


Environmental and physiological effects on cross-ability and seed production of greenhouse cucumber¹

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ABSTRACT - Seed production depends on many factors. In this study, two independent experiments were carried out to investigate the effects of pollination time, crossed node spacing, male flower age, number of crossings on each plant and deletion/non-deletion of other fruits in the crossed nodes on the cross-ability and seed production in greenhouse cucumber. In every experiment, three mentioned factors were assayed based on factorial experiment as a randomized complete block design. Crosses were done on 10 plants in every replication of treatments. The results showed that pollination at 8:00–9:45 AM, led to higher amount of full seed weight in contrast to other times of pollination. Increasing crossed node spacing from 2–3 to 4–5 nodes led to an increase in the number of empty seeds, which was ascribed to the reduced seed production. The highest amount of number of seeds per fruit, seed weigh and number of full seeds were obtained when young male flowers were used. Moreover, higher seed production was obtained from five, instead three crossings on each plant, and the non-deletion of fruits on the crossed nodes. Overall, higher percentage of seed production per fruit was obtained when crossing was done with young male flower in early morning and high number of crossing in every plant.

Index terms: pollination time, male flower age, crossed node spacing, seed production, *Cucumis sativus* L.

Efeitos ambientais e fisiológicos na capacidade de cruzamento e produção de sementes de pepino em estufa

RESUMO - A qualidade das sementes depende de muitos fatores. Neste estudo, foram realizados dois experimentos independentes para investigar os efeitos do horário da polinização, espaçamento dos nós cruzados, idade da flor masculina, número de cruzamentos em cada planta e deleção ou não de outros frutos dos nós sobre a capacidade de cruzamento e produção de sementes de pepino em estufa. Em cada experimento, três fatores mencionados foram analisados com base no experimento fatorial de um bloco completo delineado aleatoriamente. Cruzamentos foram feitos em dez plantas em cada replicação de tratamento. Os resultados de ambos os experimentos mostraram que a polinização realizada de 8:00 às 9:45 h levou a maior quantidade de sementes completamente cheias em comparação com os outros horários de polinização. O aumento da distância entre os nós utilizados para o cruzamento de 2-3 para 4-5 levou ao aumento do número de sementes vazias, contribuindo para a redução na produção de sementes. Maiores valores para número de sementes por fruto, peso total de sementes e número de sementes completas foram obtidas quando foram utilizadas flores masculinas jovens. Além disso, maior produção de sementes foi obtida com cinco, em vez de três, cruzamentos em cada planta e a não eliminação de frutos dos nós dos cruzamentos. Alta porcentagem de sementes por fruto foi obtida quando os cruzamentos foram feitos em flores masculinas jovens no início da manhã e com maior número de cruzamentos em cada planta.

Termos para indexação: horário de polinização, idade da flor masculina, cruzamento, produção de sementes, *Cucumis sativus* L.

Introduction

Cucumber (*Cucumis sativus* L.) that is a commercially

important cucurbitaceous vegetable is grown throughout the world. Cucumber that is Originated in India or China, is a member of the Cucurbitaceae family (Harlan, 1975), which

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comes in different types used either fresh or processed (Shetty and Wehner, 2002). It is grown for its tender fruits which are consumed either raw in salads, cooked as vegetable, or prepared as pickling cucumber in its immature stage. Cucumber is a rich source of vitamins B and C, carbohydrates, Ca and P (Yawalkar, 1985).

Cucumbers and gherkins can be grown in many areas. Their production can be optimized if there is support from the relevant government bodies to develop better seeds and combat such attackers as fruit flies. Based on FAOSTAT, in 2016-2017, global fruit production was 82,140.422 tons in the world and Iran's fruit production was 18,314.57 tones, as Iran ranked third in the world. To meet ever growing demand for cucumber, the use has been made of the F_1 hybrid seed. The last few decades have witnessed a dramatic increase in the hybrid seed production, taking advantage of heterosis, improved technology, and controlled environments (Nerson, 2007). Considerable heterosis is manifested in the various cucumber traits such as number of fruits per plant, earliness, and high yield (Airina et al., 2013). The first demand for producing F_1 hybrid seed is inbred lines. For this purpose, selected plants need to be self-pollinated for six to seven generations, which requires both female and male flowers. However, cucumber plants produce different sex phenotypes: monoecious (staminate and pistillate flowers), gynoeceous (pistillate flower only), and hermaphroditic (perfect flowers) (Staub et al., 2008). It is, therefore, necessary to induce sex expression in cucumber. After crossing the male and female flowers, different factors come into play that can affect fruit yield and quality.

