27’18” north latitude and 98° 54’ 26” west longitude, at an altitude of 2 240 m, with average annual temperature of 12-18 °C and average annual rainfall of 637 mm) (García, 1988). The other environment was Santa María Zacatepec, municipality of Juan C. Bonilla, Puebla (19° 06’ 00” north latitude and 98° 20’ 00” west longitude, at an altitude of 2 206 m) (INEGI, 2009).

Experimental design, experimental unit, and treatments

The combination of genotypes (2 females x 4 males) resulted in a total of eight treatments, which were established in both localities under an experimental design of randomized complete blocks with three repetitions. The experimental unit of the female plants consisted of plots of two furrows 5 m long and 0.8 m wide, where the sowing was at the rate of three seeds every 50 cm and after the second work, a thinning was carried out to leave two plants, having a final density of 55 000 plants ha^{-1}. Additionally, plots of male plants were established, which consisted of six furrows with the same sowing specifications described; pollen was taken from these plots to form the different treatments.

To avoid the presence of pollen from other sources on female plants, the baby corns of these were covered with number 8 glassine paper bags before exposure of stigmas; also, prior to anthesis, the tassels of male plants were covered with tassel bags, made of 12-gauge kraft paper, 30 cm long and 17.5 cm wide, during the early hours of the morning. The collection of pollen from the covered tassels was carried out after 10 in the morning and was deposited on the baby corns with developed stigmas of the corresponding female receptors.

Variables evaluated

From a composite sample formed by the physical mixture of the grain from five representative ears per experimental unit, the average length (GL), width (GW) and thickness (GT) of 10 random caryopses were taken, measured with a digital vernier. Similarly, 100 caryopses per experimental unit were counted, which were determined their weight (W100G) in g in an analytical balance and their volume (V100G) in cm^3 by displacement of water in a graduated cylinder.

To evaluate the popping characteristics, the harvested grain was brought to an equilibrium moisture between 13.5 and 14% in order to maximize the volume of expansion, which, according to Gökmen (2004), in popcorn, is achieved at these moisture levels; for this, 40 grams of caryopsis per experimental unit were conditioned in a controlled environment chamber at 21 °C, with a relative humidity of 70% for eight days (Ziegler, 2001).

For the popping, the method standardized by De la O *et al*. (2015) was used, which consisted of determining the volume of popped corn produced by a sample of 30 g of conditioned caryopsis. The sample was placed in a heat-resistant polypropylene container and processed in a microwave oven (Daewoo® Kor-164H), set to 70% of its power for 2:45 min, the popped corns that were obtained were placed in a graduated cylinder of 2 L to determine the popping volume in cm^3.

The percentage of non-popped caryopsis was calculated with the weight of the non-popped caryopses after heat treatment in the microwave oven over the total weight of the conditioned caryopsis sample (30 g). The type of popped corn was assessed using a visual scale of 1 to 5 according to the way they popped, a value of 1 was used to identify a spherical popped corn (mushroom type) and 5 for an elongated popped corn with bumps (butterfly type). The pulverization of the pericarp, as its disintegration after the popped corn making process, was measured with a visual scale of 1 to 5, where 1 corresponded to a fully pulverized pericarp and 5 to one with little disintegration.

The effect of Xenia caused by the pollen of each of the males on the caryopsis of each of the females for the variables evaluated was estimated using the formula proposed by the authors: $EX=\left(\frac{HM}{HF}-1\right)\times 100$. Where: EX= effect of Xenia in percentage on a characteristic of the caryopsis; HM= phenotypic expression of characteristics of the caryopsis of popcorn pollinated with pollen of a male of different type of endosperm; and HF= phenotypic expression of characteristics of the caryopsis of popcorn pollinated with pollen of the same population, equivalent to the female with fraternal cross of male plants of the same type.

Statistical analysis

An analysis of variance was performed using the linear model corresponding to the randomized complete block design. Data on percentage of non-popped caryopsis and visual scales 1-5 were transformed with the formula: arcsine in the analysis of variance. A Tukey mean comparison test at 5% was also applied using the Sas® statistical package (SAS Institute, 2002).

