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SELF-INCOMPATIBILITY AND EFFECT OF RECIPROCAL CROSS AND OPEN POLLINATION ON FRUIT SET AND FRUIT CHARACTERISTIC IN JORDANIAN ALMOND LANDRACES

S.J. Owais

Department of Plant Production, Faculty of Agriculture, P.O. Box 7, Mu'tah University, Karak, Jordan

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ABSTRACT

Limited studies were carried out to identify self- and cross-compatibility relationships among Jordanian almond landraces. Therefore, this study aimed at studying the level of self-incompatibility and the effect of cross and open pollination on fruit set and shell, nut and kernel related traits in almond. To achieve this objective, field experiments were carried out during 2012 and 2013 cropping season on five Jordanian almond landraces and one wild bitter almond (*A. communis*) available in the farmer's fields at Ajloun district, Jordan. Fruit set was recorded in the field after open-pollination, self-pollination by bagging the branches with flower buds and cross pollination after emasculation of the floral buds. All almond genotypes showed complete self-incompatibility. Genotypes showed variable percentages in fruit set with similar trend in the two growing seasons. Following cross pollination treatment, genotypes exhibited fruit set ranging from 40.3% in Hajari to 94.0% in Fark and from 34.1% in Mukhmaly to 93.3% in Fark in 2012 and 2013, respectively. Results showed that cross pollination of Hami Hallo (79.7-81.7 and 77.8-89.2% in 2012 and 2013 respectively) and Fark (83.0-94.0 and 86.1-93.3% in 2012 and 2013 respectively) with other landraces led to high level of fruit set indicating high cross-compatibility. Slight differences were recorded in fruit set in reciprocal crosses. Pollen source did not affect shell, nut and kernel traits. As a conclusion, results obtained from this study showed that, all of the genotypes were self in-compatible and all genotypes showed high level of cross-compatibility with variable degree among genotypes.

Keywords: Almond, Pollination, Pollen Type, Self-Incompatibility

1. INTRODUCTION

Almond (*Amygdalus dulcis)* is an important fruit crop in Jordan that mainly marketed as fresh consumption. Although cultivated landraces are limited in number, but considerable variation was observed both at morphological and DNA levels indicating that there Jordanian almond landraces are rich and valuable genetic materials for almond improvement (Amarin, 2012). Three almond wild species are available in Jordan including *A. communis*, *A. Korschinskyi* and *A. Arabica* (Al-Eisawi, 1996). *A. communis* is the most prevailing species in northern and central part of Jordan.

Almond is largely self-incompatible which necessitates cross-pollinator to solve fruit set problem (Oukabli *et al*., 2000; 2002; Dicenta *et al*., 2001). For cross pollination, bloom time overlapping between almond cultivars is required to ensure sufficient fruit set and consequently adequate yield (Oukabli *et al*., 2000; 2002; Sharafi *et al*., 2010). The self-incompatibility is controlled by a multi-allelic gametophytic in both pollen and style (Tamura *et al*., 2000; Tao *et al*., 1997). However, in some studies (Godini, 1977; Reina *et al*., 1985), sweet and bitter almond cultivars have been recognized as self compatible cultivar with natural self pollination ranging from 15 to 26%.

Limited studies investigated the effect of self- versus cross-pollination on fruit related traits in almond. One negative consequence of self pollination is irregular shape of the fruits (Grasselly and Olivier, 1976; Torre Grossa *et al*., 1994) and stunted kernels (Torre Grossa *et al*., 1994) following self-pollination. While some studies revealed negative consequences of self pollination, other studies (Legave *et al*., 1997; Dicenta *et al*., 2002) demonstrated no differences between self- versus cross-pollination in morpho-physical traits in almond such as fruit weight, kernel weight, shelling percentage, double kernels, empty nuts and split kernels. Other studies revealed an effect of pollination method on kernel composition (Kodad and Socias i Company, 1987; Alessandroni, 1980) indicating a possible influence of pollen origin on almond kernel quality.

Detailed studies on the effect of pollination method on fruit set and fruit characteristics were not previously studied in almond landraces from Jordan. The objectives of this research were to study the pollen type effects on fruit set and nut and kernel traits in five almond landraces and one wild bitter almond (*A. communis*) and to identify their self-and cross-compatibility relationships.

