All About Almonds
Fact Sheet 07 – Almond Bud Initiation and Development

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Welcome to the seventh edition of "All About Almonds", Almond Bud Initiation and Development. Fact sheets are distributed to almond growers via email and fax, in addition to being made available for download from the levy payers' access page on the ABA website: www.australianalmonds.com.au (follow links to the login section of the "industry" page).

The information provided in these fact sheets should be kept confidential.

Summary

Bud initiation and development determine the potential productive capacity of an almond tree. Bud initiation and formation, are directly affected by seasonal conditions (especially temperature extremes and water stress), genetics, nutrition, tree structure and the presence of viruses. Since some of these influences are within the control of growers and nurserymen, it is critical that managers understand the stages of bud formation, and the relative sensitivities of each stage, to the influential factors. This fact sheet describes these influences and the management decisions that may affect their impact.

Background

There have often been seasons in which growers have reported "patchy bloom"; bare shoots; witches' broom growth; or limited extension growth etc. Each of these reflect in part, effects on bud initiation and development. Bare shoots for example may result from failed bud formation, bud death before emergence, abnormal development or extended dormancy. The causes of disrupted or abnormal bud initiation and development are not all understood, but it is known that buds are influenced individually or in combination, by their genetics; environmental conditions; nutritional, chemical and water status; and by biological organisms.

Several of the above symptoms were visible in many almond orchards during spring 2008. In particular, patchy bloom and a vegetative growth disorder with bare shoots and witches' broom growth on Carmel, were observed. The specific contribution of recent and on-going water restrictions, pre- and post-harvest water stress, and the record high temperatures in March 2008, to these symptoms, are not known. Given the timing of bud initiation (February-March) in almonds, it is possible the extreme events of early 2008 contributed to the onset and extent of the spring 2008 symptoms.

This fact sheet has been developed to summarise the information available on bud initiation and flower development, and the influences on them. It is important that growers and nurserymen understand the effects of management decisions and environmental events, on bud formation and development.

The ABA has also initiated a bud growth disorder project that includes: systematic bud development assessments from trees that were affected or unaffected in recent seasons, and from mother trees at Monash; review of weather conditions over the period of bud development in several regions and their potential correlation with bud growth disorder onset in 2008 and/or 2009; review of post-harvest irrigation practices and the distribution of growth disorder symptoms in 2008 and 2009; and recommendations for seasonal management decisions that influence bud development.

