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Pollen Source Effects on Seed Number, Fruit Quality and Return Bloom of Apple

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Additional index words: *Malus x domestica* Borkh, metaxenia, pollination, fertilization, flower initiation, fruit size, soluble solids concentration

Abstract

Pollen source, seed set and subsequent seed development are necessary prerequisites for apple fruit production. Pollinizer genotype in particular can have a remarkable impact on fertilization and therefore seed set. However, there is little information published on the most effective and compatible pollinizers for particular commercial cultivars. This study was conducted to determine the effect of three pollen sources, crabapple ('Ralph Shay' in 2013 and *Malus floribunda* in 2014), 'Delicious', and 'Golden Delicious' on seed number, fruit quality and subsequent return bloom of 'Honeycrisp', 'Fuji' and 'Gala' apples. The effects of 'Gala' pollinizing 'Honeycrisp' trees were also investigated. There was no effect of pollen source on fruit fresh weight, soluble solids concentration or starch pattern index. Seed number per fruit and seed fresh weight per fruit were significantly influenced by pollen source. When 'Ralph Shay' or *Malus floribunda* crabapples were used as pollinizers, fruit contained fewer seeds and lower seed fresh weight compared with 'Delicious', 'Golden Delicious' and 'Gala' pollinizers; however, the trend was not statistically significant for all cultivars and years. Fruit fresh weight increased linearly with seed number. Pollen source had no influence on return bloom regardless of female cultivar or year. Return bloom was negatively related to fruit fresh weight and seed number per fruit. These results indicate that pollen source and seed number per fruit influence fruit set, fruit quality, biennial bearing potential of 'Honeycrisp', and therefore should be factors that are considered in the orchard design process. Based on our findings, we recommend growers to do not plant 'Ralph Shay' or *Malus floribunda* crabapples as pollinizers for 'Honeycrisp'.

Pollination, the delivery of pollen from male reproductive part of a plant to female parts, is necessary in many fruit crops, including apple, for seed set and subsequent fruit development. It is commonly believed that any diploid cultivar with synchronous flowering can pollinate another cultivar, including 'Honeycrisp' (Cline and Gardner, 2005). Apples generally produce 10 ovules, leading to seed set after fertilization, and it is generally accepted that at least 6 or 7 ovules must be fertilized to reduce the likelihood of misshapen or small fruit, although seed distribution within the fruit may also be important (Delaplane et al., 2000; Hirst, 2013). Pollen tube growth, endogenous gibberellin concentration, fruit set, fruit growth rate, fruit quality and seed viability were linearly correlated with the level of pollen deposition on the stigmatic surfaces of pears (*Zhang et al.,* 2010). Repeated pollination from cross-compatible cultivars was effective in increasing seed production in apples (Matsumoto et al., 2012). A positive relationship exists between seed number per fruit and fruit size, fruit weight, and fruit growth rate (Bashir et al., 2010; Denne, 1963; Keulemans et al., 1996; Volz et al., 1996), but seed number only accounts for ~25% of the variation in fruit size (Goldway et al., 2012). However, seed number was negatively related to return bloom (Chan and Cain, 1967; Jonkers, 1979; Neilsen, 1998).

Several studies reported an effect of pollen source on fruit quality (Kumar *et al.,* 2005; Nebel, 1936; Nebel and Trump, 1932).

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This phenomenon is known as metaxenia, which can be defined as the direct effects of pollen on size, shape, color, developmental timing, and chemical compositions of seed and fruits (Denney, 1992). Few studies have investigated the direct effect of pollen source on both fruit quality and return bloom in apple. It is generally accepted that pollen source can affect seed set in apple, which could influence return bloom in the following year, but the direct effect of pollen source on return bloom in apple is unclear.

'Honeycrisp' is a valuable cultivar but has the potential to be extremely biennial in its bearing habit, and often exhibits an irregular crop load from year to year (Robinson *et al.,* 2009; Luby and Bedford, 1992). Biennial bearing in apple is influenced by several factors, most importantly crop load and seed numbers per spur during the previous season (Chan and Cain, 1967; Jonkers, 1979). Crop load can affect the quality of the fruit, tree growth, fruit size, fruit color, storage disorders and subsequent return boom (Robinson and Watkins, 2003).

Since increased pollination significantly influences seed set in apple, it seems logical to suggest that factors influencing pollination may also influence return bloom in the following year. We therefore conducted experiments to determine the impact of pollen source and seed number per fruit on fruit set, fruit quality, and return bloom in apple. This information should enable growers to better design their orchards in terms of choosing compatible combinations of cultivars.

