# A Development Based Classification for Branch Architecture in Almond

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## Abstract

Branch architecture in seedling almond [*Prunus dulcis* (Mill.) D.A. Webb (syn. *P. amygdalus* Batsch)] trees was characterized by the degree lateral branching in current and previous season growth. This characterization allowed the rapid classification of the wide range of branching habits observed in almond germplasm, including backcrosses from interspecic hybrids. The approach shows promise for assessing the genetic control of branching habit, developing improved branch architectures, and evaluating the relationship between juvenile (seedling) and adult (bearing) almond tree architectures. Progeny distributions demonstrated that targeted and sometimes unique tree architectures could be readily achieved through appropriate selection of parents. Branch architectures of interest for cultivar improvement include a lateral-bearing habit on current and previous season shoots having limited branch size and consistent right-angle orientation to the primary shoot. The resulting arrangement allows improved crop density without excessive shading of lower fruitwood.

## Introduction

A primary breeding objective of almond [*Prunus dulcis* (Mill.) D.A. Webb (syn. *P. amygdalus* Batch)] improvement programs in Europe and the United States is consistent and high tree productivity (18, 20). Productivity is determined by multiple factors, including tree architecture, bearing habit, flower density, flower fecundity, and freedom from alternate bearing. Tree architecture and bearing habit are difficult to characterize (20). An effective classification should accommodate the range in structural forms common to the crop while organizing the structures within intuitive, development-based categories (26). Although promising advances in modeling shoot growth habit have been reported for pome fruits, particularly apple (*Malus* x *domestica* Borkh.) (7,8,21,22,23,25), the extensive use of winter and summer pruning for stone fruits such as peach (*Prunus persica* (L.) Batsch) and plum (*Prunus salicina* Lindl.) have resulted in limited interest in modeling natural growth habits for these species. Almond is a stone fruit grown for its edible nut that develops laterally on peach-like shoots and perennial spurs.

World production of almond exceeded 453 thousand tons M in 1999 (1) with most production in California (376 thousand tons M) and Spain (66 thousand tons M). Although closely related to peach, almond trees are not extensively pruned since yield is the main objective. Pruning to increase productivity, including the rejuvenation of older trees, has not been effective because the new bearing wood did not compensate for the older wood removed (17). Consequently, almond trees develop a wide range of natural architectures (14,18). In addition, several native, and structurally variable, Prunus species including *P. argentea* (Lam.) Rehd., *P. fenzliana* Fritch., *P. webbii* Spach, *P. tangutica* Batal. and *P. bucharica* Fedtchenko, grow in Central Asia and Europe (18). This germplasm has proven a valuable source for disease and insect resistance as well as pollen-pistil self-compatibility (13). A wide range of tree growth habits results from the hybridization of these species with *P. dulcis*, including the undesirable upright-spindle and bush forms, as well as desirable architectures such as lateral bearing habit (13, 18, 20). Because of a long juvenile period of 4 or more years for seedling almonds, breeding programs in Spain and California have been evaluating classifications of early growth habit. Such classifications would be useful for examining the inheri-

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tance of different growth habits, as well as the relationship between juvenile and adult tree form. This report describes an almond growth classification that has proven useful in our programs and briefly summarizes its application for almond improvement.

## Materials and Methods

Lateral (sylleptic) branching was characterized for current and previous season's growth (Fig. 1). Lateral shoot growth was divided into four categories based on the degree (number) and type of shoot development (spurs vs. shoots). No distinction was made among spurs (up to 5 cm), brindles (5-10 cm) and thorns. Shoots were over 10 cm long. Branching pattern for current season growth was assigned a number from 1 to 4, and branching from 1-year-old growth assigned a letter from a through d, making a unique alpha-numeric code for branching habit (Figs. 1, 2 and 3).

Three crosses were evaluated between parents selected for similar growth habits but showing divergent growth habits in progeny trees. These included the crosses: 'Nonpareil' [growth of 2nd leaf tree designated as '3-c' in Fig. 1] as seed parent crossed with breeding line 'F7,1-1' [4-c], an almond-like tree with P. persica in its lineage (Fig. 4); 'D3-6' [3-c] an almond-like tree containing both P. persica and P. webbii in its lineage crossed with 'F7,1-1' [4-c] as pollen parent; and, 'D3-6' [3-c] x 'Le Grand' [3-c] a California almond cultivar thought to possess P. persica genes as a source of its partial self-compatibility (2). At least 60 progeny from each cross were classified at the end of the third growing season following leaf fall based on the evaluation of the two most vigorous shoots. The distribution of lateral branching ratings of progeny trees was plotted (Fig. 4) using X and Y coordinates based on the lateral branching classification (Fig. 1).

