ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS

Journal of Agronomy

ISSN 1812-5379
DOI: 10.3923/ja.2020.24.30

Research Article
Xenia and Metaxenia in Maize Hybrid Varieties as a Consequence of Paternal Pollen Effect

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Abstract

Background and Objective: "Xenia and metaxenia" in maize (*Zea mays* L.) are phenomena that potentially exploited in creating promising new maize superior variety in short time. The objective of this experiment was to study the possibility to exploit both phenomena in creating the base population materials to form new superior maize variety candidate. **Materials and Methods:** Three different levels production of seeds maize hybrid varieties namely white colour and lower production of Arumba and yellow colour and higher production of both Bonanza and Ganebo were used as crossing parents. Complete diallel crossing method and natural open pollination of the parents were used in generating those F_1's of ear and kernel families in studying these phenomena. The xenia phenomenon was measured the 100 kernel weight (g) and the kernel number/ear, whereas the metaxenia phenomenon was measured the ear diameter (mm) and lengths (cm). All data gathered were analyzed by mean calculations and to draw conclusion, the one tail paired t-test at α 0.05 significant level was performed. **Results:** The research results indicated that the 100 kernels weight was generally xenia expressed, meanwhile, the kernel number/ear was also generally xenia expressed. Besides, all crossing pairings were metaxenia expressed for the ear length, but only a crossing pairing between Bonanza as a male parent and Arumba as a female parent were not ear length inherited. **Conclusion:** Both xenia and metaxenia phenomena in maize hybrid variety are included in increasing a quantitative yield corresponding to the kernel and ear traits.

Key words: Ear and kernel, maize hybrid, metaxenia, pollen parent, xenia

Citation: Suaib Suaib, Sarawa Mamma, Tresjia Corina Rakian and Darwis Suleman, 2020. Xenia and metaxenia in maize hybrid varieties as a consequence of paternal pollen effect. J. Agron., 19: 24-30.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

One of more interesting phenomena in plant genetics and breeding was in exploiting the "xenia and metaxenia" phenomena through hands pollinating of 2 parental plants followed by the individual progenies selection in the next generations. Both xenia and metaxenia phenomena are important and interesting to exploit because their effect appear sooner i.e., in F_1 seeds and fruits generation of female parent[1-3]. The advantages of both phenomena lies on the 2 aspects, not only in the increasing a measures like the addition of fruit size, but also the decreasing of it for example the lower rate of hazardous seeds chemical content[4,5].

"Xenia" is a phenomenon that expressed in morphological and biochemical features of maternal F_1 kernels derived from crossing between 2 parents of angiosperm species, in respective a qualitative and a quantitative measures like color and other chemical contents, form or size and the number of seeds[6]. Whilst "metaxenia" is the same phenomenon as in xenia but this expressed only in morphological of maternal fruit[7] as a quantitative measure which is performed as fruit length and diameter. Both phenomena are appeared in very early generation as could be observed in the first kernels or first fruit maternal generation that so-called parental pollen directly effect.

Since Focke[8] explained the term "xenia" in coined the phenomenon of which the effects of different pollen sources on seed and fruit of angiosperm species, the advanced inventions of this relates phenomenon were developed. That are indicating the explanation of "genuine xenia" in which the pollen source influences the colour, shape and chemical composition of the seed and "metaxenia" if pollen influences the fruit[9]. In the next year, Tschermak[10] also discussed about another kinds of xenia that so-called "false xenia" in which the size of crossed seeds were greater than of selfed seeds, as reported by Nicolaisen[11] in rye and pea and Kiesselbach[12] in maize kernel. From this principle, the use of top cross breeding in maize hybrid formation was wider applied until recently[13].

In recent study of some crop plants about xenia as well as metaxenia, the inbreed or pure line and the open pollinated varieties are always uses as crossing pairs in directly generating F_1 seeds hybrids at the first generation as reported by Grochowski *et al.*[14] in rye (*Secale cereale* L.), Castaneda[15] in maize (*Zea mays* L.), Piotto *et al.*[16] in tomato (*Lycopersicon esculentum* L.), Usman *et al.*[17] in guava (*Psidium guajava*), Li *et al.*[18] in rapeseed (*Brassica napus* L.) and Kahriman *et al.*[19,20] in maize. But in this study, the hybrid varieties of maize were used as parental cross pairings in observing both xenia and metaxenia phenomena, particularly in quantitative measures. In corn (*Zea mays* L.), these phenomena will appears in the F_1 kernels and ears of mother plant after pollinated by paternal pollen sources and the trait expressed could be kernels or ears characteristics/individual plant.