Bud Initiation and Development as Steps in the Almond Growth Cycle

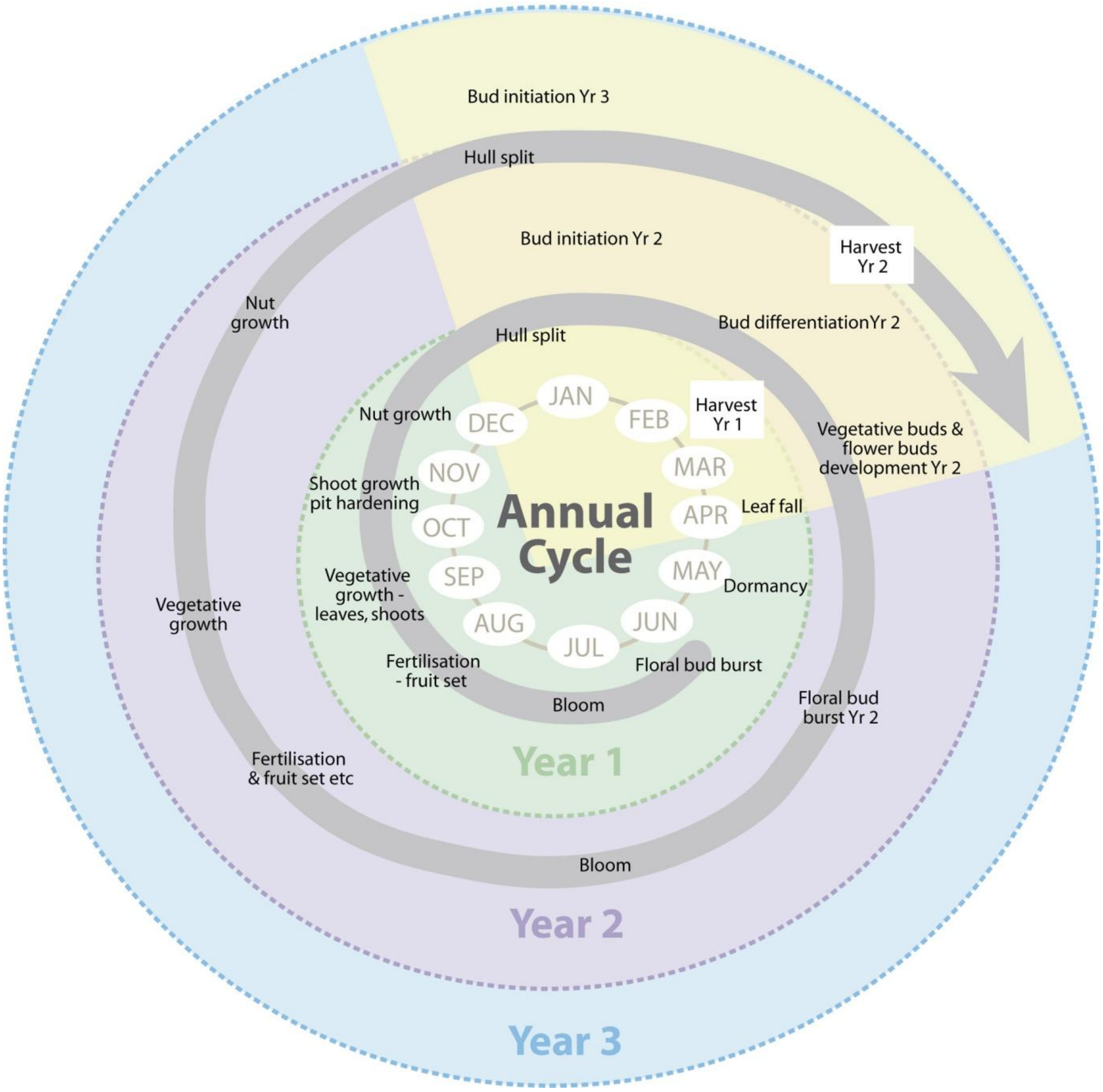
Flower bud initiation is the foundation of tree fruitfulness and yield potential. Therefore, all factors that influence initiation and development of flower buds are of economic relevance. The processes that result in nut formation start before the previous crop has been harvested. Table 1 and Figure 1 illustrate the overlapping developmental stages. The processes are complex and often in conflict with other management practices.

Table 1. Almond bud initiation and development cycle

<table>
<tr><th>SEASON</th><th>MONTH</th><th colspan="2">TREE GROWTH STAGE</th><th>BUD DEVELOPMENT STAGE</th></tr>
<tr><td rowspan="2">WINTER</td><td>July</td><td colspan="2" rowspan="2">Bud burst – Full Bloom</td><td rowspan="2">Emergence of floral buds on shoots or spurs; pollination
Emergence of vegetative buds – leaves</td></tr>
<tr><td>August</td></tr>
<tr><td rowspan="3">SPRING</td><td>September</td><td colspan="2">Shuck Fall – Early Set</td><td rowspan="2">Leaf development and active growth of new shoots</td></tr>
<tr><td>October</td><td rowspan="4">Nut growth</td><td>Pit hardening</td></tr>
<tr><td>November</td><td rowspan="2"></td><td>Growth interruption; bud maturation</td></tr>
<tr><td rowspan="3">SUMMER</td><td>December</td><td>Bud scale formation</td></tr>
<tr><td>January</td><td>Hull split</td><td rowspan="2">Vegetative buds develop. Flower buds initiated</td></tr>
<tr><td>February</td><td colspan="2" rowspan="2">Harvest</td></tr>
<tr><td rowspan="3">AUTUMN</td><td>March</td><td rowspan="2">Flower buds continue to differentiate</td></tr>
<tr><td>April</td><td colspan="2">Post Harvest</td></tr>
<tr><td>May</td><td colspan="2" rowspan="2">Leaf Fall – Dormant</td><td rowspan="2">Vegetative buds in rest period. Flower buds continue to differentiate. Chilling occurs.</td></tr>
<tr><td rowspan="2">WINTER</td><td>June</td></tr>
<tr><td>July-August</td><td colspan="2">Bud burst</td><td>Emergence of flowers, followed by leaves</td></tr>
</table>

Adapted from Kester, 2000; Kester *et al*., 1996, and Thomas, 2007

Figure 1. Cycle of fruitfulness potential in almonds



Source: Adapted from Wilson, 1996

Flower buds

The floral buds encompass a terminal flower, but no leaves. More than one floral bud may form on a single spur, or along the length of shoots more than a year old. Relative to other fruit (eg. peach and prune) and nut crops, almonds have late flower bud differentiation (i.e. the transition from vegetative to floral buds). In almonds bud initiation and development (for the following season's nuts) usually coincides with the current season's hull split-to-post-harvest period. Management decisions over that time, influence the tree's capacity and potential yield in the subsequent season, in terms of bloom density and therefore nut count (Figure 1, Figure 2 and Figure 3). Management decisions that affect crop load, carbohydrate reserves and general nutritional status, also influence fruit set. However the percentage fruit set is influenced primarily by the variety and weather conditions during bloom and fertilisation.