The seed production is quantitatively and qualitatively affected by several factors such as mother plant nutrition, climate conditions of the seed production area, number of fruits per plant, and number of seeds per fruit. An understanding of the relationships among these parameters leads to production of better F_1 cucumber seeds with higher yields (Cebeci and Padem, 2014). Maximum seed yield will be achieved under practices that promote the best compromise between maximum fruit numbers and minimum decline in seed per fruit (Ghanbari et al., 2007).

Pollination involves the release, transport, and deposition of pollen from anthers to the stigma (Brevis et al., 2006). The amount of pollen required for the fruit set depends on the number of pistillate flowers produced by the cucumber cultivar (Wehner and Kumar, 2012). The fruit and seed set in flowering plants are affected by a variety of biotic and abiotic factors, the main biotic ones being pistil receptivity, pollen viability, and pollen load size (Nepi and Pacini, 2001). For fertilization to occur, the pollen landing on stigma during the effective pollination period must be viable and able to

germinate while it is also capable of penetrating the stigma and the style to reach the ovule (Shivanna et al., 1991).

On the other hand, anthesis, pollen dehiscence, and fruit set in cucurbits affect seed production. Also, they are affected by environmental factors themselves. Usually, fruit set takes place in early morning between 6:00 AM to 8:00 AM in crops like open field cucumber, pumpkin, and watermelon. The optimum temperature range being between 13-18 °C during this period (Rajan and Markose, 2007). Munger (1988) found that pistillate flowers of cucumber are receptive to pollination for at least 24 hours after anthesis. Wehner and Horton (1989) confirmed that cucumber pollination can take place successfully in the greenhouse on the day immediately after anthesis. They also found that cucumber pollination failed when temperature exceeded 35 °C in North Carolina State. Maximum fruit set is obtained in the early phases of pistillate or perfect flowers and such fruits are called 'crown set' which are developed to full size and produce good plump seeds. Therefore, early pollination with viable pollen may lead to poor seed setting due to the non-receptivity of stigma; similarly, poor seed sets may be obtained because of dry stigma or loss of pollen viability if flowers are pollinated very late (Patil et al., 2008). If early sets are missed, fruits inferior will be produced in size and quality due to late maturation (Rajan and Markose, 2007). Moreover, the quantity of pollen depositing on stigma can be manipulated by adjusting the crossing ratio of female and male flowers. Thus, both pollination time and female/male flower crossing ratio need to be optimized in order to obtain higher seed sets (Patil et al., 2008).

Climatic effects have also been reported on pollen flow (Gingras et al., 1999). Wind velocity, temperature, and other environmental factors may influence on flower sets, thereby affecting out-crossing (Kalbarczyk, 2009; Robinson and Decker-Walters, 1997). Finally, the ratio of staminate to pistillate flowers, and thereby out-crossing, are also affected by climatic conditions.

The objective of the present study is four-fold: 1) to investigate the effects of different pollination times on seed production; 2) to identify the effects of male flower age in seed formation; 3) to investigate the effects of different numbers of crossed fruits on each plant in seed production; 4) to evaluate the effects of deletion or non-deletion of fruits on each crossed node on seed production.

Material and Methods

This experiment was conducted at Research Greenhouse of Agricultural Department of Islamic Azad University, Isfahan (Khorasgan) Branch, in Isfahan, Iran, (51°36' longitudes, 32°63' latitude and 1555 m altitude).

The parent cultivars, Danish (female parent) and Zohal (male parent), were planted in May 2015 for the spring season, in pitmas, perlite and cocopit bed. The space between and within couple rows was 90 cm and 50 cm, respectively, and 180 cm between every couple row. Dichlorvos, Trigard, Vertimec and Organic neem oil were applied for insect control. The greenhouse air temperatures at the growing period was 25-30 °C day/19-21 °C nights with a relative humidity of about 50%. Different fertilizers including potassium nitrate, ammonium nitrate, magnesium nitrate, iron, and such other mineral fertilizers as sulphate dissolved in water were used based on soil analysis. Standard production practices for cucumber were used throughout the growing season. Drip irrigation was applied when needed. The source of water was urban water with electrical conductivity (EC) of 0.4 dS m⁻¹. The pH of the irrigation water was adjusted to 6.5 by nitric acid.

This study was conducted as two separate factorial experiments performed as a randomized complete block design (RCBD) with six replications. The first experiment was performed to assess the three factors of pollination time (A) at different hours of the day at 8:00–9:45 AM, 10:00–11:45 AM, and 12:00–13:45 PM; two levels of crossed node spacing (B) including 2–3 nodes and 4–5 nodes; and two age levels of male flower (C), that is, old male flowers (one day after opening) and young male flowers (on the day of opening). The second factorial experiment was devoted to investigate three factors of pollination time (A) at different hours of the day at 8:00–9:45 AM, 10:00–11:45 AM, and 12:00–13:45 PM; number of crossings on each plant (D) including 3 and 5 crossings; and deletion or non-deletion of other fruits (E) on the crossed nodes.