The significance of this experiment was to provide some information about the superior traits to that of an individual or a population of maize which gathered from a very early generation i.e., after crossing with their parents. This experimental work in crossed with those parents from hybrid variety states was different from generally used with those open pollinated variety or an inbred line. These progenies which performed xenia and metaxenia mainly in superior yield traits which could be developed further to generate a new promising cultivar.

The aim of this study was to discuss the xenia of F_1 kernels and metaxenia of ears phenomena derived from crossing between 3 different kinds of hybrid varieties as parents i.e., Arumba, Bonanza and Ganebo varieties in natural open pollination, regular and reciprocal crossings.

MATERIALS AND METHODS

Location and plant materials: The field experiments was conducted at Faculty of Agriculture Experimental Station II, Halu Oleo University Campus Anduonohu Kendari, Southeast Sulawesi Indonesia, from January-April, 2019. Three parental crossing pairs of Indonesia national superior hybrid varieties of maize were used in this field experiment namely, a waxy maize variety of Arumba and a respective non-waxy maize of Bonanza and Ganebo hybrid varieties. An inorganic fertilizers "Mutiara" with 16:16:16 (N:P:K), 10 kg plastic pots filled with mixed of ultisol top soil and animal manure in same proportion (1 : 1 of v/v), insecticide and a set of plant breeding tools were used as experimental materials. Those plants material crossings were planted and managed according to the standard plantation recommended in the area of experiment.

Crossing procedures: Due to the synchronisation of their time anthesis of all three parental crossings, each of variety was sown in different dates so as to gain the same time of crossing between parental pairings. In artificial hands pollination, both parental pairings were emasculated before silks of shoot female parent were emerged by covered with special shoot bag. Whereas, the male parent was isolated of the pollen released before anthesis with tassel bag. When the covered shoot silks of female parent were achieved about 5 cm lengths, the silks were horizontally cutted with a pair of sterile scissors to get the silks plate surface and the pollen grains were collected from another male of different parent plant in the same time i.e., between at 07.00 until 09.00 o'clock in the morning. The ranged time was the appropriate moment in doing artificial hands pollination.

Data sources family: The 3 kernels and ears of female parent (P_1) by open pollination families, the 3 kernels and ears of male parent (P_2) by open pollination families as a consequence of parental role exchanged, the 3 kernels and ears of regular first generation (F_{1Reg}) by artificial hands crossing families and the 3 kernels and ears of reciprocal first generation (F_{1Res}) by artificial hands crossing families, were generated as data sources.

Variable observed and data collection: There were 2 main data observed in accordance with xenia and metaxenia phenomena measurements. The xenia phenomenon included both kernels number and 100 kernels weight (g). The kernel number was determined by counting all kernels of each ear in 3 replications of all families observed. While, the 100 kernels weight was weighted 100 kernels in 3 times of each families. The metaxenia phenomenon was also provided in to 2 measurements i.e., ear length (cm) and diameter (mm). The ear length were measured by line measurement of the three ear in three times of each family and the ear diameter was measured in the center part of the ear in 3 times of each families.

Statistical analysis: The data of selfing parentals (P_1 and P_2), F_1 kernels and ears from regular and reciprocal crossings gathered from complete diallel cross were calculated the mean and standard deviation from the mean values of those observed variables according to Steel and Torrie[21] procedure. The one tail paired t-test at 0.05 significant level was performed to judge the different between F_1's kernel or ear of regular or of reciprocal crossings and the open pollinated male parent (P_2) by statistical package[22] of SAS for Windows version 6.13. The research where summarized: (i) xenia/metaxenia is expressed when P_1< or >$F_1 = P_2$, P_1<F_1< P_2, P_1<F_1>P_2, P_1>F_1>F_1 and (ii) xenia/metaxenia is not expressed when P_1>F_1<P_2.

RESULTS

100 kernel weight: Mean value expression of 100 kernel weight (g) as xenia component phenomenon in this field observation were partly expressed on 4 crossing pairs.

