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Effect of Notching, 6-Benzyladenine, and 6-Benzyladenine plus Gibberellin A₄ + A₇ on Budbreak and Shoot Development from Paradormant Buds on the Leader of Young Apple Trees

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SUMMARY. Notching is a technique to stimulate shoot growth from paradormant buds with the long-term objective of increasing the cropping potential of fruit trees by developing new fruiting scaffolds. Notching is not commonly practiced by apple (*Malus × domestica*) growers in the southeastern United States because results can be inconsistent; notched buds frequently develop into weak spurs producing a few leaves rather than strong extension shoot growth. Therefore, a study was initiated to investigate the potential of 6-benzyladenine (6-BA) to enhance the shoot growth response from notched buds on 2- or 3-year-old wood. Notching paradormant buds on the leader of young ‘Granny Smith’/‘M.26 EMLA’ (‘M.26’) trees at the pink bud stage resulted in new growth developing on 59% of notched buds; however, fewer than 4% of these extended beyond 1.0 cm in length. Spray application of a solution of 1.5 g·L⁻¹ 6-BA into the notch increased budbreak to 95% and the proportion of new growth that developed into shoots to 89%, with a mean new shoot length of 7.9 cm. In a timing study on ‘Granny Smith’/‘M.26’, the optimum budbreak and shoot growth responses to notching plus 6-BA treatment were observed between budbreak and 2 weeks after budbreak. Notching paradormant buds on the leader of ‘Fuji’/‘M.9 T337’ (‘M.9’) trees increased budbreak, with 83% of the new growth developing into extension shoots. Spray application of 0.75 g·L⁻¹ 6-BA into the notch did not increase budbreak or extension growth of ‘Fuji’/‘M.9’ compared with notching alone. Spray application of a solution of 6-BA directly into a notch made above a paradormant bud may greatly enhance budbreak and shoot extension responses in cultivars or situations where a poor response to notching alone is expected.

Modern high-density apple orchard systems require the establishment of trees with many temporary fruiting scaffolds arising uniformly along the main axis or axes. This process is facilitated by planting a highly feathered tree as a result of growth regulator applications in the nursery to stimulate sylleptic shoot formation

(Elfving and Visser, 2005, 2006; Miranda Sazo and Robinson, 2011, 2012). After planting, the leader can

develop sections of blind wood, where axillary buds remain dormant rather than producing shoots capable of developing into fruiting scaffolds. Buds on sections of blind wood are paradormant according to the definition provided by Lang et al. (1987); that is, factors outside the meristem itself but still within the plant are responsible for the resting state. Blind wood can also develop on lateral branches (feathers) in cultivars such as Jazz (Palmer et al., 2005), Cox (Hipps, 1992), and Jonagold (Wertheim and de Groene, 1991). Blind wood along the leader limits full canopy development, whereas blind wood on lateral shoots results in lack of cropping in the center of the tree; both can greatly reduce the productivity and profitability of modern high-density apple orchard systems.

Lateral branching can be stimulated on young fruit trees using cultural techniques or application of various plant growth regulators. Removing a narrow strip of bark from above a bud, referred to as notching, is a technique for increasing lateral branching of young apple trees (Niu et al., 1998; Oullette et al., 1996; Zimian et al., 1998). Notching of buds on 1-year-old wood greatly increased budbreak and the proportion of buds that developed into shoots (Zimian et al., 1998). Greene and Autio (1994) reported that notching of vegetative buds on apple trees with a spur-type growth habit increased the chance of the bud growing into a lateral shoot. Earlier research had shown that notching of vegetative buds on 2-year-old ‘Starkrimson Delicious’ apple trees increased the percentage budbreak and proportion of shoots that grew >5 cm, and a whole-tree spray of 0.4 g·L⁻¹ 6-BA caused a larger percentage of notched buds to develop into lateral shoots compared with notching alone (Greene and Miller, 1988). Palmer et al. (2005) reported that localized application of thidiazuron was far more effective than 6-BA at inducing

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.001	ppm	g·L ⁻¹	1000

growth of dormant buds on lateral shoots of 'Jazz' apple trees.