The temperature and humidity of greenhouse at 8-9:45 AM were 25-27 °C and 40-45 %, respectively, at 10-11:45 AM were 30-32 °C and 25-30 %, respectively and at 12-13:45 PM were 38-40 °C and 20-25 %, respectively.

As two parents were gynoecious varieties (only female flower), gibberellic acid (Merck Schuchardt OHG) with a concentration of 1500 ppm was used on the Zohal genotype as the male parent at the 2–4 leaf stage at intervals of one to three weeks, in order to induce male flower production. In each replication, 10 plants were selected and crossings were accomplished based on each factor in each plant when 25 to 30 nodes were appeared. For example, when the male and female flowers reached adequate development, crossings were accomplished at the appropriate time based on factor A for the two experiments. Pollination was accomplished by touching the open anther sac of 2 male flowers from the donor parent to one stigma of each recipient flower in the female parent. All the pollinations were performed during the first three weeks of flowering when both female and male flowers were highly fertile.

The crossed ripe fruits were harvested 45 days after crossing, and then seeds were extracted from each fruit and placed in a container of water for 48 hours to be subsequently washed. The quantity of the seeds was determined after drying. Traits of interest were measured on ten plants per replication; these included: X1: Fruit length (cm), X2: fruit middle diameter (cm), X3: fruit weight (g), X4: seed production percentage in each fruit (%), X5: total dry seed weight (g), X6: empty seed weight (g), X7: full seed weight (g), X8: empty seed number, and X9: full seed number.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) of Statistical Analysis System program (SAS Version 9). Mean comparison was carried out by using SAS and MSTATC software. Means were compared by LSD tests at 5%.

Results and Discussion

Experiment 1

Pollination time (factor A) had significant effects on fruit length and diameter (Table 1). The spacing between crossed nodes (factor B: 2–3 nodes or 4–5 nodes) also had significant effects on fruit diameter, fruit weight, and empty seed number. Finally, male flower age (factor C) had significant effects on all studied traits (Table 1).

The interaction effect of pollination time × crossed node spacing did not have significant effects on studied traits (Table 1). The interaction of pollination time × male flower age, however, had significant effects on the percentage of seed production, total dry seed weight, full seed weight, and full seed number. Also, the interaction effects of crossed node spacing and male flower age had significant effect on fruit length and diameter as well as full seed numbers. The interaction of pollination time × crossed node spacing × male flower age (triple interactions) did not show any significant effects on studied traits.

Effects of pollination time on the traits studied

In this experiment three different pollination day times (i.e., 8:00–9:45 AM, 10:00–11:45 AM, and 12:00–13:45 PM) were carried out. It was found that pollination at 12:00–13:45 PM results in an increase in the fruit length and diameter in contrast to other two pollination times (Table 2), although traits related to seed production were higher at 8:00–9:45 AM. Dempsey and Boynton (1962) reported that time of the day, fertility status of the plant, and plant age might affect stigma

receptivity. It has also been reported that stigma receptivity decreases with increasing the temperature at early and intermediate stages, whereas higher receptivity values have been recorded at later stages with temperature increasing from 18.3 to 25.7 °C (Charles and Harris, 1972). Other important point is that pollen grains must have some moisture content at anthesis, and to maintain water levels they may manipulate carbohydrate levels in the cell membrane. Pollen viability also appeared to change depending on temperature, which could be closely tied to water loss. Low relative humidity had also been shown to reduce pollen longevity (Dafni and Firmage, 2000; Pacini et al., 2006; Franchi et al.,

2007; Fonseca and Westgate, 2005).

It seems that, as a result of reduced greenhouse humidity and increased temperature, pollination at 12:00–13:00 PM led to an enhancement in the stigma receptivity which, in turn, improved fruit growth. Also, the lower seed number and weight at 12:00–13:45 PM caused higher transition of nutrients toward fruit growth. The lowest fruit length and diameter were recorded with pollination times of 10:00–11:45 AM and 8:00–10:45 PM; however, the other traits did not exhibit any significant differences. Overall, pollination time was found to have no significant effects on the studied traits under the greenhouse conditions employed.

Table 1. Results of analysis of variance for different studied traits in experiment 1.

