J. Amer. Soc. Hort. Sci. 103(3):429–432. 1978.

Variability in Noninfectious Bud-failure of 'Nonpareil' Almond. II. Propagation Source[1]

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Additional index words. clone selection, genetic disorder, BF-susceptibility, *Prunus amygdalus*

Abstract. **Different propagation sources within 'Nonpareil' almond (*Prunus amygdalus* Batsch) showed wide differences in susceptibility to noninfectious bud-failure (BF). Seven years observations in a high temperature test location showed a range in BF-susceptibility from 0 to 100% depending on the source tree used for budwood. Selection of individual symptomless source trees resulted in separate clones that produced either no BF or high uniform percentages of BF-trees. Such single tree selection is a basis for selecting BF-resistance within cultivars. The nursery sources studied showed percentages from 0 to 62% suggesting that mixtures of normal and BF susceptible plants existed within the propagation sources. Propagation material randomly sampled from 10-year-old symptomless orchard trees from a hot summer location produced significantly higher percentages of BF trees in 6 years (2.3%) than propagation material from a cooler location (1.2%).**

Noninfectious bud-failure (BF), a disorder in commercial almond orchards in California, has been classified as a "genetic disorder that resembles virus diseases" (14). Symptoms are expressed by failure of many vegetative buds to grow in the spring, although the abnormalities in the buds develop during the previous summer (7). The resulting vigorous growth from the normal buds leads to bizarre growth patterns, referred to as "crazy top" (15).

BF is characterized by the variability in symptom severity and in distribution of affected trees. This variability is manifested in differences among branches on a tree, among trees in an orchard, among orchards in a location, and different locations. Susceptibility to BF has been associated with specific cultivars and specific propagation sources within cultivars.

A study was begun in 1969 to assess 2 factors – propagation source and environment – as influences on observed variability of BF. We have reported (9) on using a single source tree of 'Nonpareil' to study the effect of environment (location), as characterized by differences in summer and winter temp, on BF production. The studies showed that susceptibility to BF increased with time, depending on the location of the test site. Both BF-susceptibility and BF-expression were associated with increasing summer temp.

In this paper we compare the inherent BF-susceptibility (BF-potential) of propagules arising from different propagation sources within 'Nonpareil'. Comparisons are made by growing test trees together in a single site where the environment had previously been shown to produce severe BF. This study serves as a performance test for the BF-susceptibility of specific propagules within 'Nonpareil'.

Materials and Methods

Sources of budwood. Group 1 included separate accessions selected for propagation in the California Registration and Certification Program (1). These originated from single source trees which had been found free of known viruses by indexing to 6 or 8 indicator hosts. Trees of these separate accessions have been established by the Foundation Plant Materials Service (FPMS)[4] in an orchard at Davis, CA. The foundation tree and its vegetative progeny is referred to as a "clone" because its separate identity is maintained in subsequent propagations. The term "subclone" is also used herein to designate further subdivisions within a clone.

Group 2 trees originated from commercial nurseries from buds collected at random from dormant nursery trees of that nursery.

Group 3 included nursery trees supplied by commercial nurserymen as specific sources ("strains") of 'Nonpareil' which they were using in propagation and which they believed did not produce BF trees.

Group 4 included nursery trees propagated from budwood collected randomly from mature commercial orchards of unknown source except that the commercial nursery origin was known.

Test 1. Budwood from Group 1 and Group 2 trees were collected at the same time from the upper part of dormant nursery trees. The Group 1 trees were FPMS 3-8-1-63 propagated by commercial nurseries for the BF-100 experiment described in the previous paper (9). In addition, trees were propagated from buds brought directly from the FPMS orchard at Davis and clone 15-1 from IR-2 Repository, Prosser, Washington. Group 2 budwood was collected in the same manner as above, but from the commercial trees of the same nursery. The buds of both groups were collected in the winter of 1969-70, stored until March and then grafted onto 'Lovell' peach seedling rootstocks growing at the West Side Field Station, Five Points, California. Twenty-five budsticks were collected for each lot of trees and 2 trees were budded from each budstick. These trees grew 1 year in the nursery row and then were transplanted to 1.8 × 4 m spacing at the West Side Field Station. The trees were planted in replicates of 10 trees each with the FPMS 3-8-1-63 trees (Group 1) and the commercial nursery trees (Group 2) planted in sequence within each block. In some cases a replicate had fewer than 10 because of an insufficient number of trees.

Test 2. This test was in 2 parts. In part A, budwood, 50 budsticks from each source tree, was obtained of various accessions of 'Nonpareil' from FPMS at Davis, California, for June budding of trees of Group 1. Each budstick was cut in half with one half distributed to a Modesto nursery and the other to a Wasco nursery. Plants grew in the nursery for the remainder of the year and then were transplanted to the West Side Field

[1]Received for publication October 12, 1977.

