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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) in 1997 and 1998.

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' with secondary emphasis on the other two cultivars. Samples from Butte, Stanislaus and Kern Counties were collected and shipped to Davis via overnight express delivery. In 1997, collections were made weekly. 'Nonpareil' was collected from each site on each collection date. We collected 'Carmel' on a regular basis from Butte and Stanislaus counties and 'Butte' on a regular basis from Kern county. We 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. In 1998, we made our collections every other week and included all three cultivars on each collection date.

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. In this report, we will focus primarily on our results for 'Nonpareil' from 1997. We also feel that stages 2 and 7 are most informative in regard to orchard management practices. Stage 2 marks the transition from a vegetative to a reproductive state at the bud apex, and stage 7 indicates the onset of pistil initiation.

Progress continues at this time and it is important to realize that the information presented here remains preliminary. At the time of this report, we are still examining the 1998 material. Our observations are complete for 1997's collections, but some of these data are still being evaluated with the objective of developing a model of flower development based on time and temperature relationships.

Table 1. Developmental stages of almond buds. Stage numbers in this table are referred to in the results.

Number	Developmental Stage	Developmental Activity
1	Vegetative (Pre-reproductive)	Bud scales
2	Bract Initiation/Transition to Reproductive Stage	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

Results

Our 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.

The impact of year to year differences is evident from our 1998 analyses. Although evaluations are not complete, it is clear that flower development, similar to all other tree-development events, has been delayed in 1998 relative to 1997. 1998 has been an unusual weather year in several regards. The *El Nino* weather pattern produced a cool spring and early summer followed by a hot mid to late summer. As a result, flowering and harvest were exceptionally late in almond, as in nearly all tree crop species. We are finding similar effects in flower development, where the occurrences of the various stages are running 2 to 4 weeks later than 1997. It is interesting to note that these results are somewhat more comparable to what had been reported in the earlier literature. We have not investigated the weather patterns that characterized the years in which Tufts and Morrow's or Brooks's studies were made.

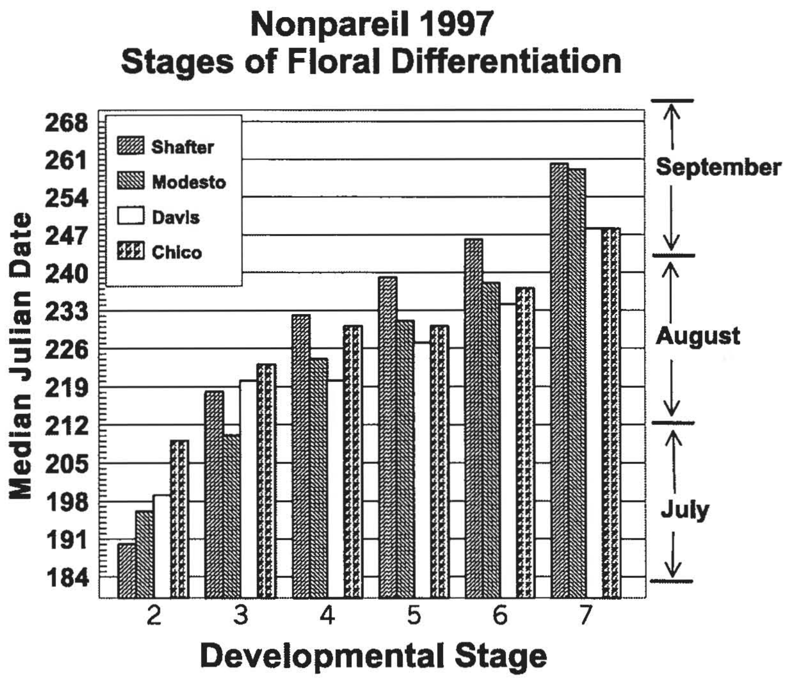

Figure 1. Median time for floral development stages 2 through 7 for 'Nonpareil' for Shafter, Modesto, Davis and Chico in 1997.