SV	df	Mean Squares								
		Fruit length	Fruit diameter	Fruit weight	Seed production percentage in each fruit	Total dry seed weight	Empty seed weight	Full seed weight	Empty seed number	Full seed number
Block	5	3.31ns	0.06ns	672.86ns	0.05ns	0.01ns	0.02*	0.02ns	1004.44ns	0.06ns
(A)	2	12.89*	0.41*	1316.64ns	0.1ns	0.02ns	0.01ns	0.02ns	3373.5ns	0.12ns
(B)	1	0.10ns	1.86**	6580.97*	0.0001ns	0.01ns	0.01ns	0.01ns	20268.65**	0.00ns
(C)	1	27.57*	0.48*	4992.71*	2.81**	0.91**	0.07**	1.58**	11625.84*	3.21**
(AB)	2	8.49ns	0.07ns	561.60ns	0.02ns	0.01ns	0.01ns	0.01ns	1943.79ns	0.01ns
(AC)	2	5.12ns	0.12ns	1540.3ns	0.6**	0.33**	0.003ns	0.48**	99.43ns	0.72**
(BC)	1	18.34*	0.57*	320.97ns	0.1ns	0.07ns	0.003ns	0.13ns	61341.44**	0.18ns
(ABC)	2	9.38ns	0.18ns	1347.69ns	0.03ns	0.03ns	0.01ns	0.02ns	4247.23ns	0.04ns
Error	55	4.55	0.13	1075.23	0.08	0.04	0.01	0.05	2423.69	0.09
CV	-	8.77	2.12	8.3	2.2	11.11	16.13	19.96	14.09	0.71
Mean	-	24.3	17.02	395.26	12.85	1.80	0.62	1.12	349.48	41.93

*, ** and ns significant at $P < 0.01$, $P < 0.05$ and not significant, respectively.

A: Pollination time (8-9:45 a.m., 10-11:45 a.m. and 12-13:45 p.m.); B: Distance between nodes at each crossing (2 to 3 nodes and 4 to 5 nodes distance); C: Age of male flowers (young and old male flowers). CV: Coefficient of variation.

Table 2. The mean comparison of different studied traits in cucumber under experiment 1.

Traits	Pollination time			Node distance		Male flower age	
	8-9:45	10-11:45	12-13:45	2-3	4-5	young	old
Fruit length	23.68 ab	23.54 b	24.88 a	24.07 a	24 a	23.41 b	24.65 a
Fruit diameter	17.06 ab	16.88 b	17.13 a	16.86 b	17.18 a	16.94 b	17.10 a
Fruit weight	397.16 a	387.08 a	401.52 a	385.70 b	404.82 a	386.94 b	403.59 a
Seed production percentage	13.56 a	12.20 a	12.78 a	12.82 a	12.88 a	17 a	8.69 b
Total dry seed weight	1.82 a	1.68 a	1.74 a	1.77 a	1.73 a	2.07 a	1.43 b
Empty seed weight	0.64 a	0.60 a	0.63 a	0.62 a	0.63 a	0.59 b	0.66 a
Full seed weight	1.17 a	1.07 a	1.11 a	1.15 a	1.09 a	1.47 a	0.77 b
Empty seed number	362.97 a	340.71 a	344.77 a	332.70 b	366.26 a	336.77 b	362.19 a
Full seed number	44.08 a	39.99 a	41.71 a	42.60 a	41.25 a	55.04 a	28.81 b

Means followed by the same letter was not significantly different at 0.05 level using LSD test. The letters compared means in row for every trait in every factor, separately.

Effects of crossed node spacing on the studied traits

Clearly, the highest mean values for fruit diameter, fruit weight, and empty seed numbers corresponded to the 4–5 node spacing (Table 2). The higher values of fruit diameter and weight were obtained with the 4–5 crossed node spacing, compared with those with the 2–3 node spacing, which led to low number of fruits, might be attributed to more nutrients reaching to fruits at this node spacing. Patil et al. (2008) revealed that maintenance of a smaller number of fruit on plants leads to more number of seed on fruit in contrast to when all fruit maintain on plant.

Seed quality depends on many factors such as mother plant nutrition, climate conditions of the seed production area, number of fruits per plant, and number of seeds per fruit (Cebeci and Padem, 2014). As observed in this experiment, increasing the spacing from 2–3 nodes to 4–5 crossed nodes lead to an increase in the empty seed numbers, indicating a declining seed quality. Thus, the transport of more nutrients to the fruit (leading to increasing fruit diameter and weight) results in the reduction in the percentage of seed production; hence, conduce to the greater empty seed numbers. Cebeci and Padem (2014) maintained that seed yield declined with increasing fruit diameter.