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[3]In addition to the assistance acknowledged in the previous paper (9) we thank Fowler Nursery, Newcastle, CA; Dave Wilson Nursery, Hughson, CA; Dr. G. Nyland, Department of Plant Pathology, U.C.D., Nursery Service and Department of Plant Pathology, State Department of Agriculture, Sacramento, CA.

[4]FPMS was changed to Foundation Seed and Plant Materials Service (FSPMS) in 1976. Accession number system for 3-8-1-63 is as follows: 3 = almond, 8 = 'Nonpareil', 1 = accession (clone) number, 63 = year established in foundation orchard.

Station at 1.4 × 4 m spacing. These trees were planted in 3 replications of 20 trees each, but in some the 3rd replication had less or more because of varying numbers per lot. Part B of this test included trees provided by commercial nurserymen as described for Group 3.

Test 3. This test compared BF production in trees propagated from buds collected at random from bearing orchards in the northern part of the San Joaquin Valley (Manteca) with moderately warm summer temp (Part A) compared to those from southern San Joaquin Valley (Wasco) where summers are very hot (Part B). Budwood collections were made at the end of May from orchards with trees about 10 years old and with no obvious BF symptoms at the time of collection. For Part A, collections were made from commercial orchards in the Manteca area from orchards representing various nursery sources. For Part B, orchards of similar age from the same nursery sources were selected in the Wasco area, also from trees with no obvious BF symptoms either in the trees used for the collection or in other trees in that particular block. Sixty trees were sampled, one budstick per tree. These budsticks were cut in half; one part was distributed to the Modesto nursery, the other to the Wasco nursery. These trees grew for the remainder of the season, and were transplanted during the following dormant season to a commercial orchard at Lost Hills.

For all tests, individual trees were examined each spring in subsequent years for symptoms of BF. The evaluation was based on numbers of trees affected with characteristic BF symptoms.

Results

Test 1. All subclones from FPMS clone 3-8-1-63 produced high percentages of BF trees by the end of the experiment (Table 1). The highest percentage BF trees was produced from plants originated from the Modesto fall-budded trees and the Merced June-budded trees. These were the same 2 subclones that produced the highest percentage of BF trees in the BF-100 experiment (9) and there was no correlation to nursery temp. BF percentage was high in trees propagated from buds delivered directly from FPMS. No BF trees have resulted from the 'Nonpareil' clone from the IR-2 Repository at Prosser, Washington, in observations through 1977.

Trees propagated from commercial trees at the same nurseries that produced the above trees showed a range of BF from 0 to 62%. The Stockton nursery material had only a single severely affected BF tree and the Modesto none. A higher percentage was affected in trees from the Merced collection and still higher from trees of the Wasco collection. The percentages of BF trees produced from these 4 sources were correlated directly with summer temp characteristic of that location (see Table 1, in reference 9). This trend could arise from differences in nursery location, source of propagation material or both.

Test 2. This test in part compared BF production from trees of separate 'Nonpareil' clones from FPMS (Table 2). Clone 3-8-1-63 began to produce BF trees after the first year, with all trees showing BF symptoms by the end of the experiment. None of the other FPMS accessions have produced any tree with obvious BF symptoms to date. Of 5 lots of trees from 4 commercial nurseries, only the lot from nursery 4 produced a significant number of BF trees (Table 3).

Test 3. A pattern of gradual increase in BF with time was found from 1972 to 1977 and numbers of BF trees from these lots should be expected to increase further in the future (Table 4). The latest observations shows some trees from both source locations exhibiting BF. Trees with BF-susceptibility existed in both budwood locations, but symptoms were not produced on trees propagated from them until 4 or more years later. Within the time of the test, the number of BF trees was significantly greater for budwood collected at Wasco than for budwood at Modesto. However, the percentage of BF trees propagated at Wasco was slightly less than at Modesto, but the difference was not significant.

Discussion

This and the preceding paper (9) indicate *BF-expression,* i.e., the percentage of BF trees, the severity of symptoms, and the age when the symptoms appear, is a function of 2 factors: 1) an inherent *BF-susceptibility* in the buds which produced the trees, and 2) the environment to which the orchard trees are exposed. The basic characteristic of BF appears to be high temp sensitivity (10). Comparisons of BF-susceptibility can thus be determined when trees from propagules of known

Table 1. Percentages of 'Nonpareil' almond trees showing BF at the end of 3 years in a test orchard as a function of the origin of initial buds. All buds came from the distal part of unpruned dormant nursery trees with different histories. Subsequent handling was 1 year in a nursery at Five Points, CA, and 3 years in a close-planted orchard (1.8 × 4m) at the same location.