Classic research on flower bud development was undertaken in 1925 (Tufts and Morrow, 1925) and more recently by Lamp *et al*. (2001). Polito *et al.* (2002) also investigated the effect of bud position and leaf area on the timing of flower differentiation, between and within spurs. Each investigation included the almond variety Nonpareil, while Lamp *et al.* (2001) also investigated Carmel and Butte with modern techniques and greater understanding of the early morphological events in flower development, and the influence of climatic conditions. These researchers found that floral initiation in some varieties (Carmel and Butte) preceded hull split, but for Nonpareil they concluded floral initiation occurred after hull split.

Lamp *et al.* (2001) photographed, numbered and described eight flower bud development stages (0-7). The stages 0-2 described bud initiation and transition, while stages 3-7 described the flower formation. Almond flowers undergo continuous development (even during tree dormancy), once their transition commences. Vegetative buds however have a rest and maturation period.

Vegetative buds

Vegetative buds form the structure and bearing potential of trees and the capacity to sustain the tree through water uptake, nutrient capture and energy conversion. Leaves are formed in vegetative buds which are pointed in shape. Flowering buds are plumper, and flat-domed at the apex. The terminal bud of a shoot or spur is always vegetative and hence the capacity of almond trees for on-going shoot growth and canopy expansion. The relative growth of terminal and lateral vegetative shoots determines the potential fruit-bearing capacity and structure of the different varieties. The vegetative terminal and lateral buds form during the previous year, then elongate and expand mid-summer. In conditions of excessive nutrition, or when mild conditions extend through autumn, the wood, leaf and bud maturation may be delayed and the duration of active growth extended. In contrast, water-stressed trees may lose leaves prematurely and have reduced vegetative growth and compact canopies. Each of these scenarios have an effect on carbohydrate accumulation at the end of a season, and its availability for leaves emerging from second year wood, in the subsequent spring.

Influences on Bud Initiation and Development

Some factors that affect bud initiation and development may be manipulated while others are inherent or result from external factors over which a grower has little control.

Difficult to manage influences on bud initiation and development

Genetics

A bud development disorder attributed to varietal genetics (and environmental triggers), is prevalent in California in the Carmel variety (but also documented in Nonpareil, Price and several other American varieties) and has curbed the planting of Carmel in California. At its worst, non-infectious bud failure (NBF) may first appear in the spring of the second leaf. It presents as leafless lengths of one-year-old wood that may or may not carry nuts. On occasions a tuft of vegetative growth appears at the ends of bare shoots suggesting that leaf buds (which are formed early or late in the season and therefore often in cooler conditions), remained viable despite the other lateral, vegetative buds between dying or failing to develop the previous summer or autumn. It has been concluded that the vegetative buds which fail in NBF trees, formed and were initially viable. However the affected buds die prior to spring in the following season, and most likely during the previous autumn and winter.

Nuts on NBF shoots are evidence that the floral buds have survived despite often being at the same position as a failed vegetative bud. In NBF trees, the bloom period may be delayed (Connell, 2007; Kester, 2000) and the tendency for almond kernel doubles has also been reported (Connell, 2007).

Key NBF researcher, the late Dale Kester found that the failure of vegetative (and sometimes floral) buds to develop was an inherited characteristic with the potential to increase in propensity with repeated vegetative propagation, and in severity with cumulative exposure to high summer temperatures (see below). Once present, NBF cannot be eliminated. Replacement (or top-working) of young (second-fourth leaf), affected trees is often justified economically, but in older trees with symptoms in the upper canopy, the yield decline (through reduction in fruiting wood primarily) often does not justify replanting, unless the framework of the tree has been affected severely.