Materials and Methods

Two experiments were conducted in 2013 and repeated in 2014 at the Samuel G. Meigs Horticulture Facility in Lafayette, Indiana USA. General methods were similar to those previously described (Jahed and Hirst, 2017). Briefly, two adjacent uniform trees of each selected cultivar were netted in late April, prior to flower opening, to avoid cross-pollination by bees. Care was taken to ensure the netting was secure and close visual examination did not observe any pollinators inside the netting. Flower clusters were selected on each cultivar and thinned to king blooms only. All other flowers were removed from the trees to ensure very low crop loads and to remove crop load as a limiting factor. The crabapple genotype used in each experiment was 'Ralph Shay' in 2013 but this was found to be a poor pollinizer of 'Honeycrisp', therefore we substituted *Malus floribunda* as the crab pollinizer in 2014. As described previously (Jahed and Hirst, 2017) pollen viability was measured in the laboratory prior to use in these experiments and all pollen used in these experiments exhibited >80% viability.

Experiment 1: Two adjacent uniform trees of 'Honeycrisp'/M.7 planted in 2003, 'Fuji'/ B.9 planted in 2001 and 'Gala'/ B.9 planted in 2001, were selected. The same trees were used in 2014. These cultivars were chosen because of their economic importance and because they represent a range of genetic potential for biennial bearing. At the tight cluster stage of flower development, ninety flowers were randomly selected across these two trees. Thirty of these flowers were hand pollinated with crabapple ('Ralph Shay' in 2013 and *Malus floribunda* in 2014), 'Delicious' or 'Golden Delicious' in both 2013 and 2014 as previously described (Jahed and Hirst, 2017). The experiment was designed as a Completely Randomized Design (CRD) where the two assigned trees of each cultivar were considered as single unit; flowers were randomly selected across both trees, thinned to only king flower and pollen was applied by hand to all cultivars at the same day. Collected data comprised individual fruit fresh weight, total seed number per fruit, total seed fresh weight, soluble solids concentration, starch index, and percent return bloom. Only fully developed seeds were counted.

Experiment 2: Six adjacent uniform 'Honeycrisp'/M.7 planted in 2003 trees were selected in 2013 each as a block. The same trees were used in 2014. Sixty flowers were randomly selected within each block (tree). Twenty of these flowers were hand pollinated with crabapple ('Ralph Shay' in 2013 and *Malus floribunda* in 2014), 'Delicious' or 'Gala' pollen. The number of fruit on tagged flowers was visually assessed every other week starting from the second week after pollination until one week before harvest. Fruits on tagged sites were counted at harvest. All tagged fruit were harvested during the normal commercial harvest period for each cultivar based on a starch pattern index rating of at least 5 on the scale of Reid et al. (1982). Harvest measurements included fruit fresh weight using a digital balance (Mettler Toledo DeltaRange Scale B3002DR, Mettler-Toledo LLC, Columbus OH), soluble solids concentration (SSC) using a digital refractometer (Atago PAL-1, Atago USA Inc., Bellevue, WA), total number of fully developed seed per fruit, total seed fresh weight per fruit using a more sensitive digital balance (EW-12Ki EW-I Series Compact Balance, AND Weighing, Tokyo Japan), and starch pattern index using the methods of Reid et al. (1982) where half fruit were dipped for 30 seconds in an iodine solution and rated on a 1-6 scale where 1 = a very dark-black color of the stained fruit, indicating higher starch content and 6 = very little staining and little starch remaining in the fruit.

Bourse buds on tagged spurs (sites of flower production for the follow year) were collected at the time of leaf abscission. Buds were placed in an FAA (Formalin-Acetic acid-Alcohol) solution containing 50% ethyl alcohol, 5% glacial acetic acid, 10% formaldehyde and 35% distilled water. Buds were then dissected under a light microscope to determine reproductive or vegetative status (Hirst and Ferree, 1995).

Statistical analysis. The first experiment was designed as a completely randomized design (CRD), where fruit was included as a random factor in the model statement and the difference of measured variables was recorded between each combination (cultivar and pollinizer). Since the experiment was a 3 x 3 factorial, we also looked at the interaction between cultivars and pollinizers. The second experiment was designed as a completely randomized block design (RCBD) where each tree was assigned as a block. Pollinizer was included as a random factor in the model statement. Response variables were analyzed by ANOVA. Statistical analyses included analysis of variance using PROC GLIMMIX, Tukey multiple range test, and regression analysis using PROC REG of Statistical Analysis System for PC (SAS 9.4, SAS Institute Inc., Cary, NC). Means and standard errors are reported. Logistic regression analysis used PROC LOGISTIC for the binary flowering data where Chi-square analysis was performed and proportion flowering reported.