Table 1: Pairing t-test of xenia component phenomenon of 100 kernel weight (g) between parentals cross pairings and their hybrid (F_1)

Crossing pairs ($P_1 \times P_2$)	100 kernel weight (g) P_1	F_1	P_2	t-stat	p ($T \leq t$) one tile
Bonanza×Ganebo	11.578	13.117	13.742	-12.860	0.003**
Ganebo×Bonanza	13.742	11.880	11.578	2.036	0.074**
Bonanza×Arumba	11.578	13.813	16.415	-1.169	0.181*
Arumba×Bonanza	16.415	16.223	11.578	57.079	0.000**
Ganebo×Arumba	13.742	16.203	16.415	-0.996	0.212*
Arumba×Ganebo	16.415	15.183	13.742	90.003	0.000**

*Significant, **Highly significant difference at α 0.01

Table 2: Pairing t-test of xenia component phenomenon of kernel number/ear between parentals cross pairings and their hybrid (F_1)

Crossing pairs ($P_1 \times P_2$)	Kernel number/ear P_1	F_1	P_2	t-stat	p ($T \leq t$) one tile
Bonanza×Ganebo	260.000	264.000	241.667	5.154	0.018*
Ganebo×Bonanza	241.667	250.000	260.000	-2.500	0.065*
Bonanza×Arumba	260.000	216.667	212.667	1.512	0.135*
Arumba×Bonanza	212.667	231.000	260.000	-18.985	0.001**
Ganebo×Arumba	241.667	215.000	212.667	0.451	0.348*
Arumba×Ganebo	212.667	229.000	241.667	-8.718	0.006**

*Significant difference at α 0.05, **Highly significant difference at α 0.01

Three of four crossing pairs were negative xenia i.e., crossing pairs between Ganebo and Arumba as male parents and Bonanza and Ganebo as female parents (Table 1). Only crossing between Bonanza as a male parent and Ganebo as a female parent was positive xenia expressed. The positive value of 100 kernel weight in one hand means that the male parent (P_2) was higher value than the female parent (P_1) and their hybrid (F_1) were higher than their male parents. The negative xenia in other hand was the value of 100 kernel weight of the male parent (P_2) higher than their female parent (P_1) and their hybrid (F_1) was lower than their male parent (P_2). The 100 kernel weight of this 3rd male parents were 13.742, 11.578 and 16.415 g, respectively, whereas their 4th hybrid kernels in respective were 13.117, 11.880, 13.813 and 16.203 g. Two crossing pairs were not indicated xenia expression namely crossing between Bonanza and Ganebo as male parents and Arumba as a female parent, because their hybrid were higher or equal than their female parent.

Kernel number/ear: The mean kernel number/ear as another xenia component phenomenon observed in this experiment was generally xenia expressed. Almost all of the crossing pairs in kernel number/ear variable which showing xenia phenomenon were expressed. These were crossing between Bonanza, Arumba and Ganebo as male parents and Ganebo, Bonanza and Arumba as female parents, depended on their cross pairings. Ganebo male parent affect Bonanza female parent in xenia expression as showed in Table 2. There were

Table 3: Pairing t-test of metaxenia component phenomenon of ear diameter (mm) between parentals crosses pairings and their hybrid (F_1)

Crossing pairs	Ear diameter (mm)				p (T≤t)
($P_1 \times P_2$)	P_1	F_1	P_2	t-stat	one tile
Bonanza×Ganebo	520.000	526.000	560.000	-6.425	0.012*
Ganebo×Bonanza	560.000	536.667	520.000	4.336	0.025*
Bonanza×Arumba	520.000	462.000	454.000	0.667	0.387*
Arumba×Bonanza	454.000	524.333	520.000	1.463	0.140*
Ganebo×Arumba	560.000	449.667	454.000	-2.335	0.072*
Arumba×Ganebo	454.000	548.667	560.000	-3.213	0.042*

*Significant difference at α 0.05

Table 4: Pairing t-test of metaxenia component phenomenon of ear length (cm) between parentals crosses pairings and their hybrid (F_1)

Crossing pairs	Ear length (cm)				p (T≤t)
($P_1 \times P_2$)	P_1	F_1	P_2	t-stat	one tile
Bonanza×Ganebo	21.500	19.533	18.700	25.000	0.001**
Ganebo×Bonanza	18.700	20.500	21.500	-5.774	0.014*
Bonanza×Arumba	21.500	16.633	17.600	-2.271	0.076 *
Arumba×Bonanza	17.600	16.967	21.500	-16.615	0.002**
Ganebo×Arumba	18.700	17.567	17.600	-0.076	0.473^{ns}
Arumba×Ganebo	17.600	21.633	18.700	13.420	0.003**

ns: Not significant difference, *Significant difference at α 0.05, **Highly significant difference at α 0.01

2 positive xenia expressed in this variable observed because the kernel number/ear of the male parents were lower than the female parents. These were crossing pairs between Arumba as male parent and Bonanza and Ganebo as female parents. The remaining crossing pairs were negative xenia due to the mean value of kernel number in male parents were lower than in female parents, i.e., crossing pairs between Bonanza and Ganebo as male parents and Ganebo and Arumba as female parents. Only one crossing pair that could not expressed the xenia phenomenon, i.e., crossing between Ganebo as a male parent and Bonanza as a female parent.

