

## Chilling Response of Arkansas Blackberry Cultivars

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### Abstract

Florican-fruiting blackberries (*Rubus* subgenus *Rubus*, Watson) require a period of chilling (hours below 7°C) during the dormant season to resume growth in the spring. Chilling requirement is cultivar dependent. The University of Arkansas blackberry breeding program includes efforts to identify genotypes better adapted to low-chill climates. In this study, experiments were conducted to evaluate response to artificial chilling in whole blackberry plants, to develop a technique for determining chilling requirement using stem cuttings, to use this technique to define the chilling requirements of some currently available blackberry cultivars, and to determine whether plant age has a bearing on chilling requirement. The response to chilling in whole plants was consistent with that in stem cuttings for both a high- and low-chill cultivar indicating that stem cuttings may be used to determine chilling requirement. The cultivars evaluated had significantly different chilling requirements as determined by the stem cutting technique. 'Kiowa', 'Ouachita', and 'Prime-Jim'® had a low chilling requirement (100-300 h), 'Arapaho', 'Choctaw', and 'Shawnee' had a medium chilling requirement (300-600 h), and 'Navaho', 'Chickasaw', and 'Apache' had a high chilling requirement (700 h or more). The exact chilling requirements for the high-chill cultivars were not clear from our data due to poor budbreak in the stem cuttings. The results of this study indicated that stem cuttings can be used to broadly determine chilling response in low, medium and high-chill blackberry cultivars, but variability in budbreak may make it difficult to pinpoint an exact chilling requirement.

### Introduction

Blackberries (*Rubus* subgenus *Rubus*, Watson) are produced commercially in many areas of the United States. Florican-fruiting blackberries require a period of chilling during the dormant season in order to resume growth in the spring. Chilling is defined as hours below 7°C (6) and one hour below 7°C constitutes one chill unit (17, 20). The temperature range in which effective chilling occurs differs with species. In raspberry (*R. ideaus* L.), temperatures between 0 °C and 7 °C were the most effective in satisfying chilling requirement (2,10). In peach [*P. persica* (L.) Batsch], temperatures below 0 °C were considered to have no effect in breaking dormancy (20). Within a species, the number of chilling hours necessary to fully break dormancy (chilling requirement) is cultivar dependent (8). Symptoms of insufficient winter chilling such as delayed or sporadic budbreak and bud abortion (9) have been observed in some blackberry cultivars in warm climates, for example 'Chester' blackberry in California (8). In Arkansas, the blackberry breeding effort includes an in-

terest in identifying genotypes better adapted to lower-chill climates. The challenge is to develop cultivars with a low chilling requirement for uniform budbreak as well as a high heat requirement for breaking dormancy in order to avoid frost damage due to early growth (11). Arkansas cultivars have in their background two important parents, 'Darrow' and 'Brazos'. 'Brazos' is a low-chill cultivar developed in Texas (1) and 'Darrow' is a high-chill New York cultivar (1). Blackberry cultivars released from the University of Arkansas breeding program include 'Shawnee' (16), 'Choctaw' (12), 'Navaho' (13), 'Arapaho' (14), 'Kiowa' (15), 'Apache', (3), 'Chickasaw' (4), and 'Ouachita' (5). Reports of sporadic budbreak in 'Navaho' in southern Arkansas (J. R. Clark, personal communication) and Mississippi (C. Gupton, personal communication) indicated that there is a need for more information on chilling requirement of 'Navaho' and other important cultivars. Information on chilling requirements would allow recommendations on potential adaptation to be made. Although chilling requirements in other crops, for ex-

ample peach and blueberry (*Vaccinium* sp.), have been investigated; thus far little work has been done to evaluate current blackberry cultivars or germplasm for chilling response. Our objectives were to evaluate response to artificial chilling in whole blackberry plants, to develop a technique for determining chilling requirement using stem cuttings, to use this technique to define the chilling requirements of some currently available blackberry cultivars, and to determine whether plant age has a bearing on chilling requirement. A series of experiments were conducted during the 1999/2000, 2000/2001, 2001/2002, and 2002/2003 dormant seasons to meet these objectives.