Effects of male flower age on the studied traits

Male flower age exhibited significant effects on all the traits investigated. According to Table 2, young male flowers yield higher mean values of seed production percentage per fruit, total seed dry weight, as well as full seed weights and numbers; these findings seem logical reasoning as pollens have shown a greater ability for penetration into the stigma

to fertilize the zygote. In contrast, old male flowers yield high enhanced fruit length, diameter, and weight as well as empty seed weights and numbers. It has been demonstrated that fruit weight and size as well as fruit seed numbers are directly proportional to the pollen load in various species (Mann, 1943; Visser and Verhaegh, 1987; Winsor et al., 1987). So, different number and viability of pollens in old and young male flowers lead to their different responses. Young male flowers are, therefore, proposed for use in production of seeds. On the other hand, old male flowers have been found to affect only seed quality and to produce more empty seeds. Clearly then, young male flowers may be beneficial for hybrid breeding programs that need greater numbers of full and viable seeds. In contrast, higher fruit length, diameter, and weight were achieved with old male flowers; this is quite expected as the nutrition available to plant can be used for filling the fruit when the number of full seeds decreases.

Interaction effects of pollination time and male flower age on the studied traits

The comparison of means for the pollination time \times male flower age interaction showed that not only the total dry seed and full seed weights, but also the percentage of seed production in the fruit for all the three pollination times were higher for young male flowers than that for old ones (Figure 1). More specifically, the highest total dry seed weight was observed for the pollination time at 12:00–13:45 PM and 10:00–11:45 AM in young male flowers (Figure 1). The lowest dry and full seed weights were observed with pollination at 10:00–11:45 AM and 12:00–13:45 PM, when

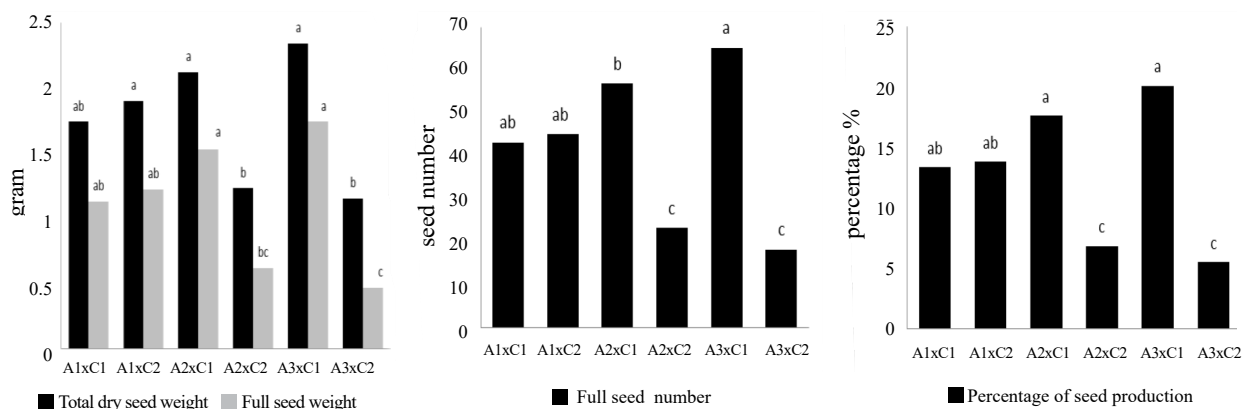


Figure 1. The mean comparison in interaction of effects of pollination time \times age of male flower for some studied traits (Means followed by the same letter in every trait separately, was not significantly different at 0.05 level using LSD test). A1, A2 and A3 are pollination time at 8-9:45 a.m., 10-11:45 a.m. and 12-13:45 p.m., respectively. C1 and C2 are young and old male flowers, respectively.

old male flowers were used (Figure 1). Also, the largest number of full seed number was obtained at 10:00-11:45 AM and 12:00–13:45 PM pollination time with young male flower. In agreement with previously reported results, male flowers were found to have greater effects on dry and full seed weight and number than pollination time, because these three traits show the highest values in crossing with young male flowers for each of the three pollination times. At 12:00–13:45 PM, greenhouse temperature and humidity are favorable to maximum reception of stigma for pollen grains, if female flowers were crossed with young male flowers, which lead to more seed production (weight and number) (Figure 1).