Results and discussion

Variation in physical and popping characteristics of the caryopsis

The analysis of variance detected high significance ($p \leq 0.01$) between localities (Loc) for three (GL, GW, and pericarp pulverization) of the nine variables (Table 1). This result indicates that the environment has an important effect on the expression of these three characteristics of the caryopsis of popcorn, due to the climatic and edaphic effects typical of the study localities, which includes the sowing dates, agronomic management, the type of soils and the elements of the climate of each locality. These results agree with those reported by Daros *et al*. (2002) in a similar work, who observed differences between environments and also detected significant effects of the genotype-environment interaction for caryopsis yield, days to flowering, plant height and popping capacity.

Among females (CA and NAYPP) (Table 1), there were highly significant differences ($p \leq 0.01$) for caryopsis length, caryopsis thickness, weight of 100 caryopses, percentage of non-popped caryopsis and type of popped corn, indicating that there is high variation for these characteristics among female materials. Among males (M), the effect on female caryopses due to their pollen contribution was highly significant ($p \leq 0.01$) for GL and popping volume, which suggests that there are differences between males for these two characteristics, so their pollen had a noticeable effect on popcorn (Table 1).

The interaction of females × males (F×M), which can be interpreted as a direct representation of the effects of Xenia, was highly significant ($p \leq 0.01$) for popping volume, percentage of non-popped caryopsis and pulverization of the pericarp, so it is evident that the type of pollen of the donor and its effect on the caryopsis of the recipient is important in the effect of Xenia, but with markedly differential effect according to the female concerned (Table 1). The interaction of localities × females, (Loc × F) (Table 1) had high significance ($p \leq 0.01$) for W100G, V100G, popping volume, type of pericarp and pulverization of the pericarp, while for GL and non-popped caryopsis, it was significant ($p \leq 0.05$), this makes it evident that females behaved differently for these characteristics across the localities, and this could be due to the different genetic response of the materials to the influence of climatic and edaphic factors of the localities, as well as to the agronomic management provided in each of them, such as sowing date, irrigation, fertilization, etc.

Table 1. Mean squares of nine characteristics of two varieties of popcorn pollinated with four males contrasting in endosperm. Spring-summer of 2018.

SV	DF	GL	GW	GT	W100G	V100G	Popping volume	Non-popped caryopsis (%)	Type of popped corn (1-5)	Pulverized pericarp (1-5)
Loc	1	516.07**	271.51**	17.93ns	39.18*	13.02ns	6302.08ns	0.47ns	3*	13.54**
Rep/Loc	4	28.45ns	49.81ns	37.06ns	8.82ns	21.04ns	3116.66ns	119.7ns	1.35*	0.36ns
F	1	8030.82**	138.17*	217.26**	116.59**	42.18*	7252.08ns	1228.77**	6.75**	0.88ns
M	3	248.98**	13.68ns	28.23ns	5.12ns	8.68ns	20974.3**	73.98ns	1.09ns	0.1ns
F × M	3	92.42ns	45.31ns	11.31ns	1.72ns	11.68ns	31035.41**	450.51**	0.56ns	2.43**
Loc × F	1	227.54*	37.24ns	2.71ns	129.92**	136.68**	15768.75**	619.49*	5.33**	9.63**
Loc × M	3	20.97ns	74.95*	38.7ns	15.16ns	14.18ns	6540.97*	40.31ns	0.62ns	0.35ns
Loc × F × M	3	97.8ns	96.21*	37.84ns	16.36ns	36.96*	24796.52**	372.91*	1.04ns	0.32ns
Error	28	50.04	23.56	17.91	8.52	10.04	1778.57	85.97	0.49	0.23

*= significance at 5%; **= significance at 1%; ns= not significant; GL= caryopsis length; GW= caryopsis width; GT= caryopsis thickness; W100G= weight of 100 caryopses; V100G= volume of 100 caryopses.

