Temperate Nut Working Group Workshop, “Pollination of Nut Crops: Practices and Problems”, at the 95th ASHS Conference in Charlotte, North Carolina

Pollination of Almonds: Practices and Problems

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Summary.

California almonds [*Prunus dulcis*, (Mill.) D.A. Webb, syn. *Prunus amygdalus* Batsch] are self-incompatible requiring cross-pollination to produce a commercial crop. Within seven known pollen groups, they also display cross-incompatibility. Coincidence of bloom between compatible cultivars is essential for cross-pollination. Since almonds are pollinated primarily by honeybees [*Apis mellifera* L.], arranging pollinizers in close proximity to one another promotes maximum pollen transfer. Almonds are frequently subject to inclement weather during their February bloom period. Strong honeybee colonies are better able to forage during marginal weather conditions than are weak colonies. Honeybee management can encourage pollen foraging and placement of colonies can affect flight activity and ultimately nut-set. Weather permitting vigorous honeybee flight activity is the most important factor for setting a good crop. Temperature also affects anther dehiscence, pollen germination, and pollen tube growth. The sooner an almond flower is cross-pollinated after opening, the greater the chance of fertilization and nut-set. Optimizing all of these pollination factors is therefore essential to achieve maximum production in almond orchards.

California’s central valley produced 76% of the world’s almonds in 1998 on 460,000 bearing acres (186,159 ha). An additional 113,000 acres (45,731 ha) are non-bearing (California Agricultural Statistics Service, 1998). Spain produces 15% of the world’s production followed by Italy, Turkey and Greece at slightly over 2% each. California acreage is 43% ‘Nonpareil’ and 18% ‘Carmel’ while numerous other cultivars constitute the remaining 39%; 74% of the California crop is exported (Almond Board of California, 1998).

Optimum pollination, setting as many flowers as possible, is critical for maximum almond production and crop thinning is never practiced. Any reduction in the number of cross-pollinated flowers reduces yield (Kester and Griggs, 1959). Almond cultivars grown in California exhibit self-incompatibility of the gametophytic type. This incompatibility results from lower pollen grain retention on the stigma, reduced and delayed pollen germination, and a low frequency of pollen tubes growing through the style (Pimienta et al., 1983). Consequently, almond does not set and mature a commercial crop with it’s own pollen. Almond orchards are therefore usually comprised of two to four cultivars. Almond pollination is affected by: a) bloom overlap between cultivars; b) compatibility of pollen with the maternal parent cultivar; c) planting arrangement of pollinizers in the orchard; d) honeybee colony strength, and e) weather during bloom.

Bloom Overlap

Bloom overlap refers to the coincidence of bloom time between cultivars in the orchard. The maximum opportunity for nut-set results when cultivars are in the same stage of bloom at approximately the same time.

There can be as much as a month between full bloom on the earliest blooming cultivars (early February) and full bloom on the latest cultivars (early March). To avoid poor overlap it's important to select pollinizers within the same or adjacent bloom groups indicated in Table 1 (Asai et al., 1996). The 'Nonpareil' and 'Carmel' cultivars have good overlap in their bloom time and therefore are excellent pollinizers for one another. Planting two pollinizers helps to thoroughly cover the bloom period when one blooms slightly before and the other blooms slightly after the main cultivar.

Almond growers may plant an orchard with several early to mid-blooming cultivars or they may plant a later-blooming orchard with several mid to late-blooming cultivars. Growers that farm both early and late-blooming orchards have the advantage of reduced risk should inclement weather occur. Poor weather for pollination may occur during part of the bloom period, but it is less likely to persist from the earliest through the latest bloom.

If cultivar selection for an orchard does not take bloom time into account, then one cultivar could be post-bloom and fully leafed at the same time another cultivar might be just emerging from dormancy. Such a mistake in cultivar selection guarantees poor production.