## Results and Discussion

The lateral branching classification (Fig. 1) allowed convenient classification of all growth habits observed in cultivars selections and seedlings. For example, the des-

ignation [1-a] describes whip-like growth where all lateral branching is suppressed (Fig. 2, a) as occurs in the Spanish cultivar 'Barte'. The designation [1-d] indicates that lateral growth on current season shoots is suppressed but lateral shoots develop profusely on second year wood as often occurs during the early growth of the Spanish cultivar 'Marcona' and many accessions of P. scoparia (Fig. 2, d). Branching habits with the designation [4-a] show lateral branching during the first growing season, but limited to no continued growth of those lateral shoots during the second season as is observed in certain hybrids of P. dulcis and P. webbii (Figs. 3,c,d). Shoot growth with no lateral suppression for both current and previous seasons [4-d] resulted in a very bushy growth habit characteristic of some P. tangutica accessions and their interspecic hybrids (13, 14).

Growth habits for most commercially acceptable almond types were placed in intermediate categories. For example, 2nd leaf budded trees of 'Nonpareil', the major California cultivar, were characterized as [3-c] as it typically shows limited lateral shoot development on vigorous shoots of both the current (Fig. 3,a) and previous season's growth. Laterals typically develop the basal one-half to two-thirds of the shoot or branch (Fig. 3,a), or from the terminal buds of previous season's growth (Fig. 2,c) similar to patterns reported by Guevara and Danjou (15) in peach x almond hybrids, and by Costes (6) in apricot (P. armeniaca). This branching habit is considered commercially desirable as it results in a moderately branched yet open tree architecture that allows continued terminal fruit-wood production without excessive shading of interior fruit bearing spurs (Fig. 3,b) (18). Similar architectures are considered desirable in apricot (6), and peach (5, 11). Crosses using 'Nonpareil' as the seed parent often result in progeny populations skewed towards this [3-c] growth habit, suggesting a high heritability and tendency towards dominance for this trait (Fig. 4,a). The widest range of shoot architectures was in progeny from the cross 'Nonpareil' (3-c) to 'F7,1-1' (4-

Suppression of Lateral Shoots on Current Season Growth



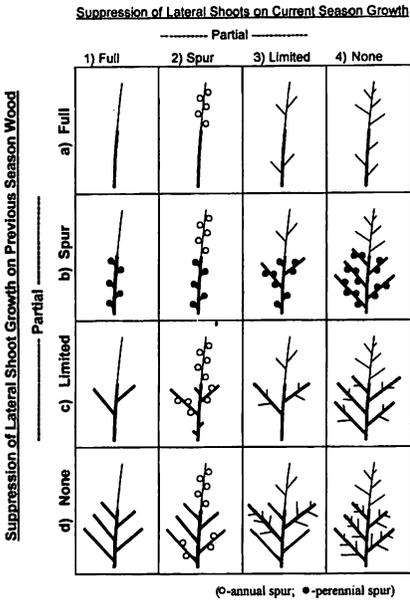(○-annual spur;  ●-perennial spur)

**Fig. 1. Chart summarizing the classification of branching patterns based on degree of suppression of lateral shoots in current season and previous season growth.**

c). Shoot growth for most progeny from this cross (149 of 245 seedling trees), was characterized as [3-c]. The other branching patterns from this cross occurred at low frequencies. Similar distributions were observed when 'Nonpareil' was used as the pollen parent or in progeny resulting from crosses with other traditional California cultivars (data not shown). Scorza (24) reported extensive variability of peach progeny in a similar study, though parents tested differed in initial architecture, as he selected compact, dwarf and pillar types for comparison. In the present study, all parents had mature tree, nut, and kernel characteristics within the range generally considered acceptable by the almond industry. Dathe (9) reported high heritability for growth habit in apple though the genetic variance appeared to be almost entirely additive. The relative uniformity observed in progeny of crosses between California cultivars is not surprising since this germplasm has been reported to

be highly inbred with most cultivars having 'Nonpareil' and 'Mission' as parents (2). This study, however, demonstrates that crosses to dissimilar germplasm can increase variability in progeny growth habit, and parent selection can be employed to skew the population towards desired growth types. The use of 'D,3-6' instead of 'Nonpareil' as seed parent in a cross with 'F7,1-1' produced a population with a distinct skewing towards a bushy [4-d] *P. tangutica/P. webbii*-type growth habit. However the cross 'D,3-6' with 'Le Grand' resulted in a population strongly skewed towards a more open [1-c] growth habit (Fig. 2,c; Fig. 4,c).