2. MATERIAL AND METHODS

This study was carried out during 2012 and 2013 growing season on 15 years old almond trees of five Jordanian almond landraces including Oga, Mukhmaly, Hajari, Hami Hallo and Fark. In addition, one wild bitter almond (*A. communis*) that widely distributed in almond orchard in Ajloun area was included in this study. The soil characteristics in the study area sandy loam texture soil (50 sand, 16% silt, 34% clay), alkaline pH (about 7.5), 1.6% organic matter, 780 ppm total Nitrogen (N), 25 ppm available Olsen Phosphorus (P), 18% calcium carbonate, CEC of 60.5 milli-equivalent (mEq) 100 g^{-1} and electrical conductivity (1: 1) of 0.54 dS m^{-1}.

The spacing between trees were 4-5 m. All almond in the study area cultivated under rainfed conditions since suffecient rains for almond growth and development are received (long term annual average rainfall about 550 mm). The trees were similar in their vigor and received similar agricultural practices.

Five trees were selected from each genotype representing five independent replicated. The trees were randomly selected from each genotype. Each tree was divided into 21 independent shoots. Each treatment on individual tree was represented by 3 shoots, resulting 7 treatments on the individual trees. The seven treatments on each individual tree were as follows: Self pollination treatment, open pollination treatment and five cross pollination treatments. For self pollination treatment, the flowering buds were bagged one week prior to flowering opening, while the cross pollination with remaining genotypes was done by bagging shoots after emasculating buds 4-7 days before bud opening and bagged. For cross-pollination treatments, the cheescloth bags were used to eliminate any external pollen grain contamination and to avoid any possible injury to flowers by branch-bagging (Grasselly and Olivier, 1976). Cross-pollinations were made late in the morning. The cheesecloth bags were removed after petal fall. The data are reported as final fruit set, calculated in mid-July, two months after the end of physiological fruit drop in almond. Fruit set was recorded by dividing number of fruit set divided by total number of flowers present on the shoot (Westwood, 1978). Open pollination treatment was represented by three branches without bagging.

Germination test for pollen grains was done using a germination medium consisted of 15% sucrose and two grams of agar which was placed in Petri-dishes, then pollen grains were spread them and thereafter incubated at 20°C for two days (Pinney and Polito, 1990). For each genotype, three fields from each of the three Petridishes were chosen in order to determine the number of germinated pollen grains under light microscope and were presented as percentage of total pollen grains counted in the field.

Fifteen fruits from each replicate for each cultivar were selected to record some physical characteristics of the fruits, including kernel weight (g), kernel length and diameter (cm), kernel shape index (L/W). The kernel weight (g) was calculated by using electrical balance, mean fruit weight length and diameter (cm) were taken to determine the fruit shape. All dimensions were recorded with a caliper with a precision of 0.01 cm.

The experimental design was a Randomized Complete Block Design (RCBD) (treatments consist from combinations of cultivars and pollination treatments in addition to their reciprocal crosses). The experiment was replicated five times. Data were analyzed by one way analysis of variance using the SAS 9.1 and the differences between the means were compared using Fisher's Least Significant Difference (LSD) at $p \leq 0.05$ (Steel and Torrie, 1980).

3. RESULTS

3.1. Fruit Set

Result showed that the percentage of pollen germination was more than 70% in all tested genotypes. Analysis of variances and means comparisons were carried out between individual crosses and their reciprocals. Results revealed that fruit set of individual crosses and their reciprocals ranged from 40.3% in Hajari to 94.0% in Fark and from 34.1% in Mukhmaly to 93.3% in Fark in 2012 and 2013, respectively (**Table 1**). The Final fruit set of crosses were measured successfully because of the optimum conditions for fruit set and development. The bloom period of the five landraces and wild form lasted from 18 February to 2 March. Selfing treatments showed that all cultivated almond landraces and *A. communuis* wild form are self-incompatible genotypes with no fruit set (0%). Results showed the need of external pollinator and local landraces are not able to be cultivated in monovarietal plantations. Therefore establishment of new plantations in solid blocks with pure stands of self-incompatible varieties is not possible.

Table 1. Fruit set of individual crosses and their reciprocals for almond landraces and wild bitter almond *(A. communis)* in 2012 and 2013 growing season