Pollen Compatibility

Cross-incompatibility in California almonds was first recognized over 75 years ago between the 'I.X.L.' and 'Nonpareil' cultivars (Tufts and Philp, 1922). Thus leading to the identification of seven cross-incompatible groups for California cultivars (Kester et al., 1994a). Cultivars within the same group are cross-incompatible (ie., will not cross-pollinate). Any cultivar in one group is cross-compatible with all cultivars in any other group. The single exception is ‘Jeffries’, which is unilaterally incompatible within certain groups (Kester et al., 1994b).

Certain cultivars do not fit into the seven known groups. They are either in their own group or in groups yet to be determined Successful cross-pollination between compatible cultivars from different pollen groups can occur in orchards provided their bloom-time is sufficiently complementary. This complex pollen compatibility situation for the major cultivars used in California is summarized in Tables 2 and 3 (Almond Board of California, 1995; Asai, 1996).

Pollinizer Arrangement

The planting pattern for pollinizers significantly influences the ultimate yield potential of an orchard. An arrangement with single rows of cultivars planted alternately efficiently maximizes exposure of each cultivar to a pollinizer and is the standard arrangement in California. Over the life of an orchard, this single-row arrangement will maximize yields (Hendricks, 1996).

‘Nonpareil’ is the most desirable cultivar in California. This is due to consistent yield and good market utility. Many orchards throughout California are planted to 50% ‘Nonpareil’. In a two-cultivar orchard both cultivars are in equal proportion in alternating rows, thus bloom overlap must be good to ensure set.

In a three-cultivar orchard, pollinizers are frequently chosen to bracket the ‘Nonpareil’ bloom. Mid-blooming ‘Nonpareil’ might be planted at 50% or every other row, with ‘Sonora’ (an early bloomer) at 25% or every fourth row, and ‘Butte’ (a later bloomer) also at 25%.

A four-cultivar orchard usually provides excellent overlap and bracketing, but makes harvesting complex because each cultivar is harvested and hulled separately due to processing efficiencies and market requirements. The four cultivars might be planted at 50%, 25%, 12% and 12%. A planting with only 12% of a particular cultivar allows the evaluation of new cultivars or the use of a less productive but excellent pollinizer while minimizing risk of crop reductions.

In specialized situations, such as a planting on 'Marianna 2624' plum rootstock (which precludes the use of 'Nonpareil' due to scion/rootstock incompatibility), there may not be a "main" cultivar. Three cultivars may be planted in single rows with each comprising one-third of the orchard. Although rare, alternating cultivars within the row to ensure optimum pollination can work well if nut characteristics are similar enough to allow harvesting, hulling, and marketing together.

Socias i Company et al. (1994) found that low nut-set was primarily attributed to orchard design where pollen interchange between cultivars was hindered. The proper proportion and distribution of cultivar combinations is essential for efficient transport of pollen from one cultivar to another.

Strong Honeybee Colonies

The transport of almond pollen from one cultivar to another is primarily accomplished by honeybees. Almond pollen is not windblown so cross-pollination by wind is insignificant (Polito et al., 1996). Bee flight activity is governed by the abiotic environment. Honeybees forage when temperatures are 55°F (12.8°C) and higher; they do not forage in rain or in wind stronger than 15 miles (24.1 km) per hour. Cloudiness can also reduce flight activity, especially when it occurs near threshold temperatures (Thorp, 1996). Strong colonies containing eight frames of bees with active brood rearing are better able to forage and cross-pollinate under marginal weather conditions than are weak colonies with four frames of bees or less. This is important because bloom occurs in February when weather is frequently cool or rainy.

Strong colonies should be comprised of at least eight frames of bees. Sheesley and Poduska (1970) found that eight frame colonies collected three times the weight of pollen collected by a four-frame colony (which was the minimum standard previously recommended by the California Beekeepers Association).

Beekeepers can help initiate brood rearing by feeding both sugar syrup and protein supplements or pollen in January. This improves colony strength and stimulates pollen foraging during almond bloom (Thorp and Briggs, 1986).

Pollen-foraging worker bees are the most efficient pollinators of almond. They scrabble atop the anthers, become heavily dusted with pollen, contact the stigma, and thus effectively transfer pollen. They tend to forage on single cultivars and on trees in similar bloom stages, hence the importance of pollinizer arrangement. Fortunately, almond blossoms are highly rewarding to honeybees and they receive frequent visitation from nearby colonies (Thorp, 1996).