### Materials and Methods

#### *Experiment 1: Using whole plants to determine chilling requirement.*

This study was conducted in the fall/winter of 1999/2000 at the Arkansas Agricultural Research and Extension Center, Fayetteville, using the thornless 'Arapaho' and 'Navaho', since previous observations of budbreak at Hope, Ark. in 1999, a year with only 600 h chilling, indicated that these cultivars differ in their chilling requirements. One-year-old bare-root plants were field-dug from a local nursery after the first killing frost of the season on 26 Oct. 1999, where temperatures below -5 °C were recorded. Plants were placed in containers with root systems covered with mulch and canes exposed to ambient conditions. Plants were then placed in a dark cold chamber. Temperature in the cold chamber was monitored with a thermometer and maintained at 3°C. Ten single-plant replications were removed at 100-hour intervals up to 1000 h. The plants in the 100-h group were removed from the cold chamber on 30 Oct. 1999, and the plants in the 1000-h group were removed on 7 Dec. 1999. Once removed from the chamber, the plants were cut back to approximately 0.6 m single-cane lengths and potted in Universal Mix Media (StrongLite

Horticultural Products, Pine Bluff, Ark.) in 10 cm pots. Plants were arranged in a completely randomized design in a heated greenhouse with a daily minimum temperature of 15°C and a daily maximum of 25°C to force budbreak. Daylength was maintained at 16h with incandescent lighting. Budbreak data were recorded at 1-week intervals. A bud was considered broken when the first leaf became visible as it unfolded from the bud, and all buds on a cane were examined and counted if broken. Data for budbreak at 5 weeks were analyzed as a two-factor factorial (two cultivars and 10 chilling treatments) for each 100-h chilling treatment using SAS (SAS Institute, Cary, N.C.). Means were separated by least significant difference ( $P=0.05$ ).

#### *Experiment 2. Evaluating a technique for measuring chilling requirement using stem cuttings.*

Samples were taken in the fall and winter of 2000-2001 from a 2-year-old planting of the cultivars Apache, Arapaho, Chickasaw, Choctaw, Kiowa, and Shawnee at the Arkansas Agricultural Research and Extension Center, Fayetteville. Plants had primocanes tipped during the growing season at 1.1 m to encourage lateral growth. To measure natural field chilling, a biophenometer (Wescor Environmental Products, Logan, Utah) was placed in the planting to record the number of hours below 7°C after the first killing frost of -5°C on 12 Oct. 2000. Ten 12-node stem cuttings from lateral branches of mature canes of each of the cultivars were taken at 100-h intervals of chilling up to 1000 h, except for 'Arapaho' which was only sampled up to 600 h due to a shortage of laterals. No samples were taken at 900 h due to a severe ice storm which made sampling impossible in late December 2000. Following sampling, the cuttings were placed in a mistbed in the greenhouse in a completely randomized design, with daylength and temperature conditions as described above. The cuttings

were misted intermittently with water (15 s every min) for 24 h per day. The mistbed was filled with perlite. The bottom two nodes of each cutting were submerged in the perlite to anchor the cutting so that 10 nodes remained exposed. Cuttings were placed 4.8 cm apart within a row with 7.2 cm between rows. Each cutting remained in the mistbed for 10 weeks. Percent budbreak in the cuttings was recorded weekly. After 10 weeks, budbreak data were analyzed for each cultivar separately using the GLM procedure of SAS (Version 8.2; SAS Institute, 1999, Cary, N.C.) and the standard errors of the means calculated.

*Experiment 3. Further evaluation of the stem cutting technique to determine cultivar differences in chilling requirement.*

This study was conducted at the University of Arkansas Southwest Research and Extension Center, Hope. 'Apache', 'Arapaho', 'Chickasaw', 'Choctaw', 'Shawnee', and 'Prime-Jim'<sup>®</sup> were planted in the field in a randomized complete block design with four replications in mid-April 1999. Primocanes were tipped to 1.1 m height during the summer. Sampling began in the fall of 2001 when the plants were 2-years-old.