Interaction effects of crossed node spacing and male flower age on the studied traits

Based on Figure 2, fruit length increased when female flowers were crossed with old male flowers at two different crossed node spaces. This means that the old male flowers were not able to produce full seeds in the fruit and, thus, only fruit length increased. On the other hand, the least fruit diameter was recorded with the 2–3 crossed node spacing in young male flowers. It may be claimed that the nutrition available to plant was used for seed production rather than for fruit pericarp production in this situation. The highest empty seed number (Figure 2) was obtained with crossing with old

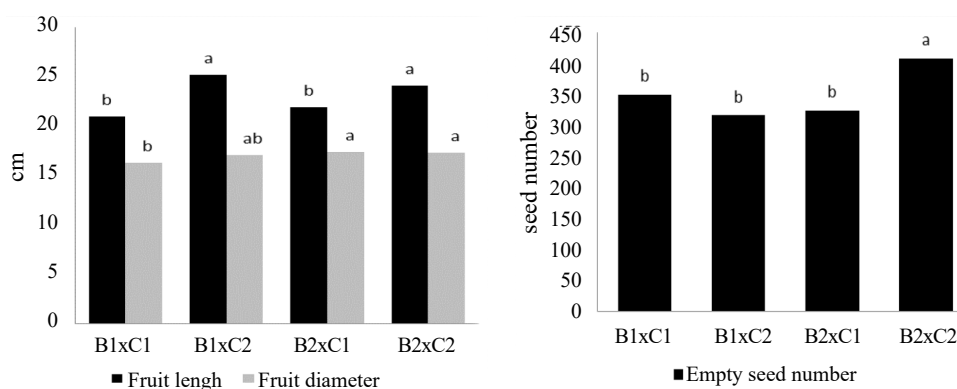


Figure 2. The mean comparison in interaction effects of distance between crossed nodes \times age of male flower for some studied traits (Means followed by the same letter in every trait separately, was not significantly different at 0.05 level using LSD test). B1 and B2 are 2 to 3 nodes distance and 4 to 5 nodes distance between crossed nodes at each plant, respectively. C1 and C2 are young and old male flowers, respectively.

Table 3. Results of analysis of variance for different studied traits in experiment 2.

SV	df	Mean Squares								
		Fruit length	Fruit diameter	Fruit weight	Seed production percentage in each fruit	Total dry seed weight	Empty seed weight	Full seed weight	Empty seed number	Full seed number
Block	5	0.53 ^{ns}	0.08 ^{ns}	823.22 ^{ns}	20.63*	0.11*	0.01 ^{ns}	0.12 ^{ns}	4402.3 ^{ns}	169.95*
(A)	2	0.03 ^{ns}	0.04 ^{ns}	65.66 ^{ns}	1.99 ^{ns}	0.02 ^{ns}	0.01 ^{ns}	0.01 ^{ns}	733.92 ^{ns}	3.31 ^{ns}
(D)	1	0.72 ^{ns}	6.01**	49.77 ^{ns}	1016.23**	3.06**	0.37**	5.20**	74899.59**	10401.65**
(E)	1	0.59 ^{ns}	2.95**	299.97 ^{ns}	449.71**	1.95**	0.47**	3.91**	42415.34**	4614.73**
(AD)	2	0.01 ^{ns}	0.01 ^{ns}	44.88 ^{ns}	1.48 ^{ns}	0.01 ^{ns}	0.003 ^{ns}	0.01 ^{ns}	967.27 ^{ns}	16.69 ^{ns}
(AE)	2	0.02 ^{ns}	0.01 ^{ns}	0.31 ^{ns}	0.85 ^{ns}	0.01 ^{ns}	0.0009 ^{ns}	0.01 ^{ns}	2810.07 ^{ns}	32.35 ^{ns}
(DE)	1	0.32 ^{ns}	0.43*	76.57 ^{ns}	52.78**	0.07 ^{ns}	0.16**	0.39*	12661.76*	249.74*
(ADE)	2	0.11 ^{ns}	0.02 ^{ns}	36.16 ^{ns}	2.80 ^{ns}	0.03 ^{ns}	0.001 ^{ns}	0.02 ^{ns}	1061.42 ^{ns}	46.20 ^{ns}
Error	55	0.28	0.13	490.27	7.33	0.05	0.01	0.06	2297.4	62.39
CV	-	2.22	2.13	5.65	19.01	11.18	12.5	19.91	11.82	17.61
Mean	-	23.63	17.16	391.88	14.20	2.00	0.80	1.23	405.63	44.86

*, ** and ns significant at $P < 0.01$, $P < 0.05$ and not significant, respectively.

A: Pollination time (8-9:45 a.m., 10-11:45 a.m. and 12-13:45 p.m.); D: Cross number in each plant (3 and 5 crosses); E: Fruit deletion (deletion or non-deletion other fruits in crossed nodes). CV: Coefficient of variation.

male flowers in 4–5 node spacing, which confirms the findings cited above. Also, the lower distance between crossed nodes led to a reduction in the empty seed numbers.