On the other hand, significant differences ($p \leq 0.05$) were only observed for GW and popping volume in the interaction of localities × males (Loc × M) (Table 1), which indicates that the effect of the pollen of each male on GW and popping volume of the caryopses of the females was different across the localities, this as a differential response of the genotype to the contrasting environmental effects of each locality.

F= females; M= males; Loc= localities; Rep= repetitions. The interaction of localities × females × males (Loc × F ×M) (Table 1) was significant ($p \leq 0.05$) for GW and V100G and highly significant ($p \leq 0.01$) for popping volume, which is important to highlight, since this variable, in addition to showing its high genetic complexity and complexity of response to the environment, represents both the most valuable and the most desirable characteristic for the production of popcorns.

Table 2 shows the results of the physical characteristics of the caryopsis on average of the localities. It was observed that, in Montecillo, the genetic materials presented statistical superiority in three (GL, GW and W100G) of the five variables evaluated, which again highlights the importance of the effects of the environment on the response of the genotypes, such as climatic and edaphic factors of the localities, as well as those of agronomic management (date of sowing, irrigation, fertilization, etc.). In the comparison of means between localities for the popping characteristics (Table 3), significant statistical differences were observed for type of popped corn and pulverization of the pericarp, a result that agrees with what was reported by Alexander and Creech (1977) in the sense that the phenomenon of expansion is a polygenetic trait, subject to some influence of the environment.

Table 2. Comparison of means of localities for five physical characteristics of the caryopsis of two varieties of popcorns pollinated with four males contrasting in endosperm. Spring-summer of 2018.

Locality	GL (mm)	GW (mm)	GT (mm)	W100G (g)	V100G (cm^3)
Montecillo	93.93 a	62.9 a	43.64 a	14.4 a	17.95 a
Zacatepec	87.37 b	58.14 b	42.41 a	12.59 b	16.91 a
HSD 5%	4.18	2.87	2.5	1.72	1.87

Means with the same letter within columns are not significantly different (Tukey 0.05). GL= caryopsis length; GW= caryopsis width; GT= caryopsis thickness; W100G= weight of 100 caryopses; V100G= volume of 100 caryopses; HSD= honest significant difference.

Table 3. Comparison of means of localities for four popping characteristics of the caryopsis of two varieties of popcorns pollinated with four males contrasting in endosperm. Spring-summer of 2018.

Locality	Popping volume (cm^3 30 g^{-1})	Non-popped caryopsis (%)	Type of popped corn (1-5)	Pericarp pulverization (1-5)
Montecillo	184.58 a	36.59 a	1.95 b	2.1 b
Zacatepec	161.67 a	36.79 a	2.45 a	3.16 a
HSD 5%	24.93	5.48	0.41	0.28

Means with the same letter within columns are not significantly different (Tukey 0.05). GL= caryopsis length; GW= caryopsis width; GT= caryopsis thickness; W100G= weight of 100 caryopses; V100G= volume of 100 caryopses; HSD= honest significant difference.

On the other hand, the comparison between averages of female (F) materials (Table 4) indicated that Compuesto Amarillo produced caryopses of greater length, width, weight, and volume and that NAYPP showed the greatest thickness of caryopsis, this because Compuesto Amarillo contains genetic information of rice-type popcorns, and NAYPP is of the pearl type (rounder grains).

The results also show that the percentage of non-popped caryopsis was not different between CA and NAYPP, but the popping volume was. The type of popped corn was different between the two varieties, as NAYPP produced elongated and slightly protruding popped corns, while CA produced more spherical and medium-sized popped corns.

Table 4 compares the means of each male mated with the two females, which on average measures the influence of each. It can be observed that the physical characteristics of the caryopsis had no significant differences, except for GL, which was diminished by the action of the CML-349 male. On the other hand, significant differences were found in the popping volume, and two different groups formed: 1) the one with the highest popping volume, where the caryopses pollinated with pollen of Compuesto Amarillo and NAYPP, both popcorns, had an increase of 22.08 cm^3 and 47.5 cm^3, respectively; and 2) the one that was obtained with the effects of pollination with Cacahuacintle and CML-349, non-popcorns of mealy and semicrystalline endosperm, respectively.