On 22 Nov. 2001 an overnight air temperature of -3.3°C was recorded, the first sub-freezing temperature of the season. This temperature was considered low enough to trigger the onset of dormancy in the blackberry cultivars. A biophenometer (Wescor Environmental Products, Logan, Utah) was placed in the field on 23 Nov. to record hours below 7°C. Samples were taken at every 100 h up to 1000 h below 7°C. One thousand hours were reached on 11 Feb. 2002. 'Prime-Jim'<sup>®</sup> was only sampled up to 800 h chilling due to a shortage of laterals. At each sampling time, two 12-node, lateral-branch cuttings were taken from each of the four plots of every cultivar. The cuttings were then arranged in a mist chamber in the greenhouse,

as described in Experiment 2, in a randomized complete block design with eight replications. Daytime maximum air temperature in the greenhouse was 26°-29°C with a minimum of 21°C at night. Daylength was maintained at 16 h with incandescent lighting. The cuttings remained in the chamber for 10 weeks and percent budbreak measured weekly as described previously. The data were analyzed as a randomized complete block design as a split-plot in time using the GLM procedure of SAS (SAS Institute, Cary, N.C.). Means were separated by least significant difference (LSD)  $P \leq 0.05$ .

*Experiment 4. Effect of plant age on chilling requirement.*

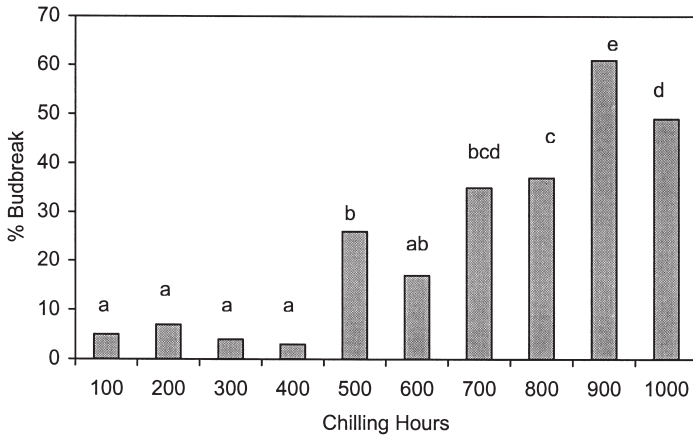
Experiment 3 was repeated at the Southwest Research and Extension Center in the dormant season of 2002/2003 for 'Arapaho', 'Apache', 'Chickasaw', 'Kiowa', and 'Prime-Jim'<sup>®</sup>. Additionally, newly released 'Ouchita' and primocane-fruiting cultivar Prime-Jan<sup>®</sup> were included in this experiment. The experiment was initiated on 26 Nov. 2002 following an overnight low of -1.7°C the previous week which was the first killing frost of the season. Samples were taken at every 100 h chilling as described in Experiment 3 and the last sample was taken on 10 Feb. 2003 when 1000 h chilling was reached. To evaluate the effect of plant age on chilling response, eight stem cuttings of each cultivar except 'Kiowa' were taken from both the 3-year-old planting used in Experiment 3 and a new 1-year-old planting at each sampling time. 'Kiowa' was not included in the new planting, therefore only 3-year-old plants of this cultivar were sampled. Plants were sampled as described in Experiment 3 and the cuttings were arranged in the mist chamber in a randomized complete block design with eight replications. Bud break data were recorded weekly for 5 weeks as described before. The data were analyzed as a split-plot design and the standard errors of the means calculated (SAS Institute, Cary, N.C.).