Notching has not been widely adopted by commercial apple growers in the southeastern United States for several reasons including the high and skillful labor input needed to perform this practice, the inconsistency of results, with a low percentage of notched buds developing into new shoots/scaffolds or only a weak growth response, and concern that notching may create sites for infection by pathogenic bacteria such as fire blight (*Erwinia amylovora*). Palmer et al. (2005) noted that notching can increase the risk of canker caused by *Nectria gallegena*. Inconsistent responses to notching have also been reported in sweet cherry (*Prunus avium*) trees (Elfving and Visser, 2007). Concerns of increased risk of bacterial canker (*Pseudomonas syringae*) infection were raised when scoring or nicking cuts were suggested as a technique for stimulating lateral branch development in young sweet cherry trees (Elfving and Visser, 2009; Elfving et al., 2011). Elfving and Visser (2007) reported that combining notching with a proprietary formulation of 6-BA plus gibberellin A₄ + A₇ (GA₄₊₇) greatly improved the branching response in sweet cherry compared with notching alone. To reduce the labor required to stimulate branching and to reduce the risk of pathogen infection, the effects of combining plant growth regulator treatments with penetrating surfactants was investigated in sweet cherry trees (Elfving and Visser, 2009). Subsequent studies demonstrated that combining a penetrant with gibberellic acid (GA₃) resulted in successful branch induction without the need to apply GA₃ to scoring or nicking cuts in the bark (Elfving et al., 2011).

The objectives of the present research were to evaluate the potential for notching and 6-BA treatments to stimulate shoot development from

paradormant buds on blind wood on the leader of young apple trees. Additional research was conducted to determine the optimum timing for notching plus 6-BA treatments, the minimum effective concentration of 6-BA for inducing shoot development from notched paradormant buds, and the potential for a penetrant to substitute for notching when using 6-BA.

Materials and methods

EFFICACY OF NOTCHING, 6-BA, AND 6-BA PLUS GA₄₊₇. Thirty uniform 5-year-old apple trees were selected in a commercial 'Granny Smith' orchard on 'M.26' rootstock in Henderson County, NC, in Mar. 2013. Ten paradormant buds were identified on the 2-year-old section of the leader on each tree. Only buds that had an obvious, but poorly developed, protuberance at the node were selected for treatment. The selected buds were sometimes, but not always, at contiguous nodes along the section of treated wood. The buds were numbered consecutively from 1 to 10 starting with the basal-most bud on each section of blind wood. The following treatments were applied to each of the 10 marked buds on each tree: 1) untreated control, 2) notching only, 3) a solution of 1.5 g·L⁻¹ 6-BA (MaxCel; Valent BioSciences, Libertyville, IL) sprayed onto the buds, 4) buds notched and a solution of 1.5 g·L⁻¹ 6-BA sprayed into the cut immediately after notching, and 5) notching plus 1.5 g·L⁻¹ 6-BA as in treatment 4, followed by application of 0.25 g·L⁻¹ of a proprietary formulation of 6-BA plus GA₄₊₇ (Promalin, Valent BioSciences) to the new shoots when they were ≈1 inch in length (23 May 2013). Notching and 6-BA treatments were applied on 15 Apr. when trees were at the pink bud stage. Budbreak and full bloom occurred on 30 May and 25 Apr., respectively. Notching was performed by making a horizontal cut ≈3 mm above each paradormant bud with two hacksaw blades fixed together so that a strip of bark ≈4 mm wide was removed down to the secondary xylem. 6-BA and 6-BA plus GA₄₊₇ were applied with a handheld trigger sprayer.

The length of each new shoot that emerged from numbered buds was measured in Winter 2013–14. Percent budbreak and percent of buds that broke and subsequently

developed into shoots >1 cm in length was calculated, in addition to the mean length of shoots. Percentage budbreak data were transformed using the arcsine function before analysis. Means were separated with the Waller–Duncan k-ratio test ($P \leq 0.05$) following a significant F test. Statistical analyses were performed using the general linear models procedure of SAS (version 9.3; SAS Institute, Cary, NC).

TIME OF NOTCHING PLUS 6-BA.

Uniform 6-year-old trees were selected from within the same commercial 'Granny Smith'/'M.26' orchard used in the previous study were identified in Mar. 2014. The trees were divided into six groups (blocks) based on location in the orchard with seven trees in each block. Ten paradormant buds were identified on the leader of each tree and numbered as in the previous study; the buds now on 3-year-old wood. Budbreak and bloom on the trees in this study occurred on 24 Mar. and 25 Apr., respectively. Notching plus 0.75 g·L⁻¹ 6-BA was applied to the numbered buds on one tree in each block –2, 0, 2, 4, 6, or 8 weeks from budbreak (24 Mar.), with an additional tree in each block left as an untreated control. Notching was performed as previously described. The number of buds that developed new growth, and the number of buds that developed into spurs (<1 cm growth), or shoots (>1 cm new growth) was recorded after all growth had ended in late July.