Results

Seed Number. Pollen source had a significant influence on seed number per fruit in 2013 (Table 1). Both 'Honeycrisp' and 'Gala' fruit pollinated with 'Ralph Shay' had fewer seeds than those pollinated with 'Delicious' or 'Golden Delicious' pollen. 'Fuji, flowers pollinated with 'Golden Delicious' pollen had the most seeds, and those pollinated with 'Ralph Shay' the fewest in 2013 (Table 1). Pollinizer did not affect seed number in any one particular cultivar in 2014 (Table 2) but overall seed number was significantly affected by both female cultivar and male pollinizer. In the second experiment, flowers pollinated with 'Ralph Shay' also exhibited lower seed numbers in 2013 (Table 3). In most cultivars and years, 'Delicious' and 'Golden Delicious' pollen performed similarly in terms of seed number. In experiment 2 (with 'Honeycrisp'), there was no effect of pollen source on seed number in 2014, although there were a number of missing plots due to poor fruit set with crabapple as the pollinizer, as reported previously (Jahed and Hirst, 2017).

Fruit fresh weight was positively related to seed number. There was a significant positive

Table 1: Effects of pollen source on seed number, seed fresh weight, fruit fresh weight, soluble solids concentration (SSC), starch pattern index and return bloom of 'Honeycrisp', 'Fuji' and 'Gala' apples in 2013. [Z]

Male	Seed number	Seed weight (g)	Fruit weight (g)	SSC (%)[Y]	Starch[X]	Fruit set (%)[V]	Return bloom (%)[W]
			Honeycrisp				
Crabapple[U]	3.7±0.8 b[T]	0.3±0.1 b	376.7±26.3 a	15.7±0.3 a	5.7±0.1 a	33.33	0
Red Delicious	8.0 ±0.5 a	0.6±0.1 a	360.1±15.5 a	15.3±0.2 a	5.9±0.1 a	66.67	70
Golden Delicious	8.3±0.5 a	0.6±0.1 a	355.7±16.4 a	15.4±0.2 a	5.8±0.1 a	60.00	53
P-Value	0.0001	0.0005	0.79	0.56	0.52		0.55
			Fuji				
Crabapple	3.0±0.9 b	0.2±0.1 b	249.6±22.7 b	18.7±0.6 a	6.0±0.1 a	33.33	63
Red Delicious	5.4±0.6 ab	0.3±0.1 ab	310.9±14.3 a	18.3±0.4 a	6.0±0.1 a	66.67	75
Golden Delicious	7.3±0.7 a	0.5±0.1 a	311.8±16.5 a	17.1±0.5 a	5.9±0.1 a	50.00	80
P-Value	0.002	0.0007	0.06	0.09	0.46		0.30
			Gala				
Crabapple	2.6±0.6 b	0.2±0.1 b	180.8±10.3 a	15.3±0.3 a	5.0±0.2 b	50.00	100
Red Delicious	5.7±0.5 a	0.4±0.1 a	197.4±7.8 a	15.5±0.2 a	5.7±0.1 a	86.67	100
Golden Delicious	6.1±0.6 a	0.4±0.1 a	186.4±9.1 a	15.5±0.3 a	5.8±0.2 a	63.33	96
P-Value	0.0002	0.0001	0.40	0.85	0.009		0.996
Male	0.0001	0.0001	0.3	0.14	0.09		0.57
Female	0.001	0.0001	0.0001	0.0001	0.0002		0.19
Male x Female	0.47	0.43	0.17	0.099	0.03		0.92

[Z] Means and standard error are presented in each cell.
[Y] Soluble solids concentration
[X] Starch was rated by staining cut fruit with an iodine solution and rated from 1-6 where 1 represents high starch and 6 represents low starch.
[W] Return bloom is calculated as the number of flowering buds divided by the total number of buds times 100.
[V] The proportion of hand-pollinated flowers that set fruit and remained until harvest time.
[U] Crabapple pollen was from 'Ralph Shay' (2013) and Malus floribunda (2014).
[T] Means within columns and female cultivars followed by common letters do not differ at P = 0.05 by Tukeys Multiple range test.

relationship between fruit fresh weight and seed number of 'Honeycrisp' in both experiments in 2014 regardless of pollen source (Figure 2). In 'Gala' the relationship between fruit fresh weight and seed number per fruit was positive in the first experiment regardless of the year and pollen source (Figure 3). No relationship between fruit fresh weight and seed number was found in 'Fuji'.

Seed Fresh Weight. Seed fresh weight per fruit followed similar trends to seed number per fruit, and was lowest when 'Ralph Shay' was used as the pollinizer in 2013 in both experiments, but in 2014, no differences were found among the treatments (Tables 1-3).