## Results and Discussion

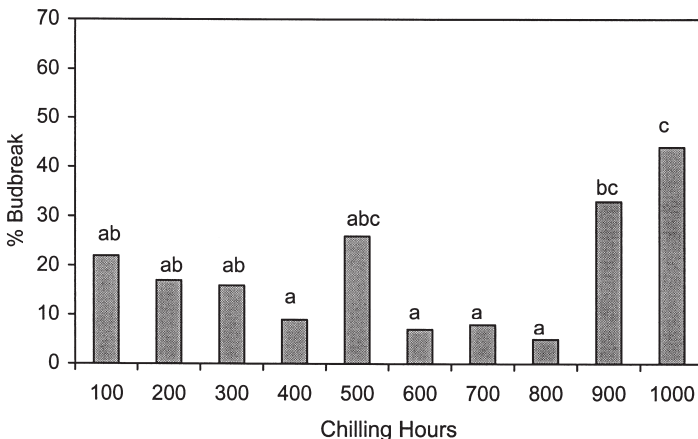
### Experiment 1.

The cultivar x chilling hours interaction was highly significant ( $P=0.01$ ). 'Arapaho' had less than 10% budbreak up to 400 h (Fig. 1). At 500 h budbreak increased significantly to 24% indicating that this is probably the chilling requirement for 'Arapaho'. Further significant increases were seen at later chilling intervals also. This parallels obser-

vations in the field in Arkansas (J. R. Clark, personal communication) and Mississippi (C. Gupton, personal communication) where 'Arapaho' broke buds reliably when chilling of approximately 500 h was experienced. Budbreak continued to increase with chilling hours to a maximum of 62% at 900 h. 'Navaho' had, on average, 20% budbreak between 100 h and 400 h (Fig. 2). This relatively high percent budbreak at low chilling hours may have



**Fig. 1.** Budbreak of 'Arapaho' thornless blackberry plants after 100 to 1000 hours at 3°C, Fayetteville, Ark. 1999/2000. Bars not followed by the same letter are significantly different as determined by LSD ( $P=0.05$ ).



**Fig. 2.** Budbreak of 'Navaho' thornless blackberry plants after 100 to 1000 hours at 3°C, Fayetteville, Ark. 1999/2000. Bars not followed by the same letter are significantly different as determined by LSD ( $P=0.05$ ).

occurred because the canes were not fully dormant when plants were removed from the cold room. The increase in budbreak to 25 % at 500 h can be explained by the fact that five plants in this treatment failed to break buds and were eliminated from the analysis. Two of the five surviving plants had an unusually high budbreak thereby skewing the results. Budbreak from 600-800 h was less than 10% with a significant increase to approximately 35% at 900 h. We concluded that the chilling requirement of 'Navaho' is probably between 800 and 900 h and this is consistent with observations of sporadic budbreak in 'Navaho' at Hope, Ark. in 1999 that indicated its chilling requirement was greater than 600 h.

#### Experiment 2.

'Arapaho' had a significant increase in budbreak between 400 and 500 h, similar to Experiment 1 (Fig. 3), and also increased from 500 to 600 h. This indicated that the stem cutting method was successful in determining the chilling requirement of this cultivar.

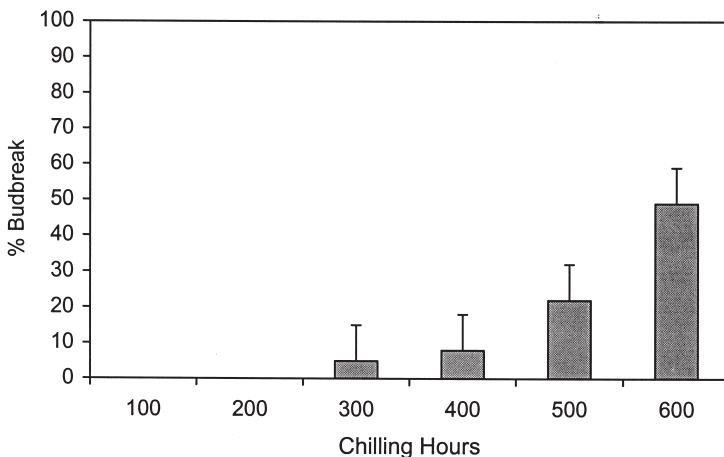
'Kiowa' had substantial budbreak at 200 h and at most other chilling hours (Fig. 4). The reduction in budbreak for 'Kiowa' at 800 and

1000 h was probably due to winter injury from a hard freeze (-16.7°C). Data from the 300 h sample could not be included due to the death of the entire stem of a large number of cuttings. It appears that 'Kiowa' has a low chilling requirement of possibly 200 h.