6-BA CONCENTRATION AND PENETRANT.

A study was initiated in 2014 to investigate the effect of 6-BA concentration on budbreak from notched paradormant buds. Since the 2013 study had shown a positive response to 1.5 g·L⁻¹ 6-BA, concentrations ranging from 0.25 to 1.25 g·L⁻¹ were used. Eighty uniform 3-year-old 'Fuji'/'M.9' apple trees were selected from within a commercial orchard in Henderson County, NC. The trees were divided into eight groups (blocks) based on location within the orchard with 10 trees in each block. Budbreak and bloom on the trees in this study occurred on 31 Mar. and 30 May, respectively. Eight paradormant buds were identified and numbered on the 2-year-old section of the leader of each tree. The following treatments were applied to each of the numbered buds on one tree in each block at the king full bloom stage: 1) untreated

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The mention of trade names implies no endorsement of the products mentioned, nor criticism of similar products not mentioned.

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Table 1. Effect of notching, 6-benzyladenine (6-BA) and 6-BA plus gibberellin A4 + gibberellin A7 (GA₄₊₇) on budbreak and lateral shoot development from paradormant buds on sections of blind wood on the 2-year-old leader of ‘Granny Smith’/‘M.26’ apple trees. Notching was performed by making a horizontal cut ≈ 3 mm (0.118 inch) above each paradormant bud with two hacksaw blades fixed together so that a strip of bark ≈ 4 mm (0.157 inch) wide was removed down to the secondary xylem. Notching and 6-BA were applied at the pink bud stage. 6-BA plus GA₄₊₇ was applied when new lateral shoots were ≈ 1 inch in length.

Treatment ^z	Budbreak (%) ^y	Buds with shoots >1 cm (%) ^{z,y}	Mean shoot length (cm) ^z
Control	0 a ^x	0 a	—
Notching	59 b	4 a	0.8 a
6-BA (1.5 g·L ⁻¹)	0 a	0 a	—
Notching + 6-BA (1.5 g·L ⁻¹)	95 c	89 b	7.9 ab
Notching + 6-BA (1.5 g·L ⁻¹), 6-BA plus GA ₄₊₇ (0.25 g·L ⁻¹)	90 c	80 b	15.5 b
Significance	***	***	*

^z1 g·L⁻¹ = 1000 ppm, 1 cm = 0.3937 inch.

^yPercentage data were transformed using the arcsine function before analysis. Data are back-transformed mean values.

^xMean separation in columns by Waller–Duncan k-ratio test following significant F test at $P \leq 0.05$.

*, ***, Significant at $P < 0.05$, and $P < 0.001$, respectively.

control, 2) notching only, 3) notching plus 0.25 g·L⁻¹ 6-BA, 4) notching plus 0.5 g·L⁻¹ 6-BA, 5) notching plus 0.75 g·L⁻¹ 6-BA, 6) notching plus 1.0 g·L⁻¹ 6-BA, 7) notching plus 1.25 g·L⁻¹ 6-BA, 8) 0.75 g·L⁻¹ 6-BA without notching, 9) 0.75 g·L⁻¹ 6-BA plus 2.5% (v/v) penetrant (Pentra-Bark; Quest Products, Linwood, KS), and 10) 2.5% (v/v) penetrant. Notching was performed as previously described. Numbered buds that developed new growth on each leader and the final length of new shoots were recorded after shoot growth ended. At the time these data were collected, the number of additional (untreated) buds that developed new shoots within the treated section of the leader on each tree was also counted.