		2012			2013		
Genotype	Treatment	No. of flower	No. of fruit set	Fruit set %	No. of flower	No. of fruit set	Fruit set %
Oga	Cross with Mukhmaly	32.67d-g	16.33h-l	49.67 g-l	42.00 f-k	20.00 g-m	47.87 h-l
	Cross with Hajari	27.33 e-k	13.00 j-n	47.33 h-m	43.00 e-j	27.33 e-g	61.92 e-h
	Cross with Hami Halo	55.00 a	41.67 a	75.67 d	86.00 a	57.33 a	68.52 c-e
	Cross with Fark	25.33 g-m	14.00 j-n	55.67 f-h	32.33 i-m	14.33 i-n	67.63 c-f
	Cross with Wild	28.00 e-k	11.33 l-n	47.33 h-m	38.00 g-l	17.67 g-m	45.71 i-l
	Open pollination	37.67 b-d	15.67 h-m	41.67 l-m	21.67 mn	10.33 l-n	47.67 h-l
Mukhmaly	Cross with Oga	41.00 bc	24.00 c-e	58.33 e-g	39.00 g-l	22.00 g-k	56.23 e-j
	Cross with Hajari	25.33 g-m	13.00 j-n	51.33 f-k	25.67 lm	12.67 j-n	49.84 h-k
	Cross with Hami Halo	37.67 b-d	22.00 c-f	58.67 ef	34.33 g-m	23.00 f-k	66.96 d-f
	Cross with Fark	18.67 l-m	9.67 n	51.67 f-k	26.67 lm	14.33 i-n	53.36 g-k
	Cross with Wild	26.33 e-l	11.00 mn	42.00 lm	22.00 mn	9.00 m-n	40.66 k-l
	Open pollination	22.67 i-m	11.33 l-n	49.67 g-l	11.67 n	4.00 n	34.09 l
Hajari	Cross with Oga	42.33 b	23.67 c-e	55.67 f-h	36.67 g-l	21.33 g-l	58.09 e-i
	Cross with Mukhmaly	51.33 a	25.67 cd	50.00 f-l	52.67 b-f	26.67 e-h	50.62 g-k
	Cross with Hami Halo	55.33 a	36.00 b	65.00 e	57.33 b-d	37.67 de	65.77 d-f
	Cross with Fark	31.67 d-i	20.67 d-h	65.67 e	33.33 h-m	21.67 g-k	64.97 d-g
	Cross with Wild	29.67 e-j	12.00 k-n	40.33 m	35.00 g-m	16.33 g-m	45.68 i-l
	Open pollination	30.00 d-i	16.67 g-k	55.67 f-h	29.00 k-m	13.33 j-n	47.46 h-l
Hami Halo	Cross with Oga	23.67 h-m	19.33 e-i	81.67 cd	56.00 b-e	50.33 a-c	89.18 ab
	Cross with Mukhmaly	30.33 d-i	24.67 cd	81.33 cd	47.33 c-g	37.33 de	79.42 a-d
	Cross with Hajari	26.33 e-l	21 d-g	79.67 cd	64.00 b	53.00 ab	82.00 a-c
	Cross with Fark	33.33 c-f	26.67 c	79.67 cd	31.67 i-m	24.67 f-i	77.83 b-d
	Cross with Wild	27.00 e-k	11.00 mn	41.33 l-m	34.33 g-m	14.33 i-n	42.05 j-l
	Open pollination	22.00 j-m	11.67 k-n	55.00 f-i	59.00 bc	26.00 f-h	45.73 i-l
Fark	Cross with Oga	18.00 m	15 i-m	83.00 b-d	44.00 d-i	39.33 cd	89.44 ab
	Cross with Mukhmaly	21.33 k-m	19.33 e-i	90.67 ab	36.00 g-l	33.33 df	92.07 ab
	Cross with Hajari	34.00 c-e	32.00 b	94.00 a	46.67 c-h	43.33 b-d	93.34 a
	Cross with Hami Halo	30.33 d-i	26.33 c	87.00 a-c	22.33 mn	19.33 g-m	86.11 ab
	Cross with Wild	26.00 f-l	14.33 i-n	54.33 f-j	26.33 lm	12.67 j-n	48.59 h-l
	Open pollination	28.33 e-k	23.33 c-e	81.67 cd	26.00 lm	18.63 g-m	70.67 c-e
Wild	Cross with Oga	28.33 e-k	13.00 j-n	46.67 i-m	32.33 i-m	15.67 hm	48.37 h-l
	Cross with Mukhmaly	31.33 d-h	14.00 j-n	44.00 k-m	30.00 j-m	14.00 i-n	46.31 i-l
	Cross with Hajari	27.33 e-k	18.00 f-j	66.67 e	31.00 i-m	21.00 g-l	66.40 d-f
	Cross with Hami Halo	25.00 g-m	14.67 i-n	58.33 e-g	29.67 j-m	17.00 g-m	57.65 e-i
	Cross with Fark	33.67 c-f	15.33 i-m	45.67 i-m	25.67 lm	12.00 k-n	46.26 i-l
	Open pollination	29.33 e-j	15.33 i-m	53.00 f-j	40.67 f-k	24.67 f-i	59.56 ei
	LSD 0.05	7.73	5.00	8.98	13.45	11.20	14.60