Fruit quality. Fruit fresh weight was not affected by pollen source across the treatments regardless of the experimental years and experiments (Tables 1-3). Similarly, fruit soluble solids concentration and starch pattern index were not significantly affected by pollen source in either of the experiments or years (Tables 1-3).

Return Bloom. Return bloom was not influenced by pollen source in either year (Tables 1-3). Only in the second experiment, seed number had a significant and negative

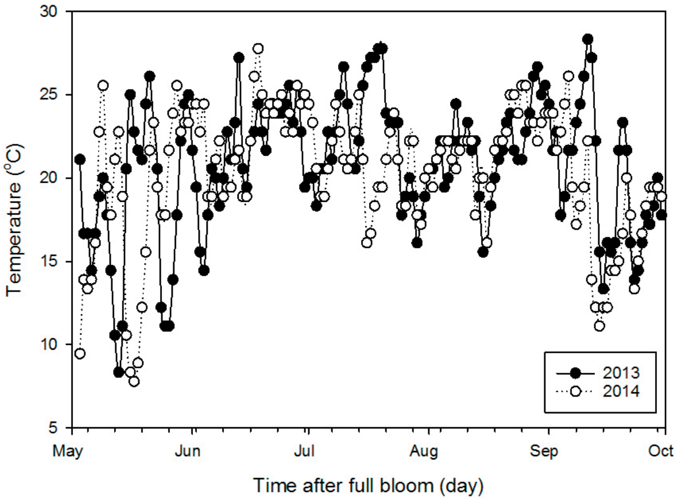

Figure 1: Daily air temperature during the pollination period and the days after pollination until harvesting time (flowers were hand-pollinated in May 3, 2013 and May 4, 2014 and fruits were harvested in September). Data presented are from May 3 to September 30.

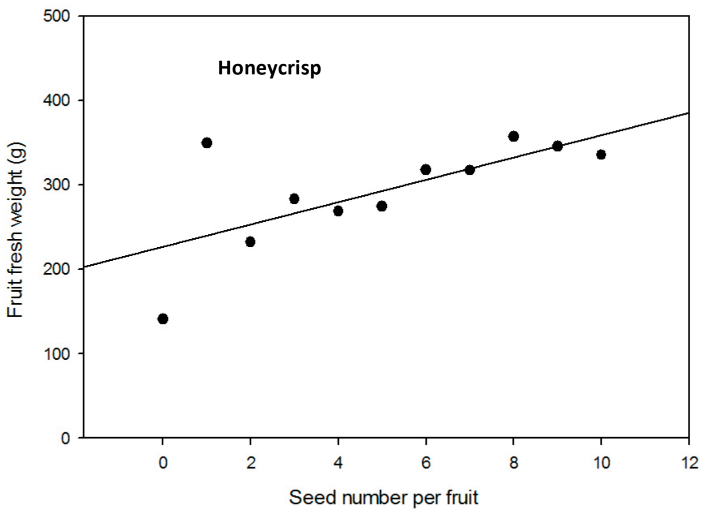

Figure 2: Relationship between fruit fresh weight and seed number per fruit of 'Honeycrisp' apple in 2014 across all pollen sources. $y = 19.5x + 188.5$, $R^2 = 0.4$, $P < 0.0001$

impact on return bloom in 2014, but not in 2013, regardless the pollen donor (Figure 4). Although this trend was significant (p=0.04) it was not particularly strong (r^2=0.206). Individual fruit fresh weight per spur also negatively influenced return bloom (Figure 5) and this relationship accounted for much of the variation in return bloom (r^2=0.902).

Table 2: Effects of pollen source on seed number, seed fresh weight, fruit fresh weight, soluble solids concentration (SSC), starch pattern index and return bloom of 'Honeycrisp', 'Fuji' and 'Gala' apples in 2014.[Z]