Ear diameter: All of crossing pairs (Table 3) were indicating metaxenia expressed in this mean ear diameter (mm) observation. The 3 of them were positive metaxenia expressed and the 3 of remainings were negative metaxenia. The three positive metaxenia expressed were crossing pairs between Bonanza and Arumba as male parents and Ganebo, Bonanza and Arumba as female parents, while the 3 remaining negative metaxenia expressed were crossing pairs between Ganebo and Arumba as male parents and Bonanza, Ganebo and Arumba as female parents.

Ear length: The last component of metaxenia in this experiment observed variable was mean value of ear length (cm). Table 4 showed that there were 2 positive and 3 negative metaxenia inheritances in accordance with ear length as observed variable. One of others was no metaxenia expressed. The 2 positive metaxenia inheritance was expressed in crossing pairs between Ganebo as a male parent and Bonanza and Arumba as female parents. Whereas, the three other crossing pairs indicating the negative metaxenia expressed i.e., crossing between Bonanza and Arumba as male parents and Ganebo and Bonanza as female parents. The only one of no metaxenia expressed was crossing pairing between Bonanza as a male parent and Arumba as a female parent.

DISCUSSION

Table 1 showed that the positive xenia of hybrid in 100 kernel weight (g) resulted from crossing between the lower value of a male parent (Bonanza) and the higher value of a female parent (Ganebo). Whilst, the xenia component inherited in negative value produce from crossing between the higher rate of male parents (Ganebo and Arumba) and the lower value of female parents (Bonanza and Ganebo). This fact showed that the use of the third hybrid varieties as male parents could inherited the 100 kernel weight to their hybrids when applied complete diallel crossing although not all crossing pairs (regular and reciprocal) will result in xenia phenomenon. From this fact, the xenia particularly in 100 kernel weight could be considered for rising maize production. The xenia phenomenon has been mainly proposed for improving maize yield[23-25]. The hypothesis assigns the mechanism of xenia to the action of hormones produced by the embryo or the endosperm[26,27]. Hormones produced by the seeds, mainly Auxins, would be responsible for fruit growth and the number of seeds (and presumably their mass) would be positively correlated with fruit size[28]. However, this general and constant effect of hormones, independent of the male genotype, would not account for the much more specific male character states transmitted to fruits affected by xenia[26]. The hormonal hypothesis would not explain the lack effect of the Auxins on the embryos and the endosperm themselves, which produce them[29]. Such receptors are likely to be necessary in the tomato fruit cells for the xenia traits to be expressed, but they may not be expressed or active in the embryo and/or endosperm cells during fruit morphogenesis, which would explain why the hormone effect might not affect the embryo or the endosperm[16]. Another cases are nut size and yield in *Macadamia integrifolia* Meiden and Betche and *Macadamia tetraphylla* L.A.S. Johnson[28] who have reported the same indication on this plants.

Amount of 2 hybrids (F_1's) were positive and another 3 remaining were negative xenia in kernel number/ear. It was because the male parents had the higher values compared to the female parents for positive xenia, whereas, if the male parents had the lower values compared to the female parents, it was negative xenia. Only crossing pair between Ganebo as male parent and Bonanza as female parent was not express xenia phenomenon mainly in kernel number/ear (Table 2). Even though the 3 parental crossing pairs were xenia in negative values, the 3 hybrids resulted were in the near amount of male parents kernel numbers. As a result, from three parentals these crossing pairings were incompletely inherited the xenia phenomenon particularly in kernel numbers even negative. Some characters that have been shown to be affected by the xenia effect in other species are also related to seed size, indicating that the phenomenon was not rare. Seed characteristics like height (mm), width (mm) and thickness (g) of grape cv. "Narince" (*Vitis vinifera* L.)[5], seed size in *Vicia faba* L.[29], seed and embryo size in *Gossypium hirsutum* L.[30] and grain weight and grain yield in *Zea mays*[31-33] were expressed in xenia component. In other cases, the effects were in chemical contents, not weight: endosperm composition and enzymatic activity in *Zea mays* L.[33], oil and fatty acid content in *Prunus amygdalus* Batsch[34].