Results revealed that cross pollination of Hami Hallo (79.7-81.7 and 77.8-89.2% in 2012 and 2013 respectively) and Fark (83.0-94.0 and 86.1-93.3% in 2012 and 2013 respectively) with other genotypes led to high level of fruit set. The fruit sets obtained by cross and open-pollination treatments were sufficiently high to provide an abundant crop in all cases (**Table 1**). Highest fruit set mean was observed in the crosses of Fark × Hajari (94%) followed by Fark × Mukhmaly (90.7%), Fark × Hami Hallo (87%) and Fark × Oga (83%) with lowest fruit abscission. Crosses with wild form had the lowest fruit set percentage with minor significant difference in the crosses and their reciprocals (**Table 1**). Regarding the open pollinated treatment that expected to be pollinated by different pollen types; final fruit set was less than the cross pollinated treatments.

Hand cross-pollination allowed very high average fruit set (**Table 1**), which in many landraces tested in this study exceeded the levels of fruit set reported as optimal for almond. The high level of fruit set might indicate that the setting ability might be genotype dependent.

Table 2. Effect of pollen source in almond landraces and wild bitter almond (*A. communis*) on shell fruit traits in 2012 and 2013 growing season

		2012			2013		
Cultivar	Treatment	Shell width (cm)	Shell length (cm)	Shell shape (Ratio)	Shell width (cm)	Shell length (cm)	Shell (Ratio)
Oga	Cross with Mukhmaly	2.40 d	5.62 b-d	2.37 a	2.76 a	5.85 a	2.12 a
	Cross with Hajari	2.42 cd	5.64 bc	2.33 a	2.67 bc	5.65 b	2.12 a
	Cross with Hami Halo	2.44 b-d	5.66 ab	2.32 a	2.77 a	5.76 ab	2.08 a
	Cross with Fark	2.67 a	5.55 d	2.07 b	2.77 a	5.83 a	2.11 a
	Cross with Wild	2.41 d	5.56 cd	2.30 a	2.70 ab	5.70 ab	2.11 a
	Open pollination	2.51 b-d	5.73 a	2.29 a	2.76 a	5.80 a	2.10 a
Mukhmaly	Cross with Oga	1.79 h-j	3.30 e-g	1.85 cd	1.74 h-k	3.24 c	1.86 bc
	Cross with Hajari	1.72 i-k	3.27 f-h	1.89 c	1.74 h-k	3.16 c	1.82 b-d
	Cross with Hami Halo	1.76 h-j	3.28 e-h	1.86 cd	1.79 g-i	3.20 c	1.78 de
	Cross with Fark	1.78 h-j	3.29 e-g	1.85 cd	1.77 g-k	3.19 c	1.81 b-e
	Cross with Wild	1.73 i-k	3.20 h	1.85 cd	1.78 g-j	3.19 c	1.79 c-e
	Open pollination	1.73 h-k	3.24 gh	1.87 cd	1.71 i-k	3.20 c	1.87 b
Hajari	Cross with Oga	1.95 e	2.35 ij	1.20 i	1.90 ef	2.65 d	1.39 f
	Cross with Mukhmaly	1.95 e	2.43 i	1.24 f-i	1.92 e	2.57 de	1.34 f-i
	Cross with Hami Halo	1.93 e-g	2.36 ij	1.22 g-i	1.92 ef	2.44 e-g	1.27 g-k
	Cross with Fark	1.97 e	2.37 ij	1.20 i	1.94 e	2.42 e-h	1.25 j-l
	Cross with Wild	1.883 e-h	2.32 jk	1.23 f-i	1.93 e	2.40 f-i	1.24 kl
	Open pollination	1.94 ef	2.35 ij	1.21 hi	1.93 e	2.55 d-f	1.32 f-j
Hami Halo	Cross with Oga	1.87 e-h	3.36 e	1.71 cd	1.75 g-k	3.15 c	1.71 c-e
	Cross with Mukhmaly	1.82 f-i	3.29 e-g	1.81 cd	1.78 g-i	3.14 c	1.76 de
	Cross with Hajari	1.82 g-i	3.29 eg	1.81 cd	1.72 h-k	3.14 c	1.81 b-e
	Cross with Fark	1.73 i-k	3.23 gh	1.87 cd	1.77 g-k	3.15 c	1.78 de
	Cross with Wild	1.79 h-j	3.27 f-h	1.83 cd	1.73 h-k	3.14 c	1.81 b-e
	Open pollination	1.87 e-h	3.32 ef	1.77 d	1.80 gh	3.14 c	1.74 e
Fark	Cross with Oga	2.51b-d	3.34 ef	1.33 e-g	2.57 d	3.23 c	1.26 j-l
	Cross with Mukhmaly	2.56 ab	3.33 ef	1.30 e-i	2.63 b-d	3.20 c	1.22 kl
	Cross with Hajari	2.47 b-d	3.29 e-g	1.33 e-g	2.58 d	3.24 c	1.26 j-l
	Cross with Hami Halo	2.54 bc	3.35 ef	1.32 e-h	2.61 cd	3.23 c	1.24 kl
	Cross with Wild	2.47 b-d	3.31 e-g	1.34 ef	2.58 d	3.14 c	1.22 kl
	Open pollination	2.47 b-d	3.30 e-g	1.33 e-g	2.63 b-d	3.13 c	1.19 l
Wild	Cross with Oga	1.80 g-j	2.29 j-l	1.27 e-i	1.69 jk	2.28 hi	1.35 fg
	Cross with Mukhmaly	1.68 jk	2.25 kl	1.34 e-g	1.83 fg	2.31 g-i	1.26 i-l
	Cross with Hajari	1.63 k	2.23 l	1.37 e	1.69 k	2.28 hi	1.34 f-h
	Cross with Hami Halo	1.73 i-k	2.26 kl	1.31 e-i	1.80 gh	2.29 hi	1.27 g-k
	Cross with Fark	1.78 h-j	2.30 j-l	1.29 e-i	1.79 g-i	2.27 h-i	1.27 h-l
	Open pollination	1.82 f-i	2.28 j-l	1.25 f-i	1.78 g-i	2.25 i	1.26 i-l
	LSD 0.05	0.13	0.086	0.12	0.09	0.15	0.08