Results

Notching paradormant buds on ‘Granny Smith’/‘M.26’ trees at the pink bud stage in 2013 stimulated 59% of the buds to resume growth, whereas buds on sections of blind wood on the leader of control trees remained dormant (Table 1). Spraying 6-BA directly onto buds was without effect. However, spraying a solution of 6-BA into the notch significantly increased budbreak compared with notching only, to 90% to 95%. There was no clear effect of the position of the bud on the treated section of wood on budbreak response. Notching provides a means for direct access of 6-BA to the vascular system, suggesting the bark is a significant barrier to the penetration of this cytokinin. While almost 60% of notched buds resumed growth, only 4% of these growing buds developed

Fig. 1. Response of paradormant buds on sections of blind 2-year-old wood on the leader of ‘Granny Smith’/‘M.26’ apple trees to notching (A, B) or notching plus 1.5 g·L⁻¹ (1500 ppm) 6-benzyladenine (6-BA) (C) treatments. Notching was performed by making a horizontal cut ≈ 3 mm (0.118 inch) above each paradormant bud with two hacksaw blades fixed together so that a strip of bark ≈ 4 mm (0.157 inch) wide was removed down to the secondary xylem. Treatments were applied on 15 Apr. at the pink bud stage. Photographs were taken ≈ 5 weeks after treatment.

into a shoot > 1.0 cm in length. The average length of new growth from notched buds was <1.0 cm. Growth from notched buds tended to be weak, producing a narrow meristem with fewer than three or four small subtending leaves (Fig. 1A and B). Mean final lateral shoot length was 7.9 cm in the notching plus 6-BA treatment, whereas shoot length was increased ($P = 0.051$) to 15.5 cm if the lateral shoots were sprayed with 6-BA plus GA₄₊₇ when new shoots were ≈ 1 inch long (5 weeks after treatment). All lateral meristems (shoots and spurs) ended in a flower cluster in Spring 2014 regardless of treatment, and lateral flower clusters develop

from buds at the apical region of most lateral shoots.

Notching plus 6-BA treatments applied to paradormant buds on ‘Granny Smith’/‘M.26’ trees in the timing study increased budbreak compared with the control, and there was a significant curvilinear effect of time of treatment; the strongest response occurred when buds were treated at the time of budbreak and a declining budbreak response was observed either before or after this time (Fig. 2). The influence of treatment timing on the proportion of growing buds that developed into shoots was positively related to the budbreak response; almost 90% of

Fig. 2. Effect of time of notching plus 6-benzyladenine [6-BA [0.75 g·L⁻¹ (750 ppm)]] treatment on budbreak from paradormant buds on 3-year-old wood on the leader of 'Granny Smith'/'M.26' apple trees. Notching was performed by making a horizontal cut ≈3 mm (0.118 inch) above each paradormant bud with two hacksaw blades fixed together so that a strip of bark ≈4 mm (0.157 inch) wide was removed down to the secondary xylem. Buds remained dormant on untreated control trees. Shoots were defined as new growth >1 cm (0.394 inch) in length. Data represent means ± SE (n = 6). Trend line represents the budbreak response ($y = 0.1453x^3 - 2.2925x^2 + 4.5158x + 56.814$; $R^2 = 0.9236$). Percent shoot values with different letters are statistically different by Duncan's multiple range test at $P \leq 0.05$.

buds that broke in response to notching plus 6-BA treatment at budbreak developed into shoots whereas only weak spurs developed in response to treatment 8 weeks after budbreak (Fig. 2). These results indicate that the strongest growth response to notching plus 6-BA treatment was observed between budbreak and 2 weeks after budbreak.

Notching paradormant buds on the leader of 'Fuji'/'M.9' trees stimulated new growth on 59% of treated buds, compared with only 1.5% of buds on control trees resuming growth (Table 2). A high percentage (87%) of the new growth on notched buds grew >1.0 cm in length, with an average new shoot length of 11.9 cm. In contrast, none of the new growth from control buds extended >1.0 cm in length. As in the 'Granny Smith'/'M.26' experiment, treatment with 6-BA alone had no effect on budbreak. However, spraying 6-BA into notched buds on 'Fuji'/'M.9' trees did not increase budbreak or shoot growth compared with notching alone (Table 2). Addition of a penetrant to 6-BA did not increase its activity. None of the unmarked paradormant buds on the leader of control trees or trees treated with a penetrant developed into new shoots. However, several of the notching plus 6-BA treatments encouraged new shoot growth from adjacent nontreated buds (Table 2). However, untreated buds that developed into shoots were not consistently

Table 2. Effect of notching, 6-benzyladenine (6-BA) and a penetrant (2.5% v/v) on budbreak and new shoot length from paradormant buds on sections of blind wood on the 2-year-old leader of 'Fuji'/'M.9' apple trees. Notching was performed by making a horizontal cut ≈3 mm (0.118 inch) above each paradormant bud with two hacksaw blades fixed together so that a strip of bark ≈4 mm (0.157 inch) wide was removed down to the secondary xylem. Treatments were applied at the pink bud stage.