Even after flowers have lost their petals due to rain and strong wind, they can remain attractive to nectar-foraging honeybees. Under ultraviolet light, Thorp et al. (1975) observed brilliant aquamarine fluorescence by almond nectar, thus nectar possibly functions as a direct visual cue for allowing bees to assess nectar availability.

Beehives are best located in open areas where morning sun warms the colony and initiates flight activity early in the day. Almond producers can help bees be more effective in cross-pollinating the crop by controlling weeds around hives and by mowing competing bloom on the orchard floor. Hive stands must be built to elevate hives above floodwaters in orchard sites prone to flooding.

Beekeepers frequently handle beehives on pallets holding six colonies. Two to three hives per acre (4.9 to 7.4 hives/ha) are recommended for almond pollination. For good flight activity and pollination during marginal conditions, hives are usually distributed at 0.10 to 0.25 mile (0.16 to 0.4 km) intervals through large orchards or spaced around the perimeter if the block is less than 40 acres (16.2 ha). A pollination contract will specify expectations and helps to ensure better pollination service (Thorp, 1986).

Weather

Good weather is essential for optimum almond pollination, yet it is often scarce in February (even in California). The effect of climate on bee flight was discussed above and this is really the limiting factor in almond pollination. Without suitable weather for honeybee activity, pollen physiology (germination and tube growth) is of little importance since no cross-pollination occurs.

Anthers normally dehisce and shed pollen within a few hours of flower opening. Optimum temperature for dehiscence is 65° to 80°F (18.3° to 26.6°C). Rain can prevent or delay dehiscence, wash away pollen, lead to bursting of pollen grains, and reduces receptivity by diluting stigmatic fluid (Polito et al., 1996).

The stigma is usually receptive for 3 to 4 d following anthesis. Cool temperatures extend this time while high temperatures with wind and low humidity can shorten receptivity by desiccating the style.

Temperature affects pollen germination and pollen tube growth differently. The optimum temperature range for pollen germination is 50° to 70°F (10° to 21.1°C). Below 40°F (4.4°C) pollen germination in almond is seriously hindered. Since bee flight begins above 55°F (12.8°C) temperatures are adequate for pollen germination once bees are able to move pollen around. Once pollen grains land on the stigma and germinate, pollen tubes penetrate the style within 60 to 90 min.

Pollen tube growth is optimized between 70° and 87°F (21.1° and 30.6°C), slightly higher than for germination. Above 90°F (32.2. °C) pollen tubes can burst and below 60°F (15.6°C) growth is greatly slowed, but this is at least partially compensated for by a reduction in the rate of decline of ovule viability (Polito et al., 1996).

Fertilization and Nut Set

In cross-pollinated almond flowers under orchard conditions, pollen tubes typically grow to the base of the style and enter the upper portion of the ovary within 96 to 120 h (Griggs and Iwakiri, 1975). At this time pollen tube growth slows greatly or stops while the final stages of embryo sac differentiation are completed. Embryo sac development is stimulated by the presence of compatible pollen tubes in the style and final elongation growth of the embryo sac is promoted by cross-pollination (Pimienta and Polito, 1983). The pollen tube resumes growth 3 to 4 d later, enters the micropyle and grows through the ovule to the embryo sac (Pimienta et al., 1983). Thus, approximately 8 d after a flower is cross-pollinated the embryo sac is mature enough to attract the pollen tube so as to complete fertilization.

Griggs and Iwakiri (1964) emasculated almond flowers and cross-pollinated them before and after normal anthesis. Flowers pollinated 1 and 2 d before normal bloom gave 18% set; 1 d after anthesis gave 30% set; 3 d after anthesis, a 21% set, and 5 d after opening, only a 1% set. This demonstrated that pollen must arrive at the stigma early enough in the receptive period to have time to grow to the ovule before viability has passed. Generally, the sooner a flower is cross-pollinated after opening, the greater the chance of fertilization and nut-set.