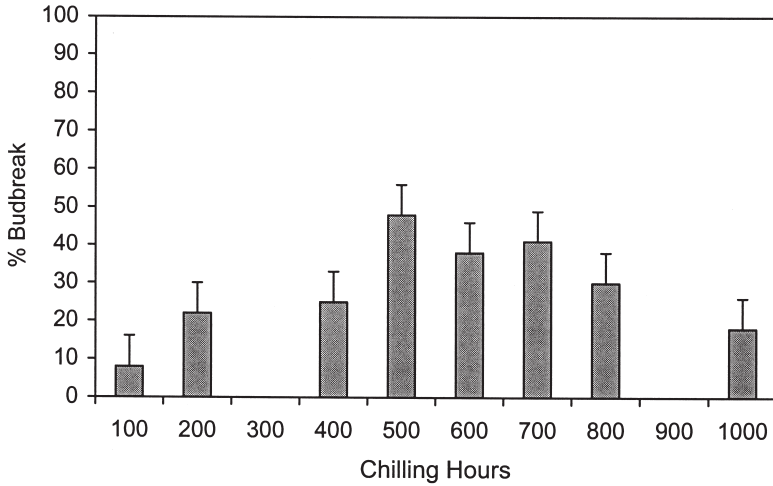
'Choctaw' had no budbreak until 400 h with higher budbreak at other chilling hours (data not shown). However, budbreak never exceeded 35% for 'Choctaw' so the chilling requirement for this cultivar is not clear from our data.

Budbreak in 'Shawnee' increased significantly by 30% between 400 and 500 h (Fig. 5) and this appears to be the chilling requirement for 'Shawnee'. This chilling range has always been reflected in field plantings as poor budbreak has never been reported even in areas of the deep south. Significant increases in budbreak were also seen from 500-600 and from 600-700 h.

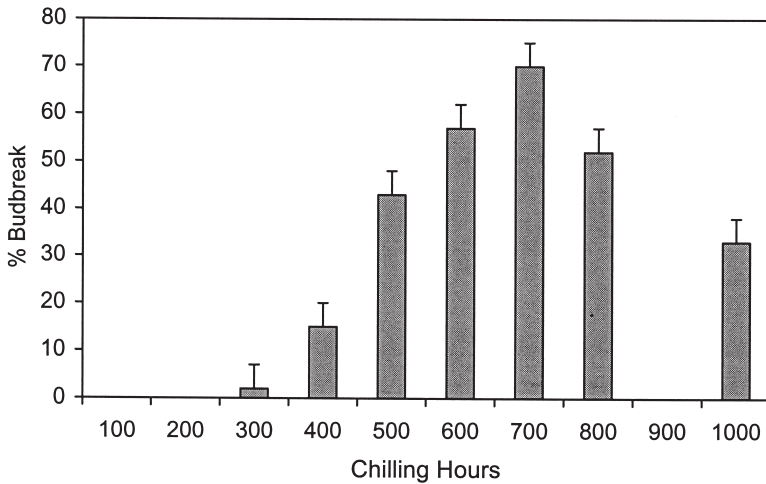
The chilling requirement of 'Chickasaw' appears to be between 600 and 700 h since there was a substantial increase in budbreak to 50% at 700 h (data not shown). Budbreak was lower at 800 and 1000 h again possibly due to winter injury of the buds.



**Fig. 3.** Budbreak of stem cuttings of 'Arapaho' thornless blackberry after 100 to 600 hours below 7°C, Fayetteville, Ark. 2000/2001. Bars represent standard errors.



**Fig. 4.** Budbreak in stem cuttings of 'Kiowa' thornless blackberry after 100 to 1000 hours below 7°C, Fayetteville, Ark. 2000/2001. Bars represent standard errors.