Experiment 2

Pollination time (A), clearly, had no significant effects on the traits investigated (Table 3). The number of crossings on each plant (D) (3 and 5 crossings) had significant effects on all the traits studied, except for fruit length and weight. Similarly, deletion or non-deletion of other fruits on crossed nodes (E) had significant effects on all the traits studied, except for fruit length and weight (Table 3). The interaction effect of number of crossings \times deletion or non-deletion of other fruits in the crossed nodes had significant effects on all the traits studied, except for fruit length, fruit weight, and total dry seed weight (Table 3).

Effects of number of crossing in each plant on the studied traits

The number of crossings on each plant exhibited significant effects on all traits studied, again except for fruit length and weight. According to Table 4, three crossings on each plant gave rise to higher mean values of fruit diameter and empty seed numbers and weight. In contrast, the five crossings on each plant gave rise to higher mean values of seed production percentage in each fruit, total dry seed weight, and full seed weight and numbers. Kumar et al. (2008) reported that the effects of crossing ratio and pollination time on fruit yield, fruit set, seed yield, and quality parameters like seed weight per fruit, number of seeds per fruit, 1000 seed weight, seed weight per plant, germination, root length, and shoot length of tomato were significantly higher when pollination was performed at 10:00 to 11:00 AM with a crossing ratio of 4:1 (female to male ratio) compared to other combinations. Therefore, the five-crossing on each plant may be

suggested for seed production in greenhouse situations. This may also be beneficial for producing more full seeds. Higher numbers of crossings on each plant may also be suggested. Cebeci and Padem (2014) reported that 6–8 fruits per plant was the most suitable as it gave rise to higher seed yields with the least decline in seed quality. Jolli et al. (2009) reported that retention of five fruits per plant in tomato records significantly higher seed weights per fruit and number of seeds per fruit. However, higher seed yields per plant have been recorded with 15-fruit per plant compared to the 5-fruit per plant.

Chen (2003) stated that the seed yield of the hybrid Brinjal is dependent on the number and size of the normally fertilized fruits borne on seed parents. The optimal fruit loading on the plant was reported to be around 4–6, 6–10, and 12–15 for the large, medium, and small fruit types, respectively. This loading was adequate to set an average fruit yield.

Effects of deletion/non-deletion of other fruits in the crossed nodes on studied traits

Deletion or non-deletion of other fruits on the crossing nodes had significant effects on all the traits studied, except for fruit length and diameter. As a rule, seed quality is enhanced but its quantity declines if fewer fruits are left on the plant, which would be clearly disadvantageous for seed producers. So, a proper balance has to be struck between seed quality and quantity by correctly manipulating the number of fruits left on the plant (Cebeci and Padem, 2014). According to Table 4, fruit deletion on the crossed nodes led to higher mean values of fruit diameter and weight as well as empty seed numbers. In contrast, non-deleted fruits on the crossed nodes gave rise to higher mean values of seed percentage produced in the fruit, dry seed weight, and full seed weight and number.

Table 4. The mean comparison of different studied traits in cucumber under experiment 2.

Traits	Pollination time			Cross number		Fruit deletion	
	8-9:45	10-11:45	12-13:45	3 crossing	5 crossing	Deletion other fruits in crossed nodes	Not deletion other fruits in crossed nodes
Fruit length	23.60 a	23.67 a	23.63 a	23.73 a	23.53 a	23.72 a	23.54 a
Fruit diameter	17.20 a	17.12 a	17.15 a	17.45 a	16.87 b	17.36 a	16.96 b
Fruit weight	391.83 a	390.26 a	393.56 a	391.05 a	392.71 a	389.84 a	393.92 a
Seed production percentage	14.63 a	13.90 a	13.86 a	11.37 b	17.20 a	11.14 b	17.32 a
Total dry seed weight	2.03 a	1.97 a	2.00 a	1.80 b	2.21 a	1.84 b	2.17 a
Empty seed weight	0.81 a	0.78 a	0.82 a	0.87 a	0.73 b	0.88 a	0.72 b
Full seed weight	1.25 a	1.22 a	1.21 a	0.96 b	1.50 a	0.99 b	1.46 a
Empty seed number	410.79 a	399.79 a	406.30 a	437.88 a	373.37 b	429.90 a	381.35 b
Full seed number	45.17 a	44.45 a	44.95 a	32.84 b	56.88 a	36.85 b	52.86 a

Means followed by the same letter was not significantly different at 0.05 level using LSD test. The letters compared means in row for every trait in every factor, separately.