Identity of budwood source material	Location of bud-source material at time of collection	No. of trees	% BF trees	Remarks
Group 1:				
FPMS 3-8-1-63[z]	Modesto (fall-budded trees)	34	82	Moderately cool at nursery
" "	Wasco (fall-budded trees)	36	69	Hot at nursery
" "	Stockton (June-budded trees)	28	52	Moderately cool at nursery
" "	Merced (June-budded trees)	34	79	Moderately hot at nursery
" "	Wasco (June-budded trees)	35	60	Hot at nursery
" "	Davis, FPMS	47	60	From tree in foundation Orchard, Davis
FPMS 3-8-2-70	Tree 15-1, IR-2 Repository, Prosser, Washington	31	0	No BF had appeared by 1977
Group 2:				
Commercial nurseries	Stockton (June-budded trees)	50	2	Moderately cool at nursery
" "	Modesto (June-budded trees)	36	0	Moderately cool at nursery
" "	Merced (June-budded trees)	47	15	Moderately hot at nursery
" "	Wasco (June-budded trees)	13	62	Hot at nursery

[z]From BF-100 Experiment (9).

Table 2. Percentages of BF trees grown in a test site at Five Points, CA, from separate 'Nonpareil' almond clones from FPMS, Davis. Sources were single plants either in the Foundation Orchard, FPMS, Davis or were being held at Davis pending inclusion into FPMS.

FPMS clone identification	Nursery location where propagated	No.	% of trees with BF 1973	1974	1975	1976	1977
FPMS 3-8-1-63	Wasco	56	2	4	20	96	100
	Modesto	50	38	88	96	100	100
FPMS 3-8-2-70	Wasco	39	0	0	0	0	0
(IR-2: 15-1)	Modesto	58	0	0	0	0	0
FPMS 3-8-4-70	Wasco	44	0	0	0	0	0
	Modesto	45	0	0	0	0	0
FPMS 3-8-5-72	Wasco	45	0	0	0	0	0
(McEnespy Tree 2)	Modesto	49	0	0	0	0	0
FPMS 3-8-6-72	Wasco	39	0	0	0	0	0
(McEnespy Tree 7)	Modesto	40	0	0	0	0	0

origin are exposed to high temp in an environmentally sensitive area, such as Five Points of Lost Hills. The source of the budwood used in propagation thus becomes critically important in almond propagation, a fact now well known to California nurserymen.

How to deal with "genetic disorders" showing the BF type of phenomenon is particularly critical for registration and certification schemes (1) where single plants of established cultivars are the progenitors of virus-tested propagation sources. In such schemes, the propagation source is selected by prescribed virus-indexing procedures and by visual inspection of the trees. That procedure is not adequate to detect BF-susceptibility in source trees that are symptomless, but the propagules of which produce BF symptoms with time if located in a suitable environment. However, certification schemes afford the protection that the identity of the source material is maintained and undesirable propagation materials can be eliminated when evidence of poor performance becomes apparent. What is needed, of course, is a precise and rapid method of indexing for problems of the BF type although testing in a proper environment can be an interim procedure.

The concept of clone needs to be clarified for horticultural terminology to take into account the single-tree selection practices in registration and certification programs. The International Code of Nomenclature (5) defines a clone as "a genetically uniform assemblage of individuals derived originally from a single individual by asexual propagation." Fruit and nut cultivars are clones that originated from either a single seedling plant or a bud-mutation, the criterion being that the cultivar be recognizable as distinct or different. Single-plant selection within known cultivars may produce, for propagation purposes, a subclone which may be indistinguishable from other plants of the cultivar, but it may differ in virus content, and other attributes which affect the horticultural performance. According to the Code, a cultivar may consist of a single clone or several very similar ones. The latter is apparently the case with regard to BF in 'Nonpareil' almond. An original seedling plant was the progenitor of the cultivar in 1879 (16), but with time and continued propagation much variation in BF-susceptibility has developed. Thus, 'Nonpareil' appears to be a mixture of plants differing in BF-susceptibility and undoubtedly other factors. Selection by nurseries produces unique propagation "lines" or "strains," and single-plant selection can lead to isolation of separate clones. Terms such as "strain," "budline," or "subclone" might be used for their designation, but the term "clone" to indicate any group of plants originating from a single known ancestor has already been used extensively (2, 3). The term *propagation-clone* has been suggested to more accurately describe this special kind of clone (11). When maintained as a unique horticultural entity, such a propagation-clone should be identified by a unique name or number.

