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ALMOND FLOWER DEVELOPMENT

Timing of Floral Differentiation in Three Cultivars in Four California Almond-Growing Areas

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Introduction

Flower development in almond, as is typical of most deciduous tree species, occurs during the growing season prior to bloom. The timing of these events varies widely among species, and even among cultivars within species. A comprehensive knowledge of timing of flower development is fundamental to informed orchard management decision-making. The information becomes especially important in managing stress. Current growth and cropping conditions are readily apparent and it is often clear how timely management of stress conditions can influence the tree and crop at this level. However, the concealed nature of events occurring in buds that lead to floral development makes it more difficult to appreciate the timing of critical stages and the potential impact of stresses on those critical developmental processes..

Our current understanding of this series of events in almond is inadequate. Almond flower differentiation has not been investigated for over 50 years. Tufts and Morrow (1925) and Brooks (1940) investigated differentiation in 'Nonpareil' in the Davis area. These results used now-obsolete methodologies and were focused in a growing area that inadequately represents the range of almond production in California today. We have, therefore, initiated a study using scanning electron microscopy to update these early findings and to extend them to the major almond-growing areas in California.

We collected potential flower buds from three almond cultivars ('Nonpareil', 'Carmel', and 'Butte') in four locations (Chico, Butte County; Davis-Winters, Yolo County; Modesto, Stanislaus County; and Shafter, Kern County). We made weekly collections from each site beginning mid-June and continuing until pistils were initiated in all samples. The material was examined using scanning electron microscopy to determine the extent of development in the buds.

Materials and Methods

We collected bud samples of 'Nonpareil', 'Carmel', and 'Butte' from three major almond growing areas — Northern Sacramento Valley (Chico, Butte County), Northern San Joaquin Valley (Modesto, Stanislaus County), and Southern San Joaquin Valley (Shafter, Kern County) — and from the UC Davis orchards at Davis ('Nonpareil) and Winters ('Butte', 'Carmel'). Well-managed commercial or experimental orchards were selected. In order to generate the most useful data, we focused primarily on 'Nonpareil', which we collected weekly from all four sites. We collected 'Carmel' on a regular basis from Butte and Stanislaus counties and 'Butte' on a regular basis from Kern county. We also collected 'Butte' from the northern locations and 'Carmel' from the south so that we could have material for comparisons, but we did so less frequently.

Samples from Butte, Stanislaus and Kern Counties were collected and shipped to Davis via overnight express delivery. Potentially reproductive buds were identified on the basis of position on the shoot. Twenty buds each from the north and south sides of the trees were dissected to reveal the developing shoot apex within the bud. The dissected buds were prepared for scanning electron microscopy using standard practices. Briefly, material was fixed in 3% glutaraldehyde in phosphate buffer, pH 6.8, at 4°C for 3 to 4 weeks, dehydrated in a graded ethanol series to dry amyl acetate, critical point dried using CO_2 as a transitional fluid, sputter-coated with 30-40nm gold and observed in the scanning electron microscope. The scanning electron microscope images were captured as digital image files, stored on a computer and scored for developmental stage.

Floral development is a sequential series of events. The growing point (meristem) of the bud begins its activity creating vegetative organs, the bud scales. At some point it undergoes a transition to reproductive development. This transition is marked by the production of three bracts (small, leaf-like organs that subtend the flowers) and a subsequent change in the three-dimensional geometry of the meristem leading to flower initiation. The floral meristems then produce organs in sequence: sepals, petals, stamens and pistils. We classified the reproductive buds according to eight stages of development at the reproductive apex as described in Table 1. It is our view that orchard managers should take special note of stages 2 and 3, leading to floral initiation, and stages 7 and 8, leading to pistil initiation, as key stages in the development of the following year's crop.

Progress continues at this time and it is important to realize that the information presented here is preliminary. We have currently processed, viewed and evaluated representative material through mid September's collections, a total of 1085 buds. These represent approximately one-quarter to one-third of the buds through mid-September. A good deal of material remains to be evaluated, including the remaining collections from June to mid September as well as material collected through October. Therefore, the results we present here will certainly be revised on the basis of these evaluations.

Results

Although we have at this time examined most of our collected material in the scanning electron microscope, we have not yet analyzed all of the images. Our current results do suggest some tentative conclusions. Our results to date for the three cultivars are summarized in Tables 2 - 4. These results represent combined data from north and south sides of the trees. It is apparent that from mid-summer on, there is a wide range of stages present at any given time on the trees. As we accumulate additional information it should be possible to determine how much, if any, of this variation is correlated with spatial location on the tree.

For 'Nonpareil' the transition to the reproductive state and the initiation of flowers (stage 3) occurs primarily during the month of July, but continues through mid August. The first pistils emerge in mid August, but by mid September's material pistils still had not been fully initiated in all buds.

'Carmel' shows similar timing with the first indications of floral transition occurring in July and continuing through mid August. Pistil initiation is first seen in August but remains incomplete in all buds through mid September.

'Butte' appears to undergo its development somewhat later than the other two cultivars, however, because we have examined limited material at this stage, it is too soon to generalize on this point. In any case, it is clear that the range of developmental time required to initiate any given stage throughout the tree is extensive in this cultivar as well.

These results indicate that development is occurring earlier than had been suggested in the older literature. This may be a consequence of our experimental methods. Improvements in digital imaging and data collection techniques have enabled us to observe large numbers of buds, many more than had been possible even a short time ago. Additionally, subtle developmental events that likely escaped the notice of previous workers are detectable using the higher resolution methodologies we employed here. Despite these technological advances and advantages, we cannot rule out the possibility that we are seeing the effects of year to year variation. Both of the previous investigations examined material in a single year. It may be possible that the differences between those results and ours merely reflect year to year differences. We intend to repeat our analyses next year to help resolve this issue. Furthermore, we expect to have complete information on this year's results for distribution in next year's report summaries.

A preliminary summary of the data for 'Nonpareil' only is presented in Figure 1. This chart shows the distribution of stages of development from floral transition to pistil initiation. The chart illustrates the variability apparent in the early stages of development — a situation which is not apparent from the existing reports in the literature. While researchers certainly understand that the buds vary in the timing of critical events of floral development, this degree of variation is certainly not seen in the literature on almond or other deciduous tree species.

It is our intention to begin to develop a degree-day driven model for floral development in almond. We will have an extensive data set with the two years' data which should make it possible to determine if relevant correlations exist and what threshold parameters most accurately predict the progress of flower development.

Table 1. Developmental stages of almond buds. Stage numbers in this table are referred to in the results. Representative scanning electron micrographs illustrating the stages are shown below the table.

Number	Developmental Stage	Developmental Activity
1	Vegetative (Pre-reproductive)	Bud scales
2	Bract Initiation	Sequential initiation of three bracts
3	Transitional/Flower Initiation	Shape changes at the apex; elevation of receptacle
4	Sepal Initiation	Sequential initiation of five sepal primordia
5	Petal Initiation	Sequential initiation of five petal primordia
6	Stamen Initiation	Sequential initiation of multiple stamen primordia
7	Early Pistil Initiation	Stamen initiation complete, concavity apparent at apex
8	Pistil Initiation	Pistil primordium visible at the center of the apex

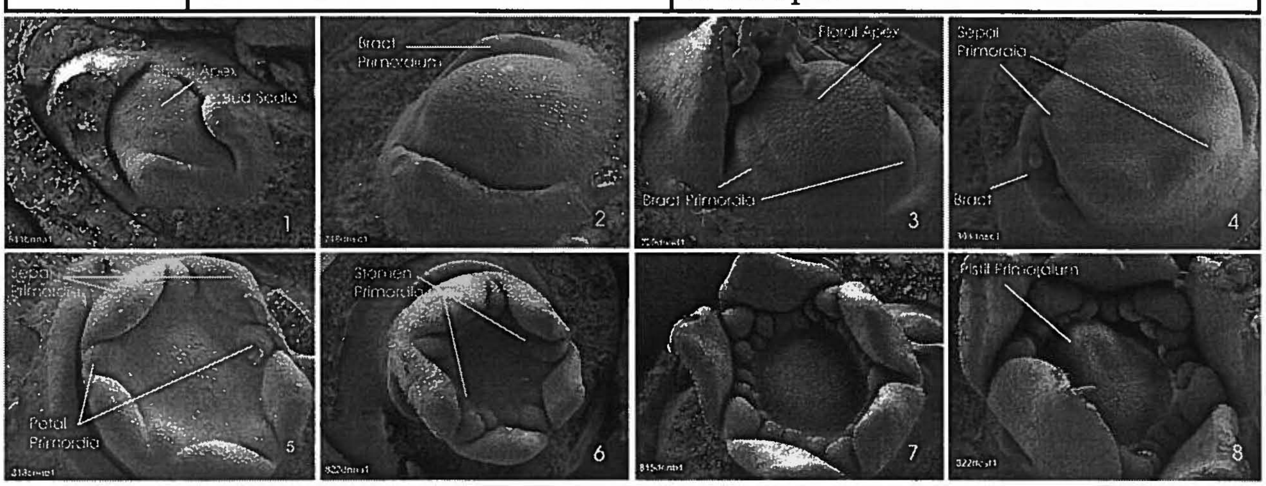


Table 2. Stages of flower development (as listed in Table 1) in 'Butte' buds from June through mid-September in Kern (Shafter), Stanislaus (Modesto), Yolo (Davis/Winters) and Butte (Chico) counties. Where a single number is listed, all buds examined were at that stage of development. Ranges indicate all stages seen at a given date.

Note that this table represents preliminary results, based on limited data available at the time of this report. Changes, especially in the ranges of development can be expected as we collect additional data on flower development.

Month	Date	Kern	Stan.	Yolo	Butte
Jun	8-14	1	1	1	
	15-21	2		1-2	
	22-28	2			
	29-5	1-2			
Jul	6-12	2		1-2	
	13-19	2	1-2		
	20-26	2-3			
	27-2	2-3		2-3	
Aug	3-9	2-3		3-4	2-4
	10-16	3-4	3-5	4-5	
	17-23	4-5		4-5	3-4
	24-30	4-6		4-6	3-5
	31-6	4-7	4-7	4-6	4-6
Sept	7-13	4-8	7-8	7-8	4-8
	14-20	3-8	8		5-8

Table 3. Stages of flower development (as listed in Table 1) in 'Carmel' buds from June through mid-September in Kern (Shafter), Stanislaus (Modesto), Yolo (Davis/Winters) and Butte (Chico) counties. Where a single number is listed, all buds examined were at that stage of development. Ranges indicate all stages seen at a given date.

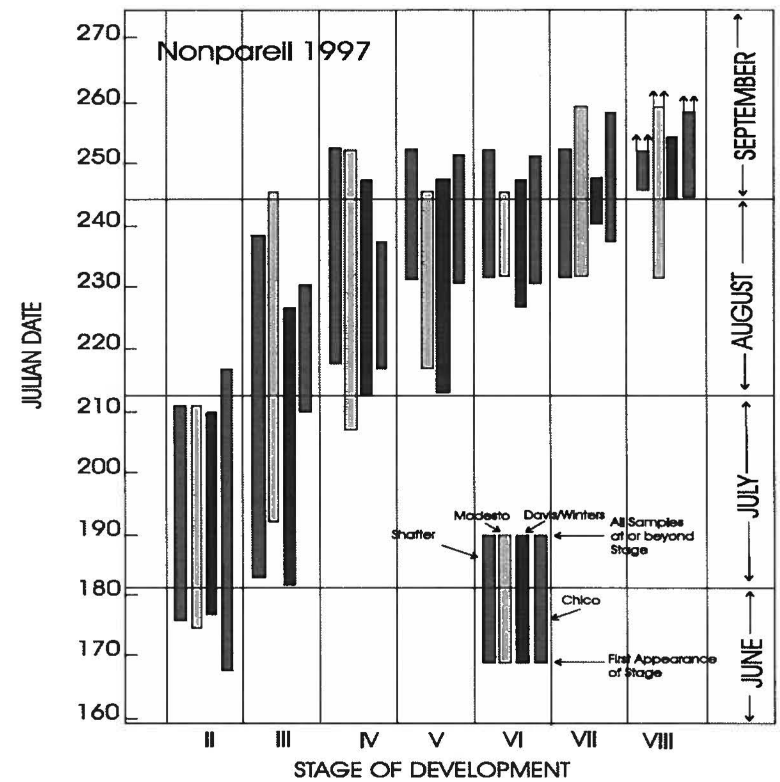
Note that this table represents preliminary results, based on limited data available at the time of this report. Changes, especially in the ranges of development can be expected as we collect additional data on flower development.

Month	Date	Kern	Stan.	Yolo	Butte
Jun	8-14				
	15-21	1-2			
	22-28		1	1-2	1-2
	29-5		1-2		2
Jul	6-12	2	2	3	2
	13-19		3-4		2-3
	20-26		3-4		2-3
	27-2	3-4	3-4	3-6	3
Aug	3-9		3-5	4-7	4
	10-16	3-6	4-6	6-8	3-5
	17-23		3-8		4-7
	24-30		5-8	8	3-8
	31-6		6-8	8	8
Sept	7-13				4-8
	14-20				

Table 4. Stages of flower development (as listed in Table 1) in 'Nonpareil' buds from June through mid-September in Kern (Shafter), Stanislaus (Modesto), Yolo (Davis/Winters) and Butte (Chico) counties. Where a single number is listed, all buds examined were at that stage of development. Ranges indicate all stages seen at a given date.

Note that this table represents preliminary results, based on limited data available at the time of this report. Changes, especially in the ranges of development can be expected as we collect additional data on flower development.

Month	Date	Kern	Stan.	Yolo	Butte
Jun	8-14	1			
	15-21	1	1	1	1-2
	22-28	1-2	1-2	1-2	1-2
	29-5	1-2	1-2	1-2	1-2
Jul	6-12	2-3	2-3	2-3	1-2
	13-19	2-3	2-4	2-3	1-2
	20-26	2-3	2-3	2-3	2
	27-2	1-2	2-3	2-5	2-3
Aug	3-9	2-4	4-5	3-5	2-4
	10-16	2-4	3-5	3-6	3-4
	17-23	4-7	3-8	4-8	4-8
	24-30	2-7	4-7	4-7	4-7
	31-6	5-8	3-8	4-8	4-8
Sept	7-13	4-7	4-8	8	5-8
	14-20		7-8		7-8



Stages of development for 'Nonpareil' flower buds from Shafter, Modesto, Davis/Winters and Chico. Stages are described in Table 1. Arrows indicate

Figure 1. This graph is based on partial data for 'Nonpareil'. As our research progresses we will expand the information presented here and generate comparable charts for the other cultivars. What is apparent, even in these incomplete data, is that there is extensive variability among buds with regard to timing of floral development. This appears to be particularly the case with the earlier stages. Note that pistil initiation shows relatively less variability.