In order to manage risk and improve planting material quality in NBF susceptible varieties, it is reasonable today for registration, certification and breeding programs, and nursery operations to identify low bud-failure potential trees and clones. The NBF-potential in each clone is dynamic, with temperature exposures, drought stresses, fruit load, tree pruning and management, and re-propagation contributing to NBF expression. Once identified there should be commitment to the selection of single tree sources of buds for mother trees, and to observe progeny (from traceable bud sources) performance and growth in areas conducive to NBF expression (eg. warm-hot areas). The mother trees of bud sources identified with low NBF-potential require management and maintenance such that NBF is minimised (eg. hedge pruning to ensure budwood is from trees and canopy locations closest to the original buds). In California, no Nonpareil or Carmel sources of budwood are considered NBF-free.

Temperature exposure

Although flower initiation is controlled by naturally-occurring plant hormones, the timing and duration of the floral development stages is directly affected by tree genetics and temperature exposures at critical times. The temperature triggers for normal bud development (eg. heat-induced dormancy, chilling hours, and the subsequent warm temperatures to break dormancy and trigger growth etc.) are well-documented.

Almonds rarely have insufficient chill, but in some *Prunus* spp. (eg. apricots, peaches) floral buds may drop before budswell if the winter has been mild. Although the vegetative buds may not drop under similar conditions, they often develop abnormally with an extended leaf out period and weaker shoots. Frosts may kill buds, flowers or cause early abortions, depending on their developmental stage, and the duration and severity of the frost.

Cumulative high-temperature (above 27°C) exposure in the previous summer, affects NBF onset and expression. It is proposed that NBF may also be indirectly triggered in stressed trees since premature defoliation may result in increased canopy temperatures.

Manageable Influences on bud initiation and development

Water status

Almond is generally considered a drought-tolerant tree, however it has been demonstrated that almond trees pass through annual development stages in which water-stress sensitivity varies. The most water-stress sensitive stages in flowering deciduous trees are flowering, fruit set and early stages of fruit growth (Fereres and Goldhamer, 1990). Although almonds are irrigated in Australia, water status still remains critical in terms of almond production levels.

The almond harvest coincides with the floral bud initiation period (Table 1 and Figure 1). The post-harvest period coincides with the floral bud development. The usual practice of 'holding off' the water in preparation for, and during harvest and drying, must be managed carefully because pre-harvest water deprivation affects current season nuts, and post-harvest water stress directly affects bud initiation and development, and therefore the subsequent season's yield (See Figure 1 – yellow sector). The benefits (minimised trunk damage from shakers, hull rot, and ground moisture and humidity for drying) of pre-harvest deprivation must be balanced alongside the less desirable effects (reduced kernel weight, increase in 'partial splits and/or 'hull-tight' nuts, reduction in late season leaf function, and stress presenting as wilt and/or premature leaf drop and biomass reduction).

The pre-harvest to post-harvest water deficit period varies in length each season and across orchards for a number of reasons: the staggered maturity of pollinators and Nonpareil; orchard size and equipment capacity and availability; and prevailing environmental conditions that may either hasten or delay harvest or drying (and therefore the resumption of irrigation). The severity and duration of the water deprivation, affect the varietal responses and capacity to compensate and/or recover.

Pre-harvest water stress. Water stress pre-harvest has less effect on bud development (and therefore subsequent flowering and leaf out) than does post-harvest water deprivation. However, it has been demonstrated in California that the negative effect on annual vegetative growth, may be cumulative over successive seasons of pre-harvest drought conditions. Fruiting spur growth (and therefore potential productivity) may be significantly reduced (Esparza *et al*., 2001a).

Post-harvest water stress. It has been clearly shown that post-harvest deficit irrigation or water stress reduces fruitfulness the following season (Goldhamer *et al*., 2006; Girona *et al*., 2003; Lamp *et al*., 2001; Goldhamer and Viveros, 2000; Goldhamer and Smith, 1995). See Figure 2 and Figure 3. Goldhamer and colleagues have undertaken the most comprehensive research on regulated deficit irrigation (RDI), its timing and magnitude. They demonstrated the primary effect of post-harvest water deprivation is yield reduction, because of its direct effect on floral bud differentiation and reduction in flower number (Figure 2). A negative effect on fruit set, kernel yield and fruit load were also reported (Goldhamer and Viveros, 2000). See Figure 3. Post-harvest water stress may also promote premature defoliation, and therefore lower carbohydrate reserves. Low leaf retention through autumn results in weaker vegetative growth and reduced fruiting capacity the following season.