Table 3. Numbers of BF trees in groups of 'Nonpareil' almond trees supplied by commercial nurseries. Trees were grown in hot summer climate at Five Points, CA.

Commercial nursery sources[z]	No. of trees	No. of BF trees in different years 1973	1974	1975	1976
1a	40	0	1[x]	0	1
1b	40	0	0	0	0
2[y]	55	0	0	0	0
3	40	0	1[x]	1[x]	0
4	80	3	5	9	7

[z]Numbers refer to separate nurseries; letters are separate sources.

[y]19 separate source trees of same nursery represented.

[x]Not certain of identity of BF.

Table 4. Percentages of 'Nonpareil' almond trees with BF produced from random collections of buds taken from specific orchards in hot (Wasco) and relatively cool (Manteca) locations, propagated in nurseries at hot (Wasco) and relatively cool (Modesto) locations and subsequently planted in a hot test site (Lost Hills). Trees were planted in January 1972. Data are as of April 1977.

Budwood source location	Nursery location	No. of orchards sampled	No. of trees grown	BF trees No.	%
Manteca	Modesto	8	407	6	1.5
	Wasco	8	143	1	0.7
Wasco	Modesto	7	298	8	2.7
	Wasco	7	222	4	1.8

Overall % by orchard sites: Manteca 1.2
Wasco 2.3**[z]

Overall % by nursery location: Modesto 2.0
Wasco 1.4 ns[z]

[z]Differences significant by t-test at 1% (**) or non-significant (ns).

Registration would then designate specific propagation-clones of a given cultivar. Certification would assure the identity of the propagation-clone and the conditions under which it was propagated. An additional category could be utilized to indicate *performance-tested* clones to apply to those that have been used successfully in commercial production under specified conditions. Coupled to this testing procedure, specification of the location and conditions for maintaining the propagation block may be needed, and a limit to the number of repropagations to avoid changes of BF-susceptibility with time. Methods of detecting and measuring BF-susceptibility are needed.

Changes in propagation potential are not unique to the BF problem. Changes from juvenile to non-juvenile material, for example, can produce differences among trees propagated from them (8). Nelson (12) reports that certain newly developed apple rootstocks which rooted readily in initial stock blocks were difficult to root when propagated in commercial nurseries, probably through loss of juvenility. The opposite effect occurs with nucellar-originated citrus cultivars, which require sufficient repropagations to outgrow the undesirable characteristics of the juvenile phase (4). In pecan, non-juvenile trunks have been found more susceptible to freeze injury than juvenile (13).

A propagation-clone may be considered comparable to a pure line in seed-propagated cultivars and results in a high degree of uniformity in performance of progeny plants. This accounts for the high percentage of BF trees appearing in tests of 'Nonpareil' clone 3-8-1-63.

Nursery sources, on the other hand, may be comparable to a line or multi-line (6), i.e., mixtures of pure-lines, since propagation stock may come from many separate trees differing in BF-susceptibility. This accounts for the sporadic appearance of BF in many commercial orchards, particularly in central and northern California, and the incidence of BF in some commercial test lots reported in this paper.

The build-up of BF in commercial source materials can be accounted for by narrow selection practiced in the initial phase of establishing a propagation stock block, which could result in inadvertent selection of a BF-susceptible propagation-clone. Because of potential induction of BF-susceptibility by high temp (9), collection of propagation materials from the central and southern San Joaquin Valley and the northern and western Sacramento Valley and/or its maintenance in these locations may carry a certain risk of eventually producing BF trees.

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ERRATA

In the paper entitled, Influence of plant spacing on yield of muscadine grape by W. T. Brightwell and M. E. Austin (*J. Amer. Soc. Hort. Sci.* 100(4):374-376. 1975), the figure in Table 2, Year 1955, 20.1 square meters, 435 plants/ha should read 9.8a instead of 26.8a and the avg for the same column should read 29.0ab instead of 29.6ab.

* * *

In the paper, Effect of growth regulators on branching, flowering, and fruit development of ornamental pepper (*Capsicum annuum* L.), by M. Khademi and M. Khosh-Khui (*J. Amer. Soc. Hort. Sci.* 102(6):796-798. 1977), the description for Figure 1 should read . . . C_1 is control and C_2 to C_4 represent 300, 600, 900 ppm ethephon, 400, 800, 1200 ppm BA, and 50, 100, 150 ppm IAA, respectively.

* * *

In the paper, Ethylene in fruits of blackberry and rabbiteye blueberry by John A. Lipe (*J. Amer. Soc. Hort. Sci.* 103(1):76-77. 1978), the ethylene concentration in the text expressed as mg/liter should be μl/liter or ppm.