Figure 1 shows the median time for floral development stages 2 through 7 for 'Nonpareil' in 1997. Note that, as expected, the early stages were achieved somewhat later in the north, but that the later stages were achieved earlier in the north. At this time, we are not sure of the significance of this result. The earliest indications of a transition from a vegetative bud to one that is poised to produce flowers are seen in July beginning in early July in the Kern county site and progressing to late July in Butte county. The range of timing for subsequent stages is somewhat less varied among the collection locations.

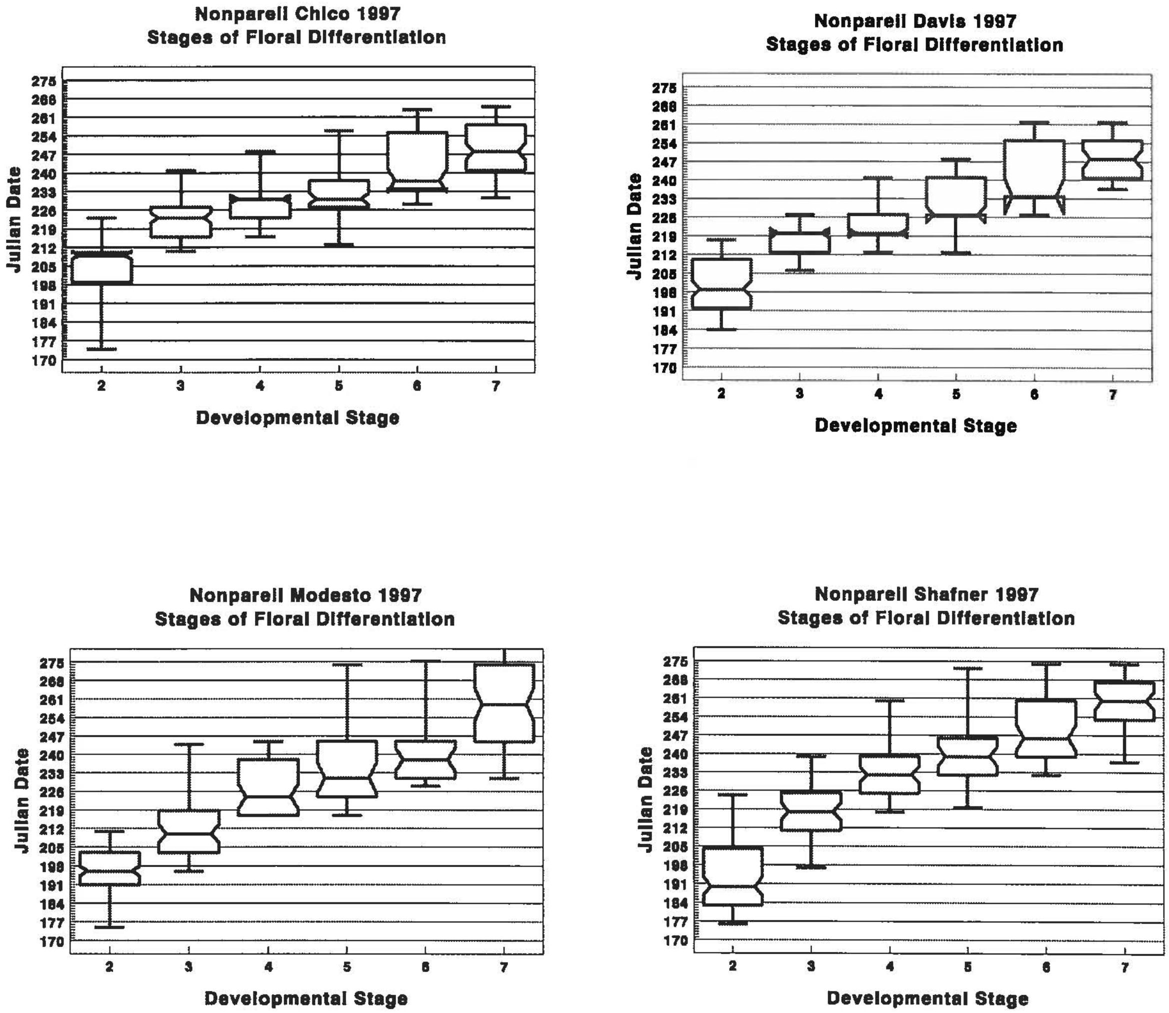

Figure 2. Box and whisker plots of timing of floral development stages 2 through 7 for 'Nonpareil' in each of the collection sites. The horizontal center line in the box represents median date for the appearance of a stage. The upper and lower bounds of the box represent the 75 and 25%tile, respectively, i. e. the time at which 25% or 75% of the buds had attained a given stage. The "whiskers" extending above and below the boxes represent 95 and 5%tiles. Thus, 90% of buds pass through a given stage during the period of time represented by the interval between the whiskers. The notched region of the box represents the 95% confidence interval for the median date.