Other Pollination Aids

Various artificial pollination methods have been evaluated but none significantly increase nut-set. These methods include pollen inserts within beehives and blower applications of pollen (Thorp et al., 1967).

Sugar sprays, bee orientation pheromone, or queen mandibular pheromone applications can attract honeybees and stimulate flight activity but they have either not shown reliable improvement in yield or have not been tested adequately. Other bees such as mason bees (*Osmia sp*.) or bumble bees (*Bombus sp*.) have shown good utility as almond pollinators but to date their management has not been commercially viable (Thorp, 1996).

In conclusion, the key factors for successful almond pollination are cultivar pollen compatibility and complementary bloom, good pollinizer arrangement, and good placement of strong honeybee colonies. Cross-pollination is enhanced by dry weather during bloom with adequate temperatures to stimulate honeybee flight activity. Moderate bloom time temperatures without drying winds will help ensure that almond orchards can achieve their maximum production potential.

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Table 1: Almond cultivars grouped by approximate bloom periods.[z]

Early (< -6d)	Early mid (-5 to -1d)	Mid (0 to +2d)	Late mid (+3 to +4d)	Late (+5 to +7d)	Very late (> +8d)
Jordanolo	Milow	Aldrich	Butte	Livingston	Planada
Ne Plus Ultra	Peerless	Carmel	Carrion	Mission	Ripon
	Sonora	Fritz	Drake	Mono	
		Harvey	LeGrand	Padre	
		Jeffries	Monarch	Ruby	
		Merced	Monterey	Thompson	
		Nonpareil	Norman		
		Price	Sauret #2		
		Sauret #1	Tokyo		
		Solano			
		Wood Colony			

[z] The numbers in the column heads indicate the days before (-) or after (+) peak 'Nonpareil' bloom. This table is based primarily on results of the Manteca regional variety trial.

Table 2: Pollen-incompatible groups of almond cultivars.

Nonpareil	Mission	NePlusUltra	Thompson	Carmel	Solano	Monterey
IXL	Ballico	Merced	Granada	Carmel	Eureka	Monterey
Jeffries[z]	Languedoc	NePlusUltra	Harvey	Carrion	Jeffries[z]	Butte
Long IXL	Mission	Norman	Mono	Jeffries[z]	Kapareil	Jeffries[z]
Nonpareil		Price	Robson	Livingston	Solano	
Profuse		Ripon	Sauret #2	Monarch	Sonora	
Tardy Nonpareil		Rosetta	Thompson	Sauret #1	Vesta	
			Wood Colony			

[z] 'Jeffries' is a mutation of 'Nonpareil' and should belong to the 'Nonpareil' incompatibility group. However, field experience combined with controlled tests in 1984 and 1985 show that 'Jeffries' possesses unilateral incompatibility. All cultivars, including the parent 'Nonpareil', can fertilize 'Jeffries'. But 'Jeffries' is unable to fertilize 'Nonpareil', 'Carmel', 'Solano', 'Monterey', and all cultivars in these incompatibility groups. On the other hand, 'Jeffries' can fertilize all cultivars in the 'Mission', 'Ne Plus Ultra', and 'Thompson' groups, as well as 'Fritz'.

Table 3: Cultivars tested for pollen incompatibility for which no separate incompatibility group has been identified.

Cultivar	Successful test crosses (cross-compatible cultivars)[z]
Aldrich	Carmel, Sonora, Monterey, Sauret #2, Nonpareil
Fritz	Carrion, Merced, Harvey, Thompson, Ripon, Nonpareil, Ne Plus Ulta, Jeffries, Sonora, Wood Colony, Monterey, Carmel, Aldrich
Padre	Nonpareil, Mission, Thompson, Fritz, Carrion, Ruby, Butte, Price
Ruby	Nonpareil, Mission, Thompson, Ripon, Merced, Padre, Price, Monterey

[z] If a cultivar in a known incompatible group is listed as compatible, then any other cultivar in that group should also be compatible.