Table 4. Comparison of means between two females of popcorn and between four males contrasting in endosperm for physical and popping characteristics of caryopsis. Spring-summer of 2018.

Female	GL (mm)	GW (mm)	GT (mm)	W100G (g)	V100G (cm^3)	Popping volume (cm^3)	Non-popped caryopsis (%)	Type of popped corn (1-5)	Pericarp pulverization (1-5)
					Female				
Compuesto Amarillo	103.59a	62.22a	40.9b	15.05a	18.37a	185.42a	41.75a	1.83b	2.77a
NAYPP	77.72b	58.83b	45.15a	11.94b	16.5b	160.83a	31.63b	2.58a	2.5a
HSD (%)	4.18	2.87	2.5	1.72	1.87	24.93	5.48	0.41	0.28
					Male				
Compuesto Amarillo	93.16a	61.97a	41.92a	14.36a	18.5a	207.5a	39.52a	2.54a	2.66a
NAYPP	92.04a	59.8a	44.92a	12.83a	16.41a	208.33a	37.48a	2.33ab	2.54a
Cacahuacintle	93.52a	60.68a	41.64a	13.58a	17.41a	152.5b	36.15a	1.83b	2.75a
CML-349	83.88b	59.64a	43.62a	13.21a	17.41a	124.17b	33.6a	2.12ab	2.58a
HSD (%)	5.91	4.05	3.53	2.44	2.65	35.26	7.75	0.58	0.4

Means with the same letter in each column within each type of parent (female or male) are not significantly different (Tukey 0.05). GL= caryopsis length; GW= caryopsis width; GT= caryopsis thickness; W100G= weight of 100 caryopses; V100G= volume of 100 caryopses; HSD= honest significant difference.

Caryopses pollinated with these materials had lower expansion volumes (55 cm^3) than when pollinated with CA and NAYPP pollen (84 cm^3). These results indicate a clear effect of Xenia, which here was characterized by the decrease in popping volume and that resembles the results obtained by Lyerly (1942), who observed a reduction of 1.4 volumes in the popping of Yellow Pearl popcorn pollinated with mealy corn, similar results were obtained by Dofing *et al*. (1991), observing a decrease in the popping volume when crossing popcorns with toothed corn; for their part, Robbins and Ashman (1984), when crossing popcorns of inbred lines of the Yellow Pearl race (HP-62-52 and 4722) with inbred lines of crystalline corn (CM80) and toothed corn (B2), found that both generations F_2 and F_3, and crosses of HP62-52 × CM80 (popcorn × crystalline) showed greater volume of expansion than the cross of HP-62-52 × B2 (popcorn × toothed), while generations F_2 and F_3 of crosses 4722 × CM80 (popcorn × crystalline) and cross 4722 × B2 (popcorn × toothed) did not show significant differences in expansion volumes, thus showing that the effects of Xenia have a variable and specific magnitude, depending on the genotypes and environments involved.

The results indicate that the genetic materials, when they acted as males, led to a clear reduction in GL, GW, W100G and V100G in the caryopses of Compuesto Amarillo, as verified when compared with the results obtained when it acted as female. This result is similar to that obtained by Dofing *et al*. (1991), where in a similar work, two crosses of popcorn × toothed corn had a decrease in the weight of caryopses. For its part, the NAYPP material was favored by an increase in the aforementioned characteristics, which agrees with the results of Bozinovic *et al*. (2012), who observed an increase in the weight of caryopses of a fertile corn hybrid compared to those of its sterile version.

Effects of Xenia for physical and popping characteristics of the caryopsis

When quantifying the effects of Xenia (Table 5), it was observed that for CA the pollen of non-popcorns (Cacahuacintle and CML-349), in general, caused a decrease in the physical characteristics of the caryopsis of Compuesto (GL, GW, GT, W100G and V100G), as well as in the popping volume. This indicates that there was a decrease in these variables due to the effect of Xenia, which did not occur when the female was pollinated with pollen of plants of the same type (fraternal cross). Similarly, the volume of popping and the percentage of non-popped caryopses were disadvantaged when CA was pollinated by males of non-popcorn.