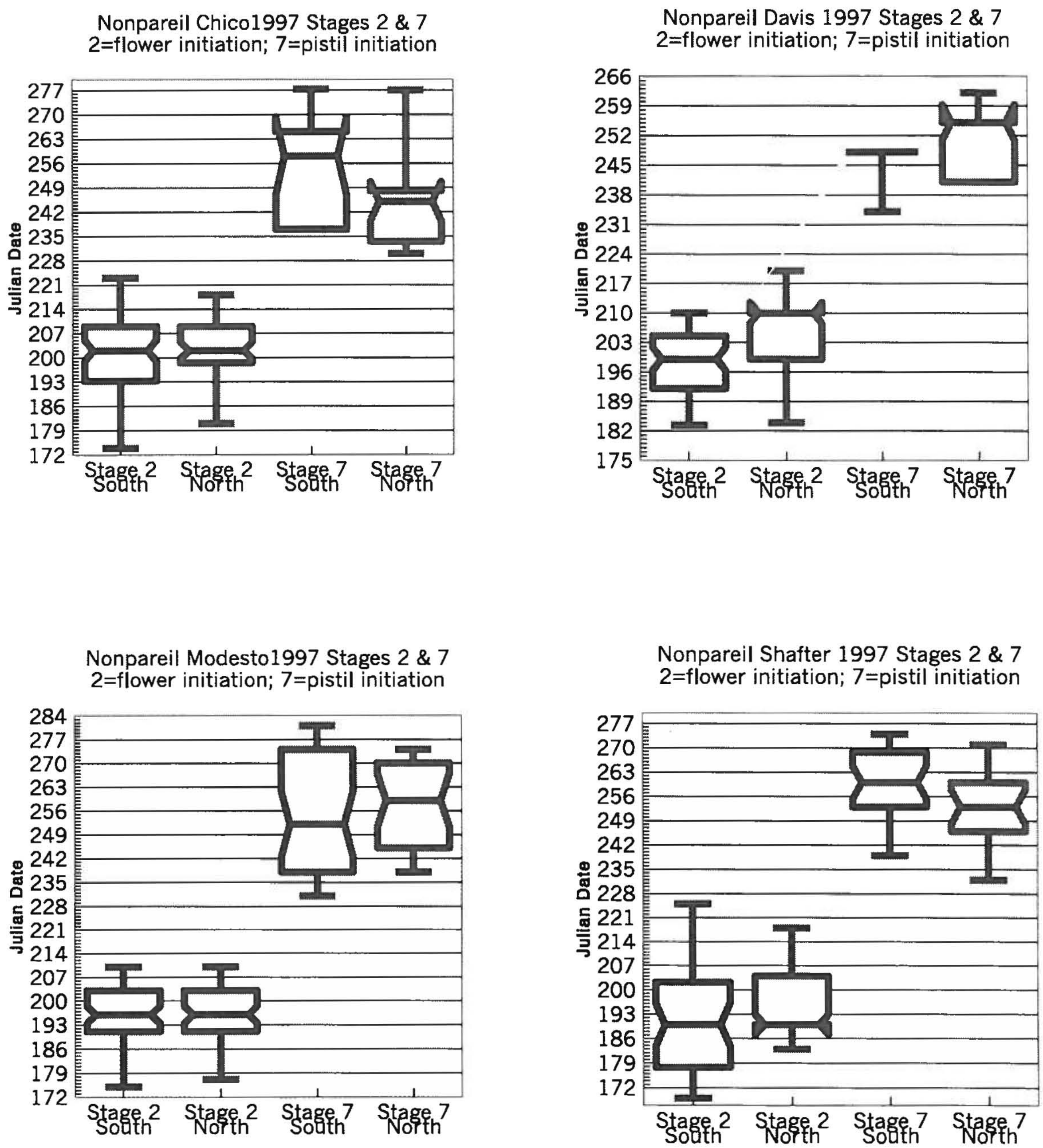

Figure 3. Bar and Whisker graphs (see fig 2 for details) of stages 2 and 7 from north and south sides of the tree for 'Nonpareil' in each collection site in 1997.

Figures 2 and 3 illustrate the extent of variation we find within 'Nonpareil' among the four collection locations (Fig. 2) and within locations for the north and south sides of the trees (Fig 3). Note that there is a range of approximately 6 weeks in the time required for 90% of the buds to enter and pass through the floral initiation stages. Thus, while it is useful to realize that the medial time of floral initiation, for example, occurs about mid-July, it must also be understood that the range of time required for the completion of a given developmental stage can be extensive. Furthermore, at any given time during the growing summer, the buds on the tree are present in a wide range of stages.

We find no consistent relationships between the north and south sides of the trees (Fig 3). A more complete analysis of these data is currently in progress, but we do anticipate any change