2000-2001(?)

ALMOND FLOWER DEVELOPMENT

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

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Objectives

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. The situation in buds contrasts with that for current growth and cropping conditions, where the situation is readily apparent and it is often clear how timely management of stress conditions can influence the tree and crop. The concealed nature of events occurring in buds that lead to floral development makes it more difficult to appreciate the timing of development and the potential impact of stresses on the critical developmental processes occurring within the buds. Our objective is to determine, as precisely as possible, the timing of key events in almond flower bud development.

We have completed three years on this project. Our results provide the first look at almond flower differentiation in over 50 years, and covers the full range of current almond-growing areas. The previous work on the subject, done by Tufts and Morrow (1925) and Brooks (1940), was done in the Davis area. These results used now-obsolete methodologies and were conducted in a growing area that inadequately represents the range of almond production in California today.

For our first two years, we focused on 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. In the third year, we concentrated exclusively on 'Nonpareil.' We have now shifted our attention from descriptive, structural analysis of the key morphological events to analysis of the molecular developmental processes involved. In this way we will build on our earlier work and develop a tool for analysis of almond flowering. We expect that this will be useful in the future as questions arise regarding flowering, the regulation of flowering, and how environmental variables can affect flowering in almond. This molecular analysis is currently in progress, and at the time of this writing, we do not have results to report.

In this report, we summarize the results of three years' morphological analysis.

Results

Bud samples of potentially reproductive buds were collected from almond orchards in Chico, Davis/Winters, Modesto and Shafter. Twenty buds each from the north and south sides of the trees were collected at regular intervals, either weekly or every other week. The buds were transported to Davis, dissected to reveal the developing shoot apex within the bud and 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 1 and 2, leading to floral initiation, and stages 6 and 7, 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 1 and 6 are most informative in regard to orchard management practices. Stage 1 marks the transition from a vegetative to a reproductive state at the bud apex, and stage 6 indicates the onset of pistil initiation. Note that the stage numbering in this report has changed from our earlier reports.

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

Stage No.	Developmental Stage	Developmental Activity
0	Vegetative (Pre-reproductive)	Bud scales
1	Transition to Reproductive Stage	Sequential initiation of three bracts
2	Transitional/Flower Initiation	Shape changes at the apex; receptacle elevation
3	Sepal Initiation	Sequential initiation of five sepal primordia
4	Petal Initiation	Sequential initiation of five petal primordia
5	Stamen Initiation	Sequential initiation of stamen primordia
6	Early Pistil Initiation	Stamen initiation complete, concavity at apex
7	Pistil Initiation	Pistil primordium visible at the apex center

Results

Timing of developmental stages for the three cultivars for 1997 and 1998 are shown in Tables 2 and 3. The data are shown as the median time to stages 1 through 6. Time is tabulated as days from bloom and as degree-days using a 50-80°F threshold. Weather data were obtained using the UCIPM weather service site (http://www.ipm.ucdavis.edu/WEATHER/ddretrieve.html).

Unfortunately, neither 1997 nor 1998 was a typical year in terms of overall weather events. 1997 was considerably warmer than normal, and 1998 was much cooler. This is reflected in the results as the same stages of floral differentiation were attained several weeks earlier in 1997 relative to 1998. Our inference is that these two years bracket the range of what may be expected. In 1999, we examined 'Nonpareil' only. The 1999 growing season closely resembled that of 1998 in that it was substantially cooler than normal, and our results were similar to that seen in 1998.

Extensive variation in the timing of bud development events was apparent. Within trees, bud development was more advanced on the south sides of trees relative to the north side. Timing of developmental events varied among locations, but no patterns emerged consistent with the north to south range which spanned 4°15' latitude (522 km). Among years, development occurred earlier in 1997, a relative warm year, and was delayed in 1998 and 1999, relatively cool years.

Our results indicate that development is occurring earlier than had been suggested in the older literature. It may be possible that the differences between those results and ours merely reflect year to year differences. However, a careful examination of the published documentation from Tufts and Morrow's (1925) work shows that they had interpreted flower initiation as occurring at a much later morphological stage than we now know is the case.

We attempted to correlate the timing of flower development events to externally visible factors. Table 4 shows the relationship between two critical developmental events in the bud—flower and pistil initiation—and the progress of hull split. Here, we see marked differences among the cultivars. The time from 10% and 90% hull spilt to bud stages 1 and 6 are shown in Table 4. For 'Nonpareil,' floral initiation occurred after hull split had begun; and, in all but one case, was complete by the time 90% of the hulls had split. The median time for buds reaching Stage 1 of development ranged from 5 days (Modesto, 1977) to 36 days (Shafter, 1997) after 10% of the hulls had split. Median time to floral initiation for all locations in both years was 24 days after 10% hull split and 7.5 days prior to 90% hull spilt.