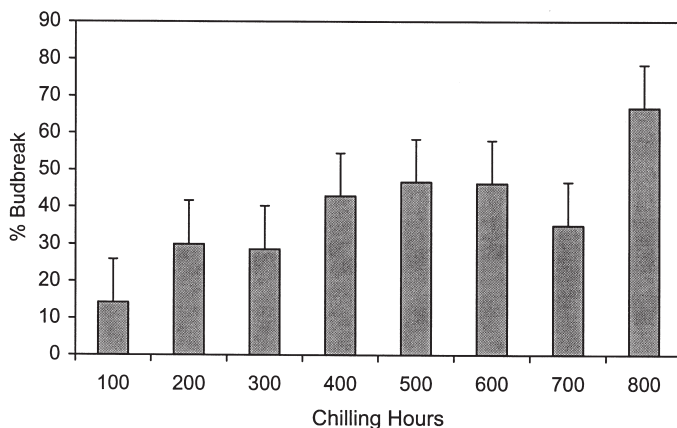


**Fig. 5.** Budbreak in stem cuttings of 'Shawnee' blackberry at 100-1000 chilling hours below 7°C, Fayetteville, Ark. 2000/2001. Bars represent standard errors.

'Apache' had low budbreak at all chilling hours reaching a maximum of only 20% at 800 h (data not shown). 'Apache' is thought to have a high chilling requirement due to 'Navaho' being one of its parents (10) and it having reduced budbreak in the field after approximately 600 h of chilling (J. R. Clark, unpublished data), but our data were inconclusive.

#### Experiment 3.

Although budbreak was rated for 1 through 10 weeks, budbreak reached a maximum at week 5. There was no statistical difference between budbreak at week 5 and budbreak in the following weeks for any chilling level or cultivar. Therefore only week 5 data are considered in this discussion. Percent bud-



**Fig. 6.** Budbreak in stem cuttings of ‘Prime Jim’<sup>®</sup> blackberry at 100-800 chilling hours below 7°C, Fayetteville, Ark. 2000/2001. Bars represent standard errors.

break at different chilling hours ranged from 10% to as high as 90% for different cultivars. The cultivar x chilling hours interaction was significant.

‘Prime-Jim’<sup>®</sup> appeared to have a low chilling requirement (Table 1). Significant increases in budbreak were seen at 200 h (30%) and 400 h (43%), and maximum budbreak occurred at 800 h (67%). New leaves and flowers were present throughout the winter indicating that ‘Prime-Jim’<sup>®</sup> never became fully dormant. The chilling requirement of

‘Prime-Jim’<sup>®</sup> seems to be between 100 and 200 hours, unless this unique plant does not truly have a chilling requirement.

‘Kiowa’, like ‘Prime-Jim’<sup>®</sup>, showed significant budbreak even at 200 h chilling (Table 1) and this was consistent with Experiment 2. Budbreak remained constant at approximately 30% until 800 h when there was a significant increase to 79%. As in the previous experiment, ‘Kiowa’ appears to have a chilling requirement of 200-300 h, based on our data and field observations (see discussion).

**Table 1:** Percent budbreak in stem cuttings of University of Arkansas blackberry cultivars in response to chilling hours below 7 °C, Experiment 3.

Cultivar	Chilling hours below 7 °C									
	100	200	300	400	500	600	700	800	900	1000
Apache	1 c <sup>z</sup>	0 c	8 b	10 a-c	11 a-c	11 a-c	16 ab	20 a	13 a-c	16 ab
Arapaho	29 d	34 cd	35 c	34 cd	53 b	44 c	54 b	54 b	80 a	90 a
Chickasaw	1 d	4 d	8 d	10 cd	14 b-d	13 cd	21 a-c	25 ab	17 b-d	27 a
Choctaw	0 f	4 ef	19 cd	14 de	11 d-f	28 bc	26 bc	62 a	53 a	33 b
Kiowa	16 d	23 c	29 bc	33 bc	30 bc	35 bc	37 b	79 a	83 a	75 a
Shawnee	3 e	3 e	6 de	16 d	28 c	41 b	84 a	83 a	89 a	83 a
Prime-Jim <sup>®</sup>	14 e	30 d	29 d	43 bc	47 b	46 bc	35 cd	67 a	--	--

<sup>z</sup>Different letters within a row denote significant difference at P=0.05; means are separated according to Fisher’s LSD.