Male	Seed number	Seed weight (g)	Fruit weight (g)	SSC (%)[Y]	Starch[X]	Fruit set (%)[V]	Return bloom (%)[W]
			Honeycrisp				
Crabapple[U]	4.5±1.5 a[T]	0.3±0.1 a	324.5±48.0 a	13.5±0.6 a	5.0±0.4 a	6.67	100
Red Delicious	7.6±0.5 a	0.5±0.1 a	355.7±16.5 a	13.5±0.2 a	5.8±0.1 a	56.67	65
Golden Delicious	6.4±0.5 a	0.4±0.1 a	307.7±17.0 a	13.8±0.2 a	5.8±0.1 a	53.33	67
P-Value	0.079	0.18	0.14	0.54	0.15		0.88
			Fuji				
Crabapple	5.2±0.9 a	0.3±0.1 a	212.0±12.4 a	17.5±0.3 a	5.2±0.2 a	56.67	89
Red Delicious	7.2±0.8 a	0.4±0.1 a	210.5±10.4 a	17.2±0.3 a	5.4±0.2 a	80.00	96
Golden Delicious	7.1±0.9 a	0.5±0.1 a	205.5±11.7 a	17.5±0.3 a	5.1±0.2 a	63.33	85
P-Value	0.21	0.18	0.92	0.76	0.58		0.47
			Gala				
Crabapple	6.7±0.6 a	0.4±0.1 a	165.5±6.3 a	16.0±0.1 a	5.5±0.2 a	26.67	100
Red Delicious	8.6±0.6 a	0.5±0.1 a	168.7±6.3 a	15.9±01 a	5.4±0.2 a	76.67	100
Golden Delicious	8.0±0.6 a	0.5±0.1 a	161.5±6.1 a	16.0±0.1 a	5.8±0.2 a	83.33	96
P-Value	0.07	0.06	0.71	0.91	0.12		0.996
Male	0.03	0.04	0.07	0.51	0.32		0.88
Female	0.04	0.63	0.0001	0.0001	0.03		0.09
Male x Female	0.94	0.77	0.32	0.96	0.16		0.96

[Z] Means and standard error are presented in each cell.
[Y] Soluble solids concentration
[X] Starch was rated by staining cut fruit with an iodine solution and rated from 1-6 where 1 represents high starch and 6 represents low starch.
[W] Return bloom is calculated as the number of flowering buds divided by the total number of buds times 100.
[V] The proportion of hand-pollinated flowers that set fruit and remained until harvest time.
[U] Crabapple pollen was from 'Ralph Shay' (2013) and Malus floribunda (2014).
[T] Means within columns and female cultivars followed by common letters do not differ at P = 0.05 by Tukeys Multiple range test.

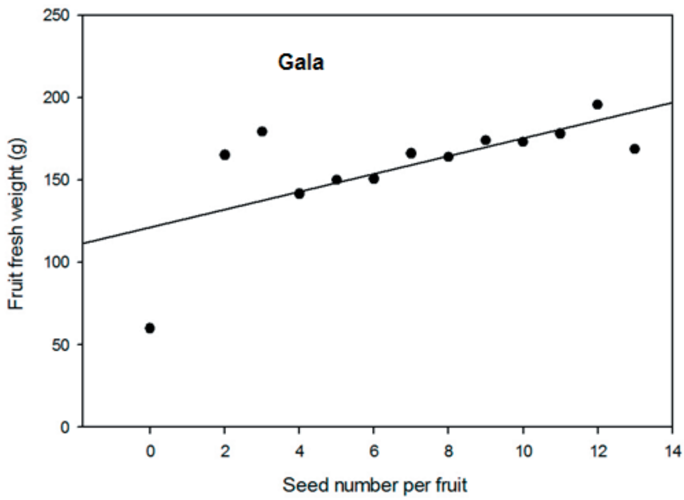

Figure 3: Relationship between fruit fresh weight and seed number per fruit of 'Gala' apple in 2014 across all pollen sources. $y = 0.8x + 0.04$, $R^2 = 0.2$, $P < 0.0001$

Table 3: Effects of pollen source on seed number, seed fresh weight, fruit fresh weight, soluble solids concentration (SSC), starch pattern index and return bloom of 'Honeycrisp' apples. [Z]

Male	Seed number	Seed number	Fruit weight (g)	SSC (%)[Y] weight (g)	Starch[X]	Fruit set (%)[V]	Return bloom (%)[W]
			2013				
Crabapple[U]	1.5±0.9 b[T]	0.1±0.1 b	330.9±46.9 a	15.1±0.7 a	5.5±0.2 a	16.67	50
Red Delicious	8.6±0.4 a	0.6±0.1 a	357.9±22.7 a	14.9±0.3 a	5.9±0.1 a	70.83	25
Gala	8.2±0.5 a	0.6±0.1 a	383.5±25.1 a	14.3±0.4 a	5.8±0.1 a	58.33	29
P-Value	0.0001	0.0001	0.56	0.43	0.24		0.63
			2014				
Crabapple	3.0±2.3 a	0.2±0.1 a	273.5±65.8 a	14.5±1.1 a	6.0±0.3 a	8.33	0
Red Delicious	5.3±0.8 a	0.3±0.1 a	247.1±23.3 a	13.1±0.4 a	5.8±0.1 a	66.67	31
Gala	5.8±0.8 a	0.4±0.1 a	275.4±24.1 a	13.5±0.5 a	5.9±0.1 a	62.50	27
P-Value	0.50	0.46	0.69	0.41	0.79		0.96

[Z] Means and standard error are presented in each cell.
[Y] Soluble solids concentration
[X] Starch was rated by staining cut fruit with an iodine solution and rated from 1-6 where 1 represents high starch and 6 represents low starch.
[W] Return bloom is calculated as the number of flowering buds divided by the total number of buds times 100.
[V] The proportion of hand-pollinated flowers that set fruit and remained until harvest time.
[U] Crabapple pollen was from 'Ralph Shay' (2013) and Malus floribunda (2014).
[T] Means within columns and female cultivars followed by common letters do not differ at P = 0.05 by Tukeys Multiple range test.