Cross-pollination increased the average fruit set in landraces as compared to open pollination treatment. However, as a general trend, the fruit set of landraces when crossed with wild form were low as compared to open and other cross-pollination treatments. Slight differences were also recorded in fruit set in reciprocal crosses for the same genotype pairs.

3.2. Effect of Pollen Source on Nut and Kernel Trait

Analysis of variance showed minor significant effect of type of pollination on shell, nut and kernel traits (**Table 2 to 4**), indicating a little possible influence of pollen source on almond shell, nut and kernel traits. Kernel taste did not influenced by pollen source, meaning that the kernel taste remains sweet in almond landraces and bitter in wild form (*A. communis*). The results were consistent in the two successive years. The results showed wide range of variation in shell nut and kernel traits among tested genotypes (**Table 2 to 4**). Oga landrace showed the highest nut and kernel dimensions, whereas minimum dimensions were obtained in Mukhmaly and almond wild form. Shell shape was maximum in Oga and minimum in Hjari landrace and almond wild form. Nut and kernel weight and size were highest for Oga and Fark followed by Mukhmaly, Hami Halo, Hajari and wild form.

Table 3. Effect of pollen source in almond landraces and wild bitter almond (*A. communis*) on nut fruit traits in 2012 and 2013 growing season

		2012 growing season			2013 growing season		
Cultivar	Treatment	Nut width (cm)	Nut length (cm)	Nut shap (Ratio)	Nut width (cm)	Nut length (cm)	Nut shap (ratio)
Oga	Cross with Mukhmaly	2.7 a	5.73 a	2.12 a	3.06 ab	6.10 a	1.99 ab
	Cross with Hajari	2.72 a	5.71 a	2.09 ab	3.00 ab	5.95 b	1.98 bc
	Cross with Hami Halo	2.77 a	5.75 a	2.07 ab	3.07 ab	6.04 ab	1.96 bc
	Cross with Fark	2.79 a	5.84 a	2.09 ab	3.05 ab	6.03 ab	1.98 bc
	Cross with Wild	2.75 a	5.76 a	2.09 ab	3.09 a	5.98 ab	1.93 c
	Open pollination	2.81 a	5.81 a	2.06 b	2.98 b	6.07 ab	2.03 a
Mukhmaly	Cross with Oga	2.33 bc	3.22 c	1.38 e-g	2.25 df	3.20 d	1.42 e
	Cross with Hajari	2.29 b-d	3.18 c	1.38 e-g	2.24 df	3.15 d	1.40 ef
	Cross with Hami Halo	2.35 bc	3.22 c	1.37 e-g	2.29 c-e	3.19 d	1.39 ef
	Cross with Fark	2.35 bc	3.23 c	1.37 e-g	2.22 ef	3.18 d	1.43 e
	Cross with Wild	2.27 b-e	3.14 c	1.38 e-g	2.26 c-f	3.19 d	1.41 ef
	Open pollination	2.28 b-d	3.18 c	1.39 ef	2.23 df	3.14 d	1.41 ef
Hajari	Cross with Oga	2.15 e-g	2.04 de	0.94 jk	1.87 j	1.97 i	1.05 k
	Cross with Mukhmaly	2.24 c-f	2.02 de	0.90 kl	1.98 gh	2.06 hi	1.03 kl
	Cross with Hami Halo	2.23 c-f	2.04 de	0.91 kl	1.98 gh	2.06 hi	1.03 kl
	Cross with Fark	2.20 d-f	1.94 ef	0.88 l	1.95 h-j	2.02 i	1.03 kl
	Cross with Wild	2.15 e-g	1.94 ef	0.90 kl	2.05 g	2.09 g-i	1.01 kl
	Open pollination	2.06 g	2.05 de	0.99 j	1.98 gh	1.98 i	0.99 l
Hami Halo	Cross with Oga	2.23 c-f	3.56 b	1.59 d	2.25 df	3.54 c	1.57 d
	Cross with Mukhmaly	2.18 d-g	3.53 b	1.61 cd	2.22 ef	3.54 c	1.59 d
	Cross with Hajari	2.19 d-f	3.53 b	1.60 d	2.20 f	3.53 c	1.60 d
	Cross with Fark	2.19 d-g	3.54 b	1.61 d	2.24 df	3.55 c	1.58 d
	Cross with Wild	2.18 d-g	3.55 b	1.63 cd	2.19 f	3.44 c	1.57 d
	Open pollination	2.12 fg	3.54 b	1.67 c	2.19 f	3.53 c	1.61 d
Fark	Cross with Oga	2.33 bc	3.17 c	1.35 e-g	2.27 c-f	3.16 d	1.39 ef
	Cross with Mukhmaly	2.34 bc	3.16 c	1.34 e-g	2.26 c-f	3.18 d	1.40 ef
	Cross with Hajari	2.34 bc	3.15 c	1.34 fg	2.30 c-e	3.18 d	1.38 ef
	Cross with Hami Halo	2.38 b	3.18 c	1.33 g	2.32 cd	3.16 d	1.36 fg
	Cross with Wild	2.27 b-e	3.20 c	1.40 e	2.25 d-f	3.13 d	1.38 ef
	Open pollination	2.30 b-d	3.17 c	1.37 e-g	2.34 c	3.10 d	1.32 g
Wild	Cross with Oga	1.76 hi	2.10 d	1.19 h	1.77 k	2.17 f-h	1.21 hi
	Cross with Mukhmaly	1.70 h-j	2.02 de	1.18 h	1.92 h-j	2.43e	1.26 h
	Cross with Hajari	1.54 k	1.82 f	1.18 h	1.88 ij	2.19f-h	1.16 j
	Cross with Hami Halo	1.62 jk	1.85 f	1.14 hi	1.97 g-i	2.30ef	1.17 ij
	Cross with Fark	1.64 i-k	1.86 f	1.12 i	1.93 h-j	2.21fg	1.14 j
	Open pollination	1.82 h	2.04 de	1.12 i	1.88 ij	2.19f-h	1.16 j
	LSD 0.05	0.13	0.13	0.06	0.09	0.14	0.05

Table 4. Effect of pollen source in almond landraces and wild bitter almond (*A. communis*) on kernel fruit traits in 2012 and 2013 growing season