The situation for 'Carmel' and 'Butte' differed. For these cultivars floral initiation preceded the onset of hull split. Floral initiation for 'Carmel' buds occurred a median of 23 days prior to 10% hull split, and for 'Butte' 13 days prior to 10% hull split. For these cultivars, the buds were in various stages of floral organ development at the time of hull split.

Table 2. Median time from bloom to Stages 1-3 of floral development and differentiation for three almond cultivars from four California almond-growing locations in 1997. DAB, Days after bloom; DD, Accumulated Degree-Days.

			Stage of Floral Development								
			1			2			3		
Cultivar	Location	Aspect	DAB	DD	n	DAB	DD	n	DAB	DD	n
Nonpareil	Chico	North	153	2173	44	174	2555	20	181	2693	26
		South	153	2173	62	174	2555	23	181	2693	21
	Davis	North	165	2280	47	175	2451	24	189	2576	28
		South	151	2019	54	168	2333	20	175	2451	30
	Modesto	North	156	1925	56	170	2184	38	184	2428	34
		South	156	1925	56	170	2184	28	184	2428	17
	Shafter	North	151	2094	53	186	2784	29	200	3059	26
		South	151	2094	39	179	2649	15	193	2918	34
Carmel	Chico	North	145	2032	11	166	2424	7	166	2424	8
		South	152	2166	15	166	2424	18	173	2549	9
	Davis	North	138	2102	8	138	2102	3	167	2631	3
		South	138	2102	13			0	167	2631	6
	Modesto	North	145	1813	35	164	2160	30	171	2278	14
		South	145	1813	40	157	2030	30	171	2278	24
	Shafter	North	150	2092	10	172	2531	8	172	2531	13
		South	150	2092	16	172	2531	15	182	2723	5
Butte	Chico	North	168	2437	10	182	2699	12	189	2839	21
		South	168	2437	7	168	2437	3	189	2839	16
	Davis	North	157	2422	14	169	2650	17	183	2901	26
		South	169	2650	26	176	2768	10	183	2901	18
	Modesto	North	148	1890	12	164	2177	6	180	2464	9
		South	148	1890	9	180	2464	1	180	2464	8
	Shafter	North	173	2518	42	173	2518	20	201	3064	20
		South	166	2380	47	173	2518	27	194	2923	15

Table 3. Median time from bloom to Stages 4-6 of floral development and differentiation for three almond cultivars from four California almond-growing locations in 1997. DAB, Days after bloom; DD, Accumulated Degree-Days.

			Stage of Floral Development								
			4			5			6		
Cultivar	Location	Aspect	DAB	DD	n	DAB	DD	n	DAB	DD	n
Nonpareil	Chico	North	181	2693	14	188	2832	16	196	2988	20
		South	188	2832	20	202	3097	16	209	3227	15
	Davis	North	196	2845	32	196	2845	18	208	3112	27
		South	189	2576	22	189	2576	6	203	2978	11
	Modesto	North	188	2490	22	198	2686	12	219	3051	24
		South	205	2807	12	198	2686	15	212	2934	33
	Shafter	North	200	3059	14	218	3395	22	214	3332	17
		South	207	3197	21	207	3197	28	221	3458	26
Carmel	Chico	North	187	2826	1	187	2826	2	187	2826	2
		South	180	2826	10	180	2826	8	187	2826	12
	Davis	North	167	2631	11	174	2748	10	174	2748	12
		South	167	2631	12	174	2748	7	181	2882	19
	Modesto	North	178	2404	10	185	2529	9	189	2596	12
		South	178	2404	14	178	2404	1	192	2662	3
	Shafter	North	182	2723	3	182	2723	6	182	2723	2
		South	182	2723	3	182	2723	1			0
Butte	Chico	North	197	2995	5	197	2995	6	200	3049	12
		South	196	2971	10	197	2995	8	203	3104	10
	Davis	North	190	3043	16	201	3257	14	239	3949	31
		South	197	3181	15	201	3257	23	232	3848	32
	Modesto	North	180	2464	2			0	204	2899	22
		South	180	2464	3	205	2913	6	208	2958	14
	Shafter	North	201	3064	7	208	3202	14	222	3463	12
		South	201	3064	11	215	3337	6	215	3337	24

Table 4. Median time from bloom to Stages 1-3 of floral development and differentiation for three almond cultivars from four California almond-growing locations in 1998. DAB, Days after bloom; DD, Accumulated Degree-Days.