Shoot growth habit is important not only for determining final tree form but also fruit bearing habit and ultimate cropping potential (3). Almond fruit are borne primarily on terminal peach-type shoots,
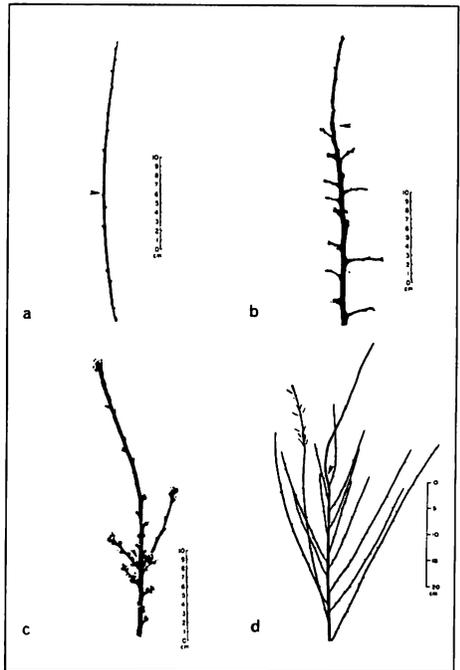


**Fig. 2. Basic branching patterns observed in almond germplasm with designations based on Figure 1: (a) 1-a; (b) 1-b; (c) 1-c; (d) 1-d. (Arrows mark the transition between the current and previous season growth).**
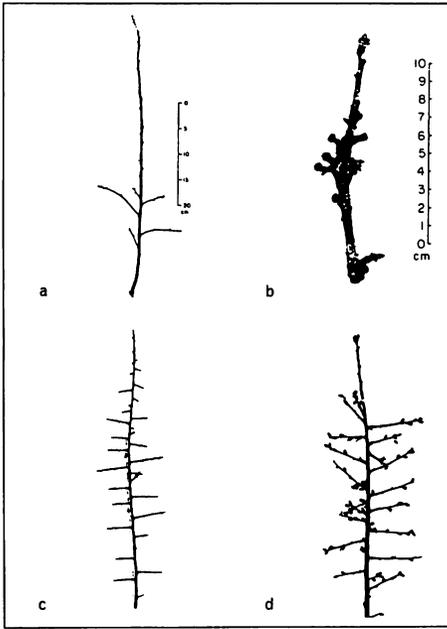
**Fig. 3. Sample of almond bearing habits:(a) current-season laterals forming at the basal section of the shoot with flower buds developing on both laterals and terminal shoot; (b) typical almond spur after about six years growth with distinct peduncle scars from earlier fruit production; (c) shoot from P. *dulcis* x P. *webbii* hybrid showing widespread growth of brindle-type (5-10 cm in length) laterals at characteristic right-angle orientations to the primary shoot; (d) shoot from progeny resulting from two generations of back-crossing from genotype shown in (c), demonstrating the more substantial fruit-wood yet continued right-angle orientation to the primary shoot.**

sometimes with limited lateral bearing occurring on current season (Fig. 3,a) and on previous season (Fig. 2,c) wood, as well as on perennial spurs (Fig. 3,b). A significant increase in lateral branching and lateral bearing have been observed in crosses between 'Nonpareil' and P. *webbii* selections. Early backcrosses show greater lateral branching in both current and previous season wood, typically resulting in short, thorn-like or brindle shoots [2-b] with growth occurring at nearly right angles to

the stem (Fig. 3,c). One to two additional backcrosses towards commercial almond types often result in a strong lateral bearing habit in current season and/or previous season wood while retaining a unique and desirable right-angle orientation to the stem (Fig. 3,d). Almond cultivars with greater tendency for lateral bearing tend to have more consistent year-to-year tree productivity. The additional bearing surface is thought to buffer against the loss of developing fruit and leaves from disease and environmental stresses (12). Bernad and Socias i Company (3) have also shown that promotion of lateral shoots in almond leads to suppression of overly vigorous vegetative growth of terminal shoots, with a greater almond productivity per unit shoot length. The development of lateral branch architectures has become an important breeding objective for walnut (*Juglans regia* L.) owing to its association with high cropping consistency (20).