Goldhamer and Smith (1995) concluded that the application of a limited (less than optimal) water volume over a shorter duration in the early part of the season was less effective than irrigating at lower volumes over a longer period (especially when it extended through the post-harvest period), in sustaining production in the subsequent season. In periods of restricted water access, it is particularly important for growers to understand the water-sensitive stages in almond development throughout the season, and to ensure post-harvest water availability.

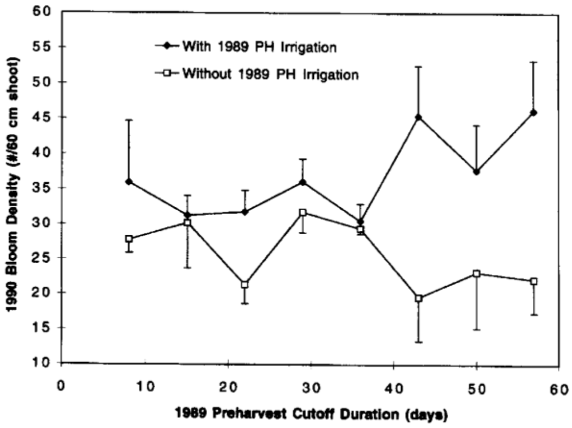


Figure 2. Bloom density related to previous season's preharvest cutoff duration and presence or absence of postharvest (PH) irrigation. Vertical bars represent one standard error (Goldhamer & Viveros, 2000)

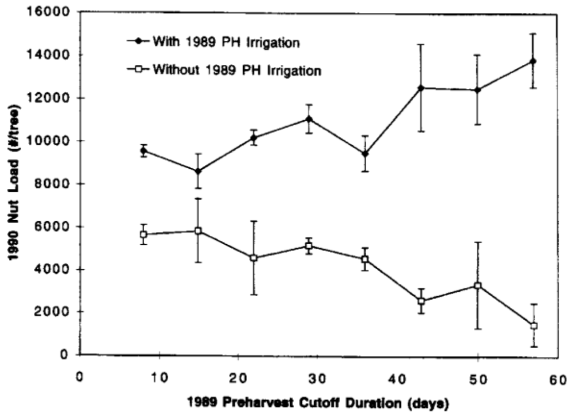


Figure 3. Nut load as related to previous season's preharvest cutoff duration and presence or absence of postharvest (PH) irrigation. Vertical bars represent two standard errors (Goldhamer & Viveros, 2000)

Biological

Viruses may cause infectious bud failure in several Prunus hosts. In almonds, such infectious bud failure is associated with the calico strain of Prunus Necrotic Ringspot Virus (PNRSV), and is characterised by both floral and vegetative bud failure. This virus (and its bud failure effects) is graft transmissible, unlike NBF. This virus is present in Australia and it is recommended that all imported budwood and rootstock material, mother trees and any other local budwood supply trees be routinely tested for its presence.

Nurserymen need to develop a schedule for testing and a system of record-keeping such that Prunus tree and/or budwood purchasers may be able to trace their budwood to its source, access its diagnostic test timeframe and the relevant results, and be assured that hygiene practices within the nursery have not contributed to the transmission of any infectious agent.

Nutritional

Tree nutrition influences tree vigour, growth rates, bud size, and the retention of leaves in autumn. Autumn is the period when carbohydrate accumulation occurs in the perennial parts of almond trees (roots, branches and trunk). This carbohydrate is used at the start of the next growing season to support early shoot growth, until the new leaves are functioning and contributing to the tree. It is therefore important to retain leaves on trees as far into autumn as possible (ideally into May). Post-harvest irrigation also assists with leaf retention and the period of carbohydrate accumulation prior to dormancy.

Since nutrition affects functions throughout the tree and season, not only is the leaf functional period important, but also the relative growth of new shoots, leaves, canopy size, fruit load, etc. Polito *et al.* (2002) provided evidence suggesting spurs with low leaf area carried fewer floral buds and that these floral buds had a slower developmental rate.

Record-keeping

Detailed record keeping of all cultural practices (pruning, fertilisation, irrigation, pest and disease control, etc.), budwood history and sources, and weather events, assist investigations of bud growth disorders when they arise.

Recommendations for Optimal Bud Initiation and Development

- Use budwood and rootstocks that have been regularly virus-tested *and* found free of detectable levels
- Use Carmel budwood from mother trees known to be propagated from original (or as close to original as possible) buds
- Minimise the pre-harvest-to-post-harvest water stress duration
- For current season crops, minimise pre-harvest water stress
- Manipulate nutrition where possible, to ensure leaf retention into May (and an extended period of carbohydrate accumulation)
- Record cultural practices and weather events

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