		2012 growing season				2013 growing season			
Genotype	Treatment	Kernel length. (cm) KL	Kernel width (cm) KWd	Kernel shape (Ratio)	Weight of kernel (g)	kernel length (cm)	kernel width (cm)	kernel shap (Ratio)	weight of kernel (g)
Oga	Cross with Mukhmaly	3.26ab	1.29g-j	2.5277 a	322.67 ab	2.30a-e	1.50ef	1.52b-f	376.33a
	Cross with Hajari	3.25ab	1.28g-j	2.5410 a	330.27 a	2.49a	1.49ef	1.67a-f	335.33c
	Cross with Hami Halo	3.28a	1.29g-j	2.5340 a	328.73 a	2.52a	1.54e	1.63a-f	348.27bc
	Cross with Fark	3.17ab	1.30g-j	2.4277 a	263.53 c	2.54a	1.53ef	1.66a-f	332.33cd
	Cross with Wild	3.14b	1.25h-k	2.5147 a	331.93 a	2.40a	1.42f-i	1.69a-e	353.20b
	Open pollination	3.28a	1.33f-h	2.4697 a	341.33 a	2.41a	1.48e-g	1.62a-f	359.27b
Mukhmaly	Cross with Oga	2.25e-h	1.36f-h	1.657 e	228.93 d	1.99b-h	1.25k-n	1.58a-f	186.93f-h
	Cross with Hajari	2.20h	1.31f-i	1.676 e	222.07 d	1.85g-j	1.15n	1.60a-f	185.40f-h
	Cross with Hami Halo	2.27d-h	1.37f-h	1.656 e	228.27 d	1.89f-j	1.19nm	1.58a-f	193.53f
	Cross with Fark	2.28d-h	1.38f-h	1.651 e	233.87 cd	1.91e-j	1.22l-n	1.56a-f	190.27fg
	Cross with Wild	2.161 h	1.29g-j	1.6737 e	225.60 d	1.82g-j	1.26j-n	1.44d-f	190.27fg
	Open pollination	2.22f-h	1.32f-h	1.682 e	214.67 de	1.97d-i	1.21nm	1.63a-f	186..20f-h
Hajari	Cross with Oga	1.61i	1.65a-c	0.9760 f	159.60 fg	1.65h-j	1.83ab	0.90g	172.07hi
	Cross with Mukhmaly	1.64i	1.68a-c	0.9767 f	152.80 g	1.71h-j	1.84a	0.93g	172.07hi
	Cross with Hami Halo	1.63i	1.68a-c	0.9737 f	156.07 fg	1.64h-j	1.82a-c	0.90g	172.80hi
	Cross with Fark	1.60i	1.66a-c	0.9677 f	150.33 g	1.60ij	1.85a	0.86g	173.93gh
	Cross with Wild	1.58i	1.58b-d	0.9983 f	150.20 g	1.63h-j	1.86a	0.87g	172.67hi
	Open pollination	1.60i	1.73ab	0.9300 f	150.00 g	1.64h-j	1.83ab	0.89g	172.67hi
Hami Halo	Cross with Oga	2.23f-h	1.17i-k	1.9083 b-d	219.13 d	2.27a-f	1.50ef	1.51b-f	147.53j-l