Discussion

Suitable pollinizer is one of the most decisive factors of apple fruit set (Hartman and Howlett 1954; Degrandi-Hoffman *et al.* 1987).Though 'Manchurian' crabapple was found to be a good pollinizer of 'Oregon Spur' apple (Das *et al.* 2011), although we found that both crabapple pollen donors used in these studies ('Ralph Shay' in 2013 and *M. floribunda* in 2014) were poor pollinizers for 'Honeycrisp'. 'Ralph Shay' pollen resulted in less than 10% fruit set in 2013, whereas fruit set with *M. floribunda* was less than 2% in 2014 (Jahed and Hirst, 2017). This was not due to pollen viability since testing showed the pollen to be highly viable. 'Gala' performed well as a pollinizer for 'Honeycrisp' regardless of the year. Therefore, it seems reasonable to assume that the variation among the treatments is limited only by the pollinizer and its compatibility to the cultivar. Temperature (Degrandi-Hoffman *et al.,* 1987), inadequate number of pollinators and environment (Hartman and Howlett, 1954) have significant influence on fruit set. However, there was little variation in air temperature between 2013 and 2014 during the growing season (Figure 1), so it seems reasonable to assume any differences in fruit set between the years were not due to temperature. Thus, the year-to-year variation in fruit set in these studies is not only due to temperature differences (our data suggested that temperature is not the limiting factor), but presumably due to other factors such as cultivar bearing habits. This leads us to a deeper investigation of both pollen donor and cultivar, their reproductive systems and their allelic combinations. We propose that the 'Honeycrisp' reproductive system be studied further as well as extend the research to other pollinizer sources and locations.

Seed number per fruit (Chan and Cain, 1967; Jonkers, 1979; Neilsen, 1998), endogenic gibberellins concentration (Fulford, 1965; Dennis and Neilsen, 1999), fruit load (Embree *et al.,* 2007; Robinson *et al.,* 2009), and fruit thinning time (Wright *et al.,* 2006; Meland, 2009) reduce return bloom in apples. We found that seed number per fruit only accounted for 20% of the observed variation in return bloom (Figure 4). However,

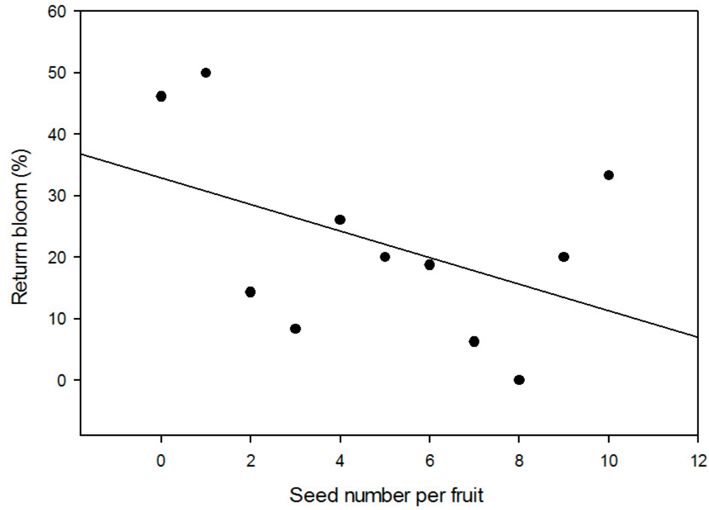

Figure 4: Effect of seed number per fruit of 'Honeycrisp' on return bloom in 2014 across all pollen sources y = -0.02x + 0.33, R^2 = 0.2, P = 0.04