'Arapaho' had budbreak of approximately 30-35% between 100 and 400 h (Table 1). Budbreak increased significantly at 500 h to 53% corroborating our findings in Experiments 1 and 2, and further significant increases were seen at higher chilling levels. We conclude the chilling requirement for this cultivar is 400-500 h, based on the first significant increase in budbreak.

'Shawnee' showed significant increases in budbreak between 400-500, 500-600, and 600-700 h (Table 1). Maximum budbreak was at 900 h (89%). These results closely match our findings in Experiment 2 and suggest that the chilling requirement of 'Shawnee' is 400-500 h.

'Choctaw' showed little budbreak until 300 h when budbreak increased significantly to 19% (Table 1). Further significant increases occurred between 500 and 600 h and between 700 and 800 h. As in Experiment 2, the results for 'Choctaw' are inconclusive.

The response of 'Apache' to chilling hours was difficult to determine. Little or no budbreak was seen between 100 and 400 h suggesting a higher chilling requirement. However, even at 800 h, maximum budbreak was only 20% (Table 1). As in Experiment 2, the exact requirement for 'Apache' is not clear from our data, although 'Apache' appears likely to be a high chill cultivar. Observations of sporadic budbreak in a year of approximately 600 h chilling at Hope, Ark. (J.R. Clark, unpublished data) indicate that 'Apache' likely requires higher chilling than 600 h.

'Chickasaw', like 'Apache', had relatively low budbreak at low chilling hours with an increase to 21% at 700 h (Table 1). Maximum budbreak was only 27% at 1000 h. It is difficult to pinpoint the chilling requirement of 'Chickasaw' since overall budbreak was so low.

#### *Experiment 4*

The response to chilling seen in stem cuttings from 3-year-old plants of 'Arapaho',

'Prime-Jim'<sup>®</sup>, and 'Kiowa' is in agreement with the chilling response of these cultivars observed in Experiment 3 if it is assumed that dormancy is broken when 30% or more budbreak occurs (Table 2). The chilling requirements for 'Arapaho', 'Prime-Jim'<sup>®</sup>, and 'Kiowa' for 30% or more budbreak to occur were 100, 300, and 300 h respectively, in both Experiments 3 and 4. However, unlike in the previous experiments, no significant increase in budbreak was observed in 'Arapaho' between 400 and 600 h in experiment 4 (Table 2).

'Prime-Jan'<sup>®</sup> had a similar chilling response to 'Prime-Jim'<sup>®</sup> with more than 50% budbreak occurring at 300 h for both 1-year-old and 3-year-old plants, indicating a low chilling requirement for this cultivar (Table 2).

The chilling requirement of 1-year-old plants of 'Apache' could not be determined since budbreak barely exceeded 30% at any chilling level (Table 2). However, in the 3-year-old plants of 'Apache' there was a significant increase in budbreak to 40% at 900 h which is in accordance with the field observations discussed previously that indicate that 'Apache' has a high chilling requirement.

Budbreak for 'Chickasaw' was 38% at 800 h in 3-year-old plants and 36% at 1000 h in 1-year-old plants (Table 2). This is in accordance with the results from experiments 2 and 3 which indicate that 'Chickasaw' might have a chilling requirement of 700 h or more.

Newly released 'Ouachita' appears to have a lower chilling requirement than the other thornless cultivars Arapaho, Apache, and Navaho. Three-year-old plants of 'Ouachita' had 38% budbreak at 200 h and young plants had over 60% budbreak at 300 h indicating that the chilling requirement of this cultivar appears to be 200 to 300 h (Table 2).

Overall, the age of the plant material did not seem to influence the amount of budbreak in stem cuttings. The responses to chilling were generally similar for stem cuttings from

**Table 2.** Percent budbreak in stem cuttings of one-year-old and three-year-old University of Arkansas blackberry cultivars, Experiment 4.