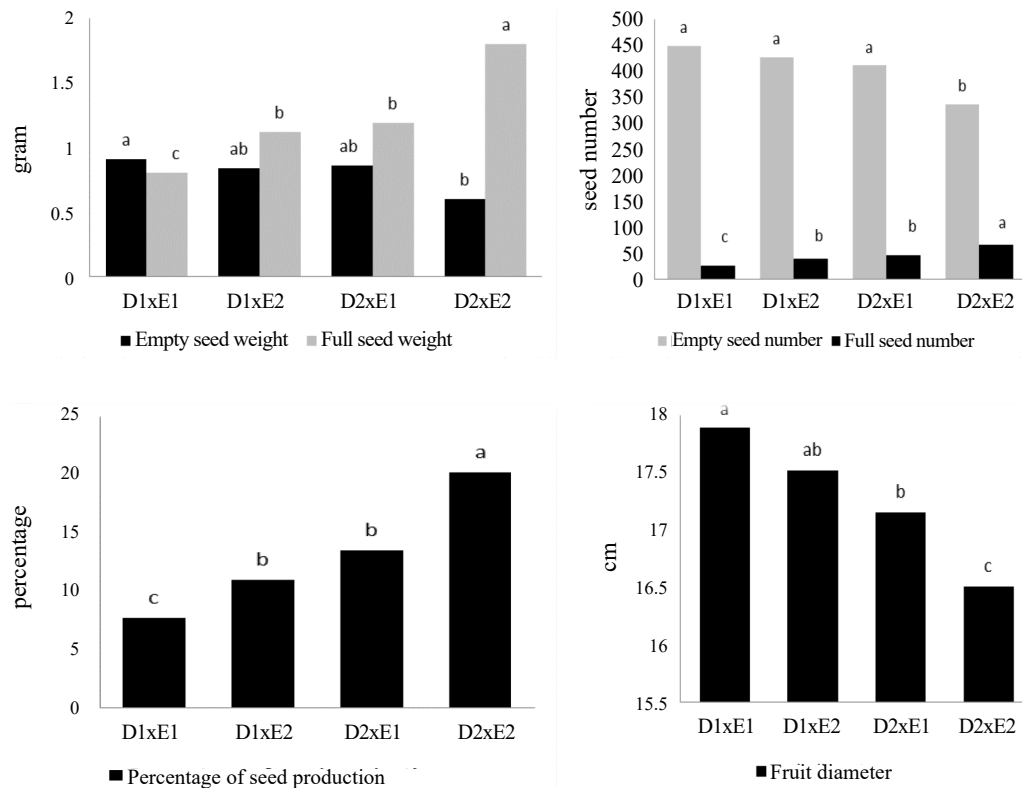


Figure 3. The mean comparison in interaction effects of the number of crossing in each plant \times deletion or not deletion other fruits in crossed nodes for some studied traits (Means followed by the same letter was not significantly different at 0.05 level using LSD test). D1 and D2 are 3 and 5 crossing in each plant, respectively. E1 and E2 are deletion or not deletion other fruits in crossed nodes, respectively).

Interaction effects of the number of crossing in each plant and deletion/non-deletion of other fruits in the nodes on the studied traits

Interaction of the number of crossings in each plant \times deletion/non-deletion of other fruits in crossed nodes showed that larger fruit diameters obtained as a result of three crossings in each plant and deletion of other fruits on the crossing nodes than in the other treatments. In contrast, the highest percentage of seed production in the fruits was obtained for five crossings in each plant and non-deletion of other fruits on the crossing nodes. The lowest seed number and weight and the highest full seed number and weight were obtained for five crossings in each plant and the non-deletion of other fruits in crossed nodes (Figures 2 and 3). Based on the observed results, more fruits on the plant led to an enhancement in the seed quality. After embryo formation, the amount of oxins increases in plant. Therefore, it is possible to increase this hormone in 5 crosses of each plants and no deletion of fruits in nodes leads to more ability of seeds in absorption of nutrients. Simsek (2014) reported that

in hybrid cucumber seed production, the number of crossed fruits could vary from 12 to 24 for hybrid seed production with an acceptable seed quality. Moreover, spring seemed to provide better climatic conditions for high seed yields and high-quality hybrid seeds. There were some important interactions between these factors that difficult choose the best level of studied factors, however it was clear that pollination time did not have serious effect on seed production in these conditions that was probably because of the acceptable greenhouse humidity and temperature in three pollination times for pollen viability and stigma reception.

Conclusions

Increasing crossed node spacing from 2–3 to 4–5 nodes led to an increase in the number of empty seeds, which was ascribed to the reduced number of seed production. The highest number of traits related to seed production was obtained when young male flowers were used. Moreover, higher seed production was obtained from five crossings on each plant, and the non-deletion of fruits on the crossed nodes.

Overall, higher percentage of seed production per fruit was obtained when crossing was done with young male flower in early morning and high number of crossing in every plant. Young male flowers showed positive effect on seed formation in the majority of conditions.

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