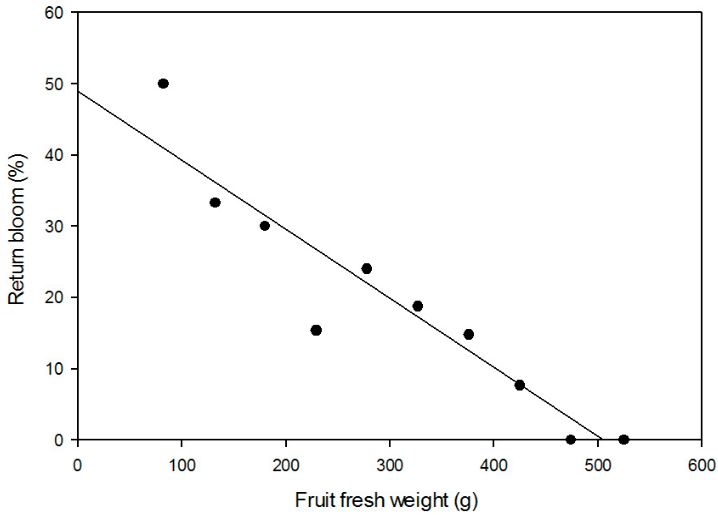

Figure 5: Effect of fruit fresh weight of 'Honeycrisp' on return bloom in 2014 across all pollen sources. y = -0.0009x + 0.54, R^2 = 0.90 and P < 0.0001

approximately 90% of the variation in return bloom was due to individual fruit mass per spur (Figure 5). Therefore, it appears that not only total crop load per tree is important in return bloom, but individual fruit weight per spur plays a significant role in determining return boom. Several other unknown factors may be involved in return bloom. Thus, we suggest further investigation include a wider range of cultivars, pollinizer sources, and environments than included in the research presented here.

Conclusion

Seed number per fruit and seed fresh weight per fruit were significantly influenced by pollen source, but only in 2013. Pollination with 'Ralph Shay' and *M. floribunda* pollen produced fewer seeds per fruit as well as lower seed fresh weight compared with those pollinated by 'Delicious' or 'Gala' pollen. Fruit fresh weight, soluble solids concentration and starch pattern index were unaffected by pollen source.

Seed number per fruit was positively related to fruit fresh weight, but no differences were found in other fruit quality attributes, such as SSC and starch pattern index. Pollen source did not influence return boom in either year. The percentage of return boom was negatively related to fruit fresh weight per spur and seed number per fruit.

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Literature Cited

Bashir, R., G. Sharma, and N. Sharma. 2010. Studies on fruit set and fruit characteristics as affected by different pollinizers in apple (*Malus x domestica* Borkh.). Adv. Hort. Sci. 24 (2): 137-144.

Chan, B.G. and J.C. Cain. 1967. The effect of seed formation on subsequent flowering in apple. Proc. Amer. Soc. Hort. Sci. 91: 63-68.

Cline, J. A. and J. Gardner. 2005. Commercial production of Honeycrisp apples in Ontario. Factsheet 05-047. Queens Pinter of Ontario, Toronto, Canada.

Das, B., N. Ahmad, K. K. Srivastava, and P. Ranjan. 2011. Top working method and bloom density of pollinizers as productive determinant for spur type apple (*Malus x domestica* Borkh.) cultivars. Sci. Hort. *129* (4): 642-648.

Degrandi-Hoffman, G., R. Hoopingarner, and R. Pulcer. 1987. REDAPOL: Pollination and Fruit-set Prediction Model for 'Delicious' Apples. Environ. Entomol. 16 (2): 309-318.

Delaplane, K. S., D. R. Mayer, and D. F. Mayer. 2000. Crop pollination by bees. New York, NY: CABI Publishing.

Denne Patricia, M. 1963. Fruit development and some tree factors affecting it. New Zealand J. Bot. 1(3): 265-294.

Denney, J. O. (1992). Xenia includes metaxenia. HortScience 27(7): 722-728.

Dennis, F. G. and J. C. Neilsen. 1999. Physiological factors affecting biennial bearing in tree fruit: the role of seeds in apple. HortTechnol., *9*(3): 317-322.

Embree, C. G., M. T. Myra, D. S. Nichols, and A. H. Wright. 2007. Effect of blossom density and crop load on growth, fruit quality, and return bloom in 'Honeycrisp' apple. HortScience 42(7): 1622-1625.

Fulford, R. M. 1965. Regular and irregular bearing in fruit plants. Ann. Rep. E. Malling Res. Sta. 48: 71-82.

Goldway, M., Stern, R., Zisovich, A., Raz, A., Sapir, G., Schnieder, D.,and Nyska, R. 2012. The self-incompatibility fertilization system in Rosaceae: agricultural and genetic aspects. Acta Hort. (967), 77.

Hartman, F. O. and F. S. Howlett. 1954. Fruit setting of the Delicious apple. Bull. Ohio Agric. Exp. Sta. Vol. 745.