			Stage of Floral Development								
			1			2			3		
Cultivar	Location	Aspect	DAB	DD	n	DAB	DD	n	DAB	DD	n
Nonpareil	Chico	North	183	2325	20	198	2586	16	211	2818	12
		South	183	2325	16	205	2702	12	211	2818	23
	Davis	North	186	2214	28	186	2214	8	200	2474	14
		South	172	1977	21	186	2214	11	200	2474	19
	Modesto	North	179	2126	22	186	2255	12	193	2385	10
		South	179	2126	29	193	2385	14	207	2616	4
	Shafter	North	170	2263	10	189	2615	10	199	2813	18
		South	170	2263	21	189	2615	14	199	2813	14
Carmel	Chico	North	177	2308	7	192	2570	10	192	2570	6
		South	177	2308	14	192	2570	13	192	2570	12
	Davis	North	170	1970	13	170	1970	8	184	2207	19
		South	170	1970	25	184	2207	14	184	2207	10
	Modesto	North	164	1886	31	192	2379	14	192	2379	15
		South	178	2121	16	185	2250	18	192	2379	9
	Shafter	North	156	1997	22	189	2615	11	199	2813	16
		South	170	2263	31	189	2615	15	199	2813	14
Butte	Chico	North	175	2298	19	190	2559	7	190	2559	10
		South	175	2298	13	190	2559	8	190	2559	15
	Davis	North	178	2189	24	192	2449	9	192	2449	15
		South	178	2189	26	192	2449	6	192	2449	11
	Modesto	North	189	2363	22	175	2105	7	203	2591	20
		South	189	2363	29	189	2363	7	203	2591	9
	Shafter	North	181	2585	10	191	2783	20	191	2783	14
		South	172	2409	32	181	2585	22	191	2783	10

Table 5. Median time from bloom to Stages 4-6 of floral development and differentiation for three almond cultivars from four California almond-growing locations in 1998. DAB, Days after bloom; DD, Accumulated Degree-Days.

			Stage of Floral Development								
			4			5			6		
Cultivar	Location	Aspect	DAB	DD	n	DAB	DD	n	DAB	DD	n
Nonpareil	Chico	North	225	3010	3	225	3010	5	211	2818	6
		South	225	3010	7	225	3010	7	225	3010	6
	Davis	North	214	2699	7	214	2699	6	214	2699	10
		South	214	2699	1	214	2699	2	214	2699	13
	Modesto	North	207	2616	15	207	2616	3	279	2765	11
		South	207	2616	16	279	2765	8	279	2765	7
	Shafter	North	199	2813	12	212	3044	5	212	3044	6
		South	199	2813	7	212	3044	10	212	3044	8
Carmel	Chico	North	205	2801	4	205	2801	8	205	2801	8
		South	205	2801	1	205	2801	1	205	2801	7
	Davis	North	198	2467	3	198	2467	2	198	2467	14
		South	198	2467	1	198	2467	5	198	2467	8
	Modesto	North	206	2607	11	206	2607	1			0
		South	206	2607	3	206	2607	12	206	2607	3
	Shafter	North	199	2813	10	212	3044	5	226	3254	13
		South	199	2813	5	212	3044	7	212	3044	8
Butte	Chico	North	203	2791	15	203	2791	7	203	2791	3
		South	203	2791	13	203	2791	9	217	2983	3
	Davis	North	206	2674	5	206	2674	15	220	2863	2
		South	206	2674	20	220	2863	1	220	2863	1
	Modesto	North			0	217	2744	2	217	2744	11
		South	203	2591	7	217	2744	2	217	2744	4
	Shafter	North	204	3014	12	204	3014	9	204	3014	4
		South	204	3014	13	204	3014	6	204	3014	5

Table 6. Time (days) from 10% and 90% hull split (HS) to median date for Stages 1 and 6 of bud development for three almond cultivars.

Cultivar	Location	Year	Stage 1		Stage 6	
			10% HS	90% HS	10% HS	90% HS
Nonpareil	Chico	1997	19	-16	75	40
	Modesto	1997	5	-7	61	49
	Shafter	1997	36	-26	106	44
	Chico	1998	16	-2	59	40
	Modesto	1998	35	15	76	56
	Shafter	1998	29	-8	65	35
	median		24	-7.5	70	42
Carmel	Chico	1997	-23	-54	12	-19
	Modesto	1997	-34	-32	13	5
	Shafter	1997	-34	-61	-2	29
	Chico	1998	-19	-30	9	-2
	Modesto	1998	-23	-39	5	-11
	Shafter	1998	5	-39	53	3
	median		-23	-39	10.5	0.5
Butte	Chico	1997	-19	-27	16	8
	Modesto	1997	-32	-46	26	12
	Shafter	1997	-7	-37	42	12
	Chico	1998	-11	-30	31	12
	Modesto	1998	-16	-35	26	7
	Shafter	1998	8	-34	40	-1
	median		-13.5	-34.5	26	10