Treatment ^z	Budbreak		Buds with shoots >1 cm (%) ^{z,y}	Mean shoot length (cm) ^z
	Treated buds (%) ^y	Nontreated buds (no./leader)		
Control	1.5 a ^x	0.0 d	0 a	0.1 a
Notching	58.7 b	1.1 bcd	83 b	11.9 b
6-BA (0.75 g·L ⁻¹)	8.2 a	0.1 d	0 a	0.3 a
Notching + 6-BA (0.25 g·L ⁻¹)	66.1 b	0.8 bcd	88 b	11.0 b
Notching + 6-BA (0.5 g·L ⁻¹)	75.0 b	1.6 abc	90 b	14.7 b
Notching + 6-BA (0.75 g·L ⁻¹)	67.6 b	0.8 bcd	94 b	10.4 b
Notching + 6-BA (1.0 g·L ⁻¹)	79.1 b	2.0 ab	98 b	11.9 b
Notching + 6-BA (1.25 g·L ⁻¹)	75.0 b	2.9 a	96 b	14.4 b
6-BA (0.75 g·L ⁻¹) + penetrant (2.5% v/v)	9.5 a	0.4 cd	15 a	0.4 a
Penetrant (2.5% v/v)	1.5 a	0.0 d	0 a	0.1 a
Significance	***	***	***	***

^z1 g·L⁻¹ = 1000 ppm, 1 cm = 0.3937 inch.

^yPercentage data were transformed using the arcsine function before analysis. Data are back-transformed mean values.

^zMean separation in columns by Waller-Duncan k-ratio test following significant F test at $P \leq 0.05$.

***Significant at $P < 0.001$.

basipetal or acropetal in relation to proximal treated buds.

Discussion

Notching paradormant buds on 'Granny Smith'/'M.26' trees stimulated budbreak in these studies, but only a small proportion of notched buds (4%) developed into extension growth >1.0 cm in the year of treatment. In contrast, notching of paradormant buds on 'Fuji'/'M.9' trees stimulated new growth in a higher proportion of treated buds (59%), with most of the new growth developing into extension shoots. No fire blight infections were observed in notched buds in these studies. These results support the view held by many growers in the southeastern United States that notching responses are inconsistent. Notched buds on the leader of 'Granny Smith'/'M.26' trees produced new growth with weak meristems that failed to develop into extension shoots. In contrast, notching of buds on 'Fuji'/'M.9' trees stimulated a strong growth response with most of the treated buds developing into extension shoots. Furthermore, nontreated buds within the section of treated leader were also stimulated to resume growth in 'Fuji'/'M.9' trees, but not in 'Granny Smith'/'M.26' trees. Inconsistent responses to notching have previously been reported in sweet cherry (Elfving and Visser, 2007). Additional studies should be conducted across multiple locations to determine if these different responses are a true cultivar effect. Data from the present studies indicate that spraying 6-BA directly into the notch above a paradormant bud can greatly improve the growth response where a weak response to notching is expected.

Spraying 6-BA onto individual paradormant buds was without effect in either cultivar. However, when 6-BA was sprayed directly into the notch then budbreak and extension of the resulting shoot was greatly enhanced in 'Granny Smith'/'M.26'. These results suggest the presence of an intact bark layer provides a significant barrier to penetration of 6-BA, and to movement of this cytokinin to the dormant meristem in the bud

beneath the notch. Similar responses were reported in 1-year-old sweet cherry shoots for combinations of notching plus 6-BA plus GA₄₊₇ (Elfving and Visser, 2007). In the case of 'Fuji'/'M.9', there was an increase in the number of untreated buds proximal to treated buds (notched plus 6-BA) that resumed growth and developed into extension shoots. This increase suggests movement of 6-BA occurred over short distances from the initial site of penetration.

Addition of a penetrant was without effect on activity of 6-BA applied directly to paradormant buds, indicating this surfactant did not increase penetration through the bark. This is in contrast to sweet cherry, where adding a penetrant to a solution of 6-BA plus GA₄₊₇ resulted in about the same increase in branching that was produced by application of 6-BA plus GA₄₊₇ to scoring or nicking cuts (Elfving and Visser, 2009). Since the bark layer in apple is generally thicker than that in sweet cherry, physical disruption of the bark layer may be necessary to facilitate penetration of branching agents such as 6-BA.

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