Hirst, P.M. 2013. Flower bud formation, pollination, and fruit set. In: Concise Encyclopedia of Temperate Tree Fruit. T.A. Baugher and S. Singha (Eds.). The Hayworth Press, Binghamton, NY.

Hirst, P.M. and D.C. Ferree. 1995. Rootstock effects on the flowering of 'Delicious' apple. I. Bud development. J. Amer. Soc. Hort. Sci. 120(6):1010-1017.

Jahed, K.R. and P.M. Hirst. 2017. Pollen tube growth and fruit set in apple. HortScience 50(8): 1054-1059.

Jonkers, H. 1979. Biennial bearing in apple and pear: a literature survey. Scientia Hort. 11(4): 303-317.

Keulemans, J., A. Brusselle, R. Eyssen, J. Vercammen, and G. Van Daele. 1996. Fruit weight in apple as influenced by seed number and pollinizer. Acta Horticulturae *423*: 201-210.

Kumar, R., R. L. Sharma, and K. Kumar. 2005. Results of Experiments on Metaxenia in Apple. Acta Horticulturae *696*: 43-48.

Luby, J. J. and D. S. Bedford. 1992. Honeycrisp apple. Univ. Minn. Agr. Expt. Sta. Rpt. 225-1992 (AD-MR-5877-B).

Matsumoto, S., Soejima, J., and Maejima, T. 2012. Influence of repeated pollination on seed number and fruit shape of 'Fuji'apples. Scientia Horticulturae *137*: 131-137.

Meland, M. 2009. Effects of different crop loads and thinning times on yield, fruit quality, and return bloom in *Malus domestica* Borkh.'Elstar'. J. Hort. Sci. and Biotechnol. 84: 117-121.

Nebel, B. R. 1936. Metaxenia in apples. J. Hered. 27(9): 345-350.

Nebel, B. R. and I. J. Trump. 1932. Xenia and Metaxenia in Apples: II. Proc.Natl. Acad. Sci. United States of America, 18(5): 356.

Neilsen, J.C. 1998. Effects of fruit, seed and shoot development on flower induction in apple. PhD. Dissertation. Michigan State University.

Reid, M. S., Padfield, C. A. S., Watkins, C. B., and Harman, J. E. 1982. Starch iodine pattern as a maturity index for Granny Smith apples: 1. Comparison with flesh firmness and soluble solids content. New Zealand J. Agr. Res., 25(2): 229-237.

Robinson, T. 2008. Crop load management of new high-density apple orchards. New York Fruit Quarterly 16(2):3-7.

Robinson, T., S. Lopez, K. Iungerman, and G. Reginato. 2009. Crop load management for consistent production of Honeycrisp apples. New York Fruit Quartley 17:24-28.

Robinson, T.L. and C.B. Watkins. 2003. Crop load of Honeycrisp affects not only fruit size but also many quality attributes. New York Fruit Quarterly 11(3): 7-10.

Volz, R. K., D. S. Tustin, and I. B. Ferguson. 1996. Pollination effects on fruit mineral composition, seeds and cropping characteristics of 'Braeburn' apple trees. Sci. Hort. *66*(3): 169-180.

Wright, A. H., C. G. Embree, D. S. Nichols, R. K. Prange, P. A. Harrison, and J. M. Delong. 2006. Fruit mass, colour and yield of 'Honeycrisp'™ apples are influenced by manually-adjusted fruit population and tree form. J. Hort. Sci. Biotechnol. 81(3): 397-401.

Zhang, C., Tateishi, N., and Tanabe, K. 2010. Pollen density on the stigma affects endogenous gibberellin metabolism, seed and fruit set, and fruit quality in *Pyrus pyrifolia*. J. Expt. Bot. 61:4291- 4302.

2017 Shepard Award

The Shepard Award was instituted to recognize outstanding research and to promote the publication of good research in the official publication of the American Pomological Society. The 2017 recipient of the Shepard Award is Dr. John A. Cline for his paper "Thinnnig of Peach Trees Using High-Pressure Water", published in volume 71, N. 4, Pages: 203-213 of the Journal of the American Pomological Society.

About the cover

Carob (*Ceratonia siliqua* L.) is an evergreen tree in the pea family (Fabaceae) and is cultivated for its edible pods and as an ornamental tree. It is native to the Mediterranean region, including Sothern Europe, Northern Africa, and Middle-east of Western Asia to Iran. The carob tree shown on the cover is growing in the area of *Deir Janine*, in Akkar region, North of Lebanon, at 433 m asl. The foot circumference is 6.4 m, the crown projection is 4.5 m and the central cavity is 0.36 m^3. This tree is growing near an old church built in 1851 and is likely about 150 years old. *Photo by Lamis Chalak.*