In summary, a lateral branching classification has proven useful in the characterization of almond cultivars as well as breeding populations. Branch architecture classifications have been developed for a range of temperate and tropical tree species beginning with the early work by Zimmerman and Brown (27) and Halle et al. (16) and continuing to present (4). Recent classifications of tree architecture are often based on ontogenetic models where final branch habit is seen as the consequence of 'apical dominance' and 'apical control'. This developmental approach has provided an effective framework for the classification of the wide range of temperate, tropical and subtropical forest tree species (10), but becomes more cumbersome for describing differences within a species or related species group due to the wide variability in branching habits possible, as well as differences among researchers in usage of the terms 'apical dominance', 'apical control', and 'correlative inhibition' (see 4, 10). Our classification simply characterizes the degree and type of lateral branching (Fig. 1) and is not based on hypothetical apical growth responses. In addition to pursuing novel
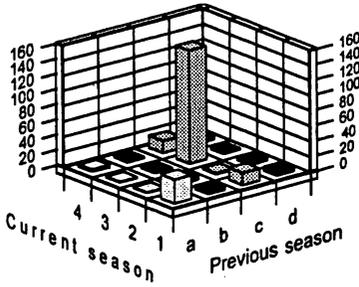
(a)

'Nonpareil'- F7,1-1 seedling selection

Sol. Selection 5-15 ⊥ WSB3B25 Alm. sdl.

'Nonpareil'⊥Selection 22-2

'Lukens Honey' peach ⊥ 'Mission'
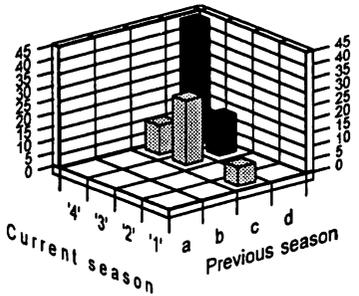
(b)

D,3-6 seedling       -F7,1-1 (as above)

F5,4-10 seedling⊥ 'Solano'

P. webbii⊥SB6,56-88 seedling

Sol. selection 5-15          ⊥Selection 24-6

(as above)          ('Nonpareil' x 'Eureka')
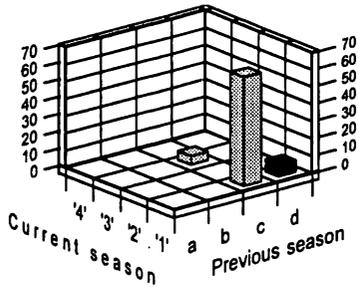
(c)

D,3-6 (as above)———— 'LeGrand' almond

(peach in lineage?)

**Fig. 4. Parentage and branch architecture distribution of three-year-old own-rooted progeny trees based on the classification in Fig. 1.**

growth habits, the development-based classification is currently being employed as the basis for long-term studies on the relationship of juvenile (seedling) with adult (bearing) tree form in almond.

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# Impact of Apple Rootstock/Cultivar on Processing Market Profitability

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## Abstract.

Four apple cultivars suitable for processing ('York Imperial', 'Rome Beauty', 'Stayman', and 'Smoothee Golden Delicious') and four rootstocks (M.26 EMLA, M.9 EMLA, O.3 and B.9) used in a ten-year experiment at Rock Springs, PA were evaluated for relative profitability. Based on cash flow measures, 'Rome Beauty' out performed the other three cultivars by a wide margin because of early yields of large sized fruit. M.26 EMLA was found to be the best rootstock for 'Rome Beauty' because of its high expected cash flow and low variability of income. O.3 was found to be the best rootstock for 'York Imperial', 'Stayman', and 'Smoothee Golden Delicious' based on the same measures. B.9 was found to have the lowest average cash flow and highest income variability for all four cultivars at the experiment's density of 961 trees/ha. However, at higher densities which would be possible given tree cross sectional area measurement, B.9 was found to be the best rootstock in terms of cash flow for 'York Imperial', 'Rome Beauty', and 'Smoothee Golden Delicious', while O.3 remained the best rootstock for 'Stayman'. To overcome the cash flow differential between 'Rome Beauty' and the other cultivars, prices would need to be 23-94% higher depending on the rootstock used.

## Introduction.

Selection of a profitable cultivar/root-
stock combination is a critical aspect in the
production of any tree fruit. The cost of
establishing an apple orchard makes it im-
perative that a fruit producer have the most
complete information available when se-
lecting cultivars and rootstocks. The
choice of cultivar and rootstock will affect
the future profitability of the orchard
through its impact on yield and fruit qual-
ity. Evaluating the economic feasibility of
alternative cultivar/rootstock combina-
tions is vital to preserving and improving
the competitive position of Mid-Atlantic
apple growers.

In recent years there has been consider-
able research looking at the impacts of
apple rootstocks on tree yield and growth
(6, 7, 8). Studies by Harper and Greene (4)
and Harper, Greene, and Swaminathan (5)
have evaluated the impact of rootstocks on
profitability for single fresh-market peach
and apple cultivars in the NC-140 trials at
Biglerville, PA. This analysis will expand
on these earlier studies by evaluating the
relative profitability of four processing
cultivars and four rootstocks.

## Materials and Methods.

As part of the NC-140 apple rootstock
trial, four processing cultivars ('Smoothee

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