	Cross with Mukhmaly	2.19h	1.11k	1.9643 b	223.47 d	2.25a-f	1.56e	1.44d-f	153.67jk
	Cross with Hajari	2.21gh	1.16jk	1.9053 b-d	226.40 d	2.24a-f	1.52ef	1.47c-f	156.67ij
	Cross with Fark	2.22f-h	1.12k	1.9827 b	225.13 d	2.26a-f	1.56e	1.45d-f	149.20j-l
	Cross with Wild	2.27d-h	1.17i-k	1.9393 bc	215.33 de	2.20a-g	1.56e	1.40f	152jk
	Open pollination	2.20h	1.31f-i	1.8227 b-e	186.53 ef	1.97c-i	1.46e-h	1.42ef	152.80jk
Fark	Cross with Oga	2.43c	1.40e-g	1.7237 de	348.13 a	2.36a-c	1.36h-k	1.73a-c	314.07e
	Cross with Mukhmaly	2.39cd	1.38f-h	1.7267 de	344.80 a	2.34a-d	1.37g-j	1.71a-d	312.67e
	Cross with Hajari	2.36c-f	1.36f-h	1.7243 de	326.53 ab	2.37ab	1.33i-l	1.78ab	315.33e
	Cross with Hami Halo	2.39c-e	1.39f-h	1.7147 de	333.13 a	2.32a-d	1.34i-k	1.75ab	313.933e
	Cross with Wild	2.34c-g	1.33f-h	1.7553 c-e	317.53 ab	2.34a-d	1.28j-m	1.82a	309.33e
	Open pollination	2.38c-e	1.31g-j	1.8183 b-e	297 b	2.32a-d	1.30j-m	1.78ab	318de
Wild	Cross with Oga	1.59i	1.74a	0.9157 f	142.53 gh	1.59ij	1.73b-d	0.92g	137.73kl
	Cross with Mukhmaly	1.56i	1.57cd	0.9910 f	135.07 gh	1.61h-j	1.75a-d	0.91g	150.40j-l
	Cross with Hajari	1.52i	1.46d-f	1.0367 f	116.40 h	1.55j	1.71d	0.91g	138.60kl
	Cross with Hami Halo	1.65i	1.57cd	1.0457 f	132.60 gh	1.60h-j	1.72cd	0.93g	141.20j-l
	Cross with Fark	1.64i	1.55c-e	1.0557 f	136.47 gh	1.65h-j	1.77a-d	0.94g	135.40l
	Open pollination	1.52i	1.69a-c	0.9310 f	136.60 gh	1.59ij	1.81a-d	0.88g	138.60kl
	LSD 0.05	0.13	0.15	0.21	30.97	0.39	0.11	0.28	16.35

4. DISCUSSION

Weather conditions were favorable for pollen germination, pollen tube growth and fertilization. The mean temperature throughout blooming period was 15°C, ranging from 11.5 to 25°C. Total rainfall received in the study area was 685 and 628 mm during 2012 and 2013 growing season respectively and average wind speed was 5-6 m sec^{-1}. Relative humidity ranged from 65-75%.