Table 5. Quantification of the effects of Xenia (%) for physical and popping characteristics of four corns contrasting in endosperm on the caryopses of two popcorns. Spring-summer of 20118.

Female	Male	GL	GW	GT	W100G	V100G	Popping volume	Non-popped caryopsis (%)	Type of popped corn (1-5)	Pulverized pericarp (1-5)
CA	CA	0	0	0	0	0	0	0	0	0
	CAC	-0.17	-2.32	-0.95	-7.11	-13.94	-25	0.24	-16.66	14.28
	NAYPP	-6.19	2.32	11.18	-10.83	-10.67	-42.94	23.69	-12.5	39.28
	CML-349	-12.51	-4.54	2.01	-12.51	-13.92	-46.79	24.06	-4.16	21.42
NAYPP	NAYPP	0	0	0	0	0	0	0	0	0
	CAC	-4.36	8.45	-3.78	393.93	18.17	-59	24.48	-31.42	54.54
	CML-349	-11.52	7.24	2.27	9.29	18.17	-59	12.49	-20	27.27
	CA	-5.49	10.5	-3.39	11.59	13.6	-42.23	13.42	5.71	63.63

In relation to the type of popped corn, the effect of Xenia was more accentuated with the pollen of Cacahuacintle (-16.66%), as it caused a more spherical type of popped corn in relation to the fraternal cross of Compuesto Amarillo. The effect that NAYPP pollen originated for pericarp pulverization in CA was the most relevant, because it increased this characteristic by 39.28%.

In the case of NAYPP popcorn (Table 5), the results indicate that the effect of Xenia caused an increase in the variables GW, W100G and V100G when this variety was pollinated with the pollen of plants of the same type (fraternal cross) and when the pollen came from Compuesto Amarillo popcorn, there was an increase of 10.5% in the GW variable. In the case of W100G, it was the male Cacahuacintle who caused a more accentuated effect (393.33%) and for V100G, both CML-349 and CAC were the ones that caused a greater increase (18.7%).

The popping volume, as happened in CA, was decreased in equal proportion by both Cacahuacintle and CML-349 pollen (-59%), results that, when they occur in the field, are not favorable for the producer or the consumer. The percentage of non-popped caryopsis increased by 24.48% and

12.49% with pollen of Cacahuacintle and CML-349, respectively, a result that is not favorable because it represents a greater amount of wasted caryopses. The type of popped corn was also modified, going from a unilateral expansion (NAYPP × NAYPP) to a hemispherical one (NAYPP × Cacahuacintle). The pulverization of the pericarp went from being almost intact (NAYPP × NAYPP) to semi-pulverized (NAYPP × CA and NAYPP × CAC).

Conclusions

Effects of Xenia were found for both the physical characteristics of the caryopsis and its popping characteristics when the popcorn was pollinated with a different type of corn; however, this effect was generally greater for the volume of expansion and pulverization of the pericarp than for the characteristics of caryopsis. The effects of Xenia are specific in magnitude according to the trait and genotype evaluated. In the physical characteristics of the caryopsis, Compuesto Amarillo had Xenia effect, which was reflected in the decrease in the size of the caryopsis (GL, GW, GT and W100G), except for the volume of 100 caryopses, where it increased only 0.13 cm^3 on average.

NAYPP also had Xenia effect, reflected in the increase in the size of the caryopsis (GL, GW, W100G and V100G), with the exception of thickness, which had a decrease of 0.23 mm on average. The males caused different Xenia effects and only CML-349 produced Xenia in the length of the caryopsis, being negative since the length of the caryopsis decreased 12.51% in Compuesto Amarillo and 11.52% in NAYPP. Likewise, popcorns pollinated with non-popcorn materials produced a lower volume and percentage of popping.

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