Cultivar	Chilling hours below 7 °C									
	100	200	300	400	500	600	700	800	900	1000
<u>1-year-old plants</u>										
Apache	5 ez	15 d-f	31 ef	26 d	19 e	19 d	13 e	26 gh	18 c	24 e
Arapaho	31 bc	29 b-d	71 a	43 bc	53 a-c	76 a	61 a	66 ab	73 a	81 bc
Chickasaw	6 e	5 f	21 f	30 cd	24 de	26 d	16 e	13 h	28 bc	36 de
Ouachita	13 de	18 d-f	63 a-c	60 a	40 cd	60 bc	43 bc	66 ab	79 a	94 ab
Prime-Jan®	38 b	19 d-f	65 ab	35 cd	40 cd	68 ab	59 ab	33 fg	80 a	96 a
Prime-Jim®	21 c-e	25 b-e	55 b-d	41 b-d	65 a	58 bc	49 a-c	51 c-e	80 a	96 a
<u>3-year-old plants</u>										
Apache	21 c-e	25 b-e	31 ef	28 cd	18 e	18 d	20 e	15 h	41 b	50 d
Arapaho	54 a	54 a	56 a-d	55 ab	64 ab	68 ab	58 a-c	64 a-c	73 a	85 a-c
Chickasaw	23 cd	10 ef	29 ef	28 cd	24 de	19 d	25 de	38 e-g	26 bc	46 d
Kiowa	21 c-e	23 c-e	43 d-e	35 cd	39 c-e	48 c	50 a-c	45 d-f	73 a	88 ab
Ouachita	30 bc	38 bc	49 c	40 b-d	41 c	55 bc	38 cd	66 ab	65 a	71 c
Prime-Jan®	38 b	39 a	53 b-d	60 a	59 ab	53 bc	63 a	78 a	88 a	98 a
Prime-Jim®	28 cd	28 b-d	55 b-d	40 b-d	48 bc	60 bc	43 bc	56 b-d	83 a	77 bc

<sup>a</sup>Different letters within a column denote significant difference at P=0.05; means are separated according to Fisher's LSD. LSD for comparing means within a row =15 (P=0.05).

both young and older plants. Field observations of the cultivars and selections on 1 Apr. 2003 after 1448 h chilling showed close to 100% budbreak in 'Kiowa', and in young and older plants of 'Arapaho', 'Prime-Jan'®, 'Prime-Jim'®, and 'Ouachita'. However, 'Chickasaw' had only 68% budbreak in the old planting compared to 80% in the new planting. Likewise, 'Apache' had 60% budbreak in the old planting and 90% in the new planting (field data not shown). Although not observed in stem cuttings, age of plant material appeared to be a factor influencing budbreak in the field for 'Chickasaw' and 'Apache'.

In reviewing the data from our experiments, it is apparent that the genotypes evaluated had differences in chilling requirement. However, the percent budbreak attained varied substantially in the studies, raising questions as to what might be considered "ful-

fillment" of chilling, and whether chilling requirement was well measured for cultivars such as 'Apache' and possibly 'Chickasaw', which showed low budbreak even at high chill levels. Warmund and Byers (18) reported that buds of 'Apache' were slower to grow than those of 'Shawnee', 'Kiowa', and 'Arapaho' and they suggest that bud physiology may influence budbreak in 'Apache'. For most cultivars, the first significant increase in budbreak occurred when the chilling requirement had been met, even if the percent budbreak remained low. Therefore, the first significant increase in budbreak can be an additional indicator that the chilling requirement has been met.

Another potential source of variability in budbreak among the studies might be attributed to the variation in chilling inception temperature in each study. In experiments 1, 2, 3, and 4 the chilling inception tempera-

tures were  $-5^{\circ}\text{C}$ ,  $-5^{\circ}\text{C}$ ,  $-3.3^{\circ}\text{C}$ , and  $-1.7^{\circ}\text{C}$ , respectively. The temperature at which a killing