Selfing proved inadequate and none of the genotypes showed fruit set. Self-pollination treatment revealed that all investigated almond landraces including wild form are self-incompatible. It is essential in self-incompatible crops to have a suitable compatible cross-pollinator for efficient fruit set in Jordanian almond landraces. Here, timing of blooming overlapping in cross-compatible is a critical factor for high fruit set and consequently high yield (Oukabli *et al*., 2000; 2002). Self-compatibility became an interesting desirable trait in almond breeding programs. Incorporating this trait in almond tree will allow the establishment of monovarietal almond orchards and eliminate the need for cross-pollinator (Martinez-Garcia *et al*., 2012). The low level of fruit set in landraces when cross with wild (*A. communis*) indicates that wild form was less effective in increasing the fruit set, thus might point its partial cross-compatibility of wild form with prevailing almond landraces in Ajloun area.

For commercial production with high quality fruits, the fruit set ranging from 25 to 40% is considered optimal (Kester and Griggs, 1959). In general, the cross-pollination treatment and their reciprocals were more than 40% fruit set which is horticulturally adequate for commercial almond production. The natural open pollination treatment showed fruit set ranging from 42-48% in Oga landrace to 71 to 82% in Fark landrace, indicating that fruit set with open pollen source is more than sufficient to attain sufficient commercial yield in orchards locating in Ajloun area. Almond cultivated as scattered trees in fruit trees orchards in Ajloun district and it is rarely seen in solid orchids. The farmers in Ajloun area are usually grow mixed varieties especially Oga, Mukmaly and Farak for fresh fruits consumption. Moreover, wild almond is grown as hedges surrounding orchard trees. Therefore, there is a high possibility for cross pollination and consequently adequate commercial yield by local farmers and it seems to be that no need to recommend suitable pollinizer for small-scaled almond growers. However, for orchid planted with solid blocks, it is essential to plant a pollinizer with overlapping in blooming time to enhance fruit set. The open pollination in almond might occur either by wind and or by insect vectors (Kester and Asay, 1975; Weinbaum, 1985).

The results showed that Hami Hallo and Fark had higher tendencies for higher fruit sets in cross pollination treatments, which might indicate high level of cross-comptabilities with other genotypes. The effect of pollen source (genotype) on fruit set in almond has been invistigated by using different pollen source (Socias i Company and Felipe, 1987) and they found that the cross pollination is highly effective in increasing fruit set. However, other studies showed no differences in fruit traits following cross-and self-pollination in almond (Dicenta *et al*., 2002).

Shell, nut and kernel weight did not show significant differences between different pollination types and only slight differences were observed within the same genotype pollinated with pollen from different sources (**Table 2 to 4**). However, the differences were obvious among landraces, which showed high level of variability for shell, nut and kernel traits (Amarin, 2012). Very slight differences were also observed between the cross- and open pollination treatments. Pollen source was found to be effective in improving fruit characteristics in almond (Fattah *et al*., 2014). Ortega *et al*. (2006; Martín and Rovira, 2011) showed that self-compatible almond genotypes exhibited differences in some almond fruit related traits following cross-and self-pollination treatment. In contrast, Dicenta *et al*. (2002) did not show any significant effect of self-versus cross-pollination in several self-compatible almond cultivars on fruit traits.

5. CONCLUSION

Results of this study indicate that all Jordanian almond landraces and *A. communuis* are self-incompatible. If Jordanian almond landraces are grown in solid blocks, they required cross-pollinizer. The high level fruit set obtained by open pollination level obtained in this study indicates adequate pollination vectors available that ensured optimum cross-pollination.

Jordanian almond growers ignore the relationship between the yield and pollinizer requirements and the reason behind that almond in Jordan rarely grown in solid blocks and in traditional plantations two or more varieties are grown mixed in the field. Sufficient source of pollens might the wild almond that grown as fences to protect orchards. Because of the high availability of the wild vector populations in Ajloun district, pollen transfer and fruit sets are generally high. Under such conditions, self-incompatible almond landraces set consistently adequate commercial crop. Almond landraces planted in commercial orchards in Jordan are self-incompatible and it is recommended to introduce self-compatibility into the genome of self-incompatible Jordanian landraces in the future plant breeding program.

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