The 3 crossing pairs showed increase in the ear diameter of their hybrid in which they were higher than their male parents, but another three crossing pairs were lower than their male parents. One regular crossing pair between the higher ear diameter of male parent and the lower one of female parent and the remaining 2 reciprocal crossing pairs were between the lower ear diameter of female parents and the higher ear diameter of male parents were positive metaxenia expressed. Ear diameter as a yield component indicating metaxenia expressed on all crossing pairings as showed in Table 3. The metaxenia effect in diameter variable with the higher diameter in their hybrids compared to the parents as source of pollen were crossing pairs between Bonanza and Arumba as male parents of the respective lower and higher ear diameter and Ganebo, Bonanza and Arumba as female parents of the higher and lower ear diameter, respectively. This finding were similar to the another reports namely by Weiland[35] in maize (*Zea mays* L.), Olfati *et al*.[36] in cucumber (*Cucumis sativus* L.), Piotto *et al*.[16] in tomato (*Lycopersicon esculentum* L.), Al-Khalifah[37] in date palm (*Phoenix dactylifera* L.) and Shanker *et al*.[38] in sunflower (*Helianthus annuus* L.), but different with Militaru *et al*.[39] in average of fruit weight of scab resistant apple (*Malus domestica* L.) varieties and Tsuda *et al*.[40] in *Brassica juncea* L. cv. Kikarashina × *B. napus*.

Hybrid variety of Ganebo as a male parent and Bonanza and Arumba as female parents were appropriately in this crossing scheme due to the ability to inherit the ear length to their hybrid (Table 4). There were 3 crossing pairs indicated the lower value of their hybrid compared to their male parents, which were crossing pairs between Bonanza and Arumba as male parents and Ganebo and Bonanza as female parents. This finding is in disagreement with Zhang *et al*.[41] in *Castanea henryi* in several quality traits observed and Militaru *et al*.[39] in fruit quality scab resistant apple varieties in which the inheritance of this trait was in unpredictable patterns. The predictable patterns in several traits of subtropical maize were indicated in Iqbal *et al*.[42] which reported the crossing between 4 parental lines that expressed the 2 class of heterosis i.e., mid parent- and better parent-heterosis. In mid parent heterosis, the hybrid (F_1) obtained would be lower than the male parent (P_2) and the female parent would also be lower than their hybrids. Meanwhile the better parent heterosis would be the hybrid which has the higher value than both female and male parents. This observed variable, both Bonanza and Arumba varieties could be used as female parents and Ganebo as a male parent in yielding the inheritance of ear diameter as metaxenia component.

From these findings, the Bonanza variety as male parent resulted in xenia effect particularly in 100 kernel weight when crossed with Ganebo as female parent, whereas the Arumba variety as male parent was appropriately in crossed with both Bonanza and Ganebo varieties as female parents in expressed the kernel number/ear. In one side, the 2 varieties of Bonanza and Arumba as male parents were appropriate when crossing with Ganebo, Bonanza and Arumba as male parents in resulting the metaxenia effect especially the ear diameter. But, in other sides, the Ganebo variety as male parent when used as male parent and Bonanza and Arumba as female parents could be resulted the ear length as another metaxenia component. Only 2 crossing pairs that could be resulted the better parent heterosis in this observation mainly in expressed metaxenia i.e., crossing between Bonanza as male parent and Arumba as female parent in ear diameter and Ganebo as male parent and Arumba as female parent in ear length. There was no xenia expressed in this observed variable particularly in the 100 kernel weight and the kernel number/ear.

CONCLUSION

The xenia components phenomenon were expressed in 100 kernel weight (g) and kernel number/ear. These cross pairings were between Ganebo x Bonanza which expressed in 100 kernel weight and Arumba as male parent and Bonanza and Ganebo was expressed in kernel number/ear. The metaxenia components phenomenon were expressed in ear diameter (mm) and ear length (cm). Crossing pairings of parentals i.e., between Bonanza and Arumba as male parents and Ganebo, Bonanza and Arumba were expressed in ear length (mm) trait, while the cross pairings between Ganebo as male parent and Bonanza and Arumba as female parents were also expressed in ear length (cm).

SIGNIFICANCE STATEMENTS

This paper reported the results of study on maize xenia and metaxenia phenomena derived from hybrid varieties as parents and generated from complete diallel cross mating. Results generated here help plant breeder to form new superior variety of maize based population in shorted time. The crossing of some parental pairing would be generated the best progeny to form a promising new candidate of a superior variety that could be developed further.

ACKNOWLEDGMENT

This project was supported by a grant No. 056/SP2H/LT/DRPM/2018; January 30, 2018 which was made available by the Ministry of Research, Technology and Higher Education of Republic of Indonesia to the Department of Research and Development and Social Services of Halu Oleo University and the corresponding author.

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