in this observation. As the graphs in Fig. 3 illustrate, the 95% confidence intervals for the median dates for stages 2 and 7 generally overlap. This indicates that there is no significant difference between the north and south sides of the trees. The one exception is in the Davis collections. Here we found a consistent difference between north and south sides, with the south side consistently ahead of the north side (Fig. 4). Although the difference appears to have statistical significance, it is not clear why we should see this relationship in Davis, but not in the other collection sites.

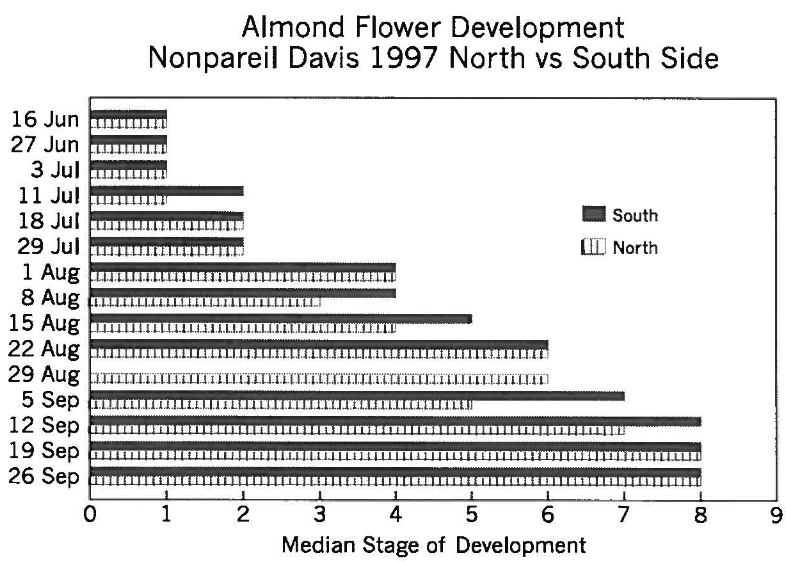

Figure 4. Median stages of floral development attained in of 'Nonpareil' almond buds from north and south sides of the trees. These results are from collections made in Davis during the 1997 season.

Work continues on this project. We are completing our evaluations on the 1998 material, and are currently working on interpreting the data on the basis of degree-days rather than calendar date which may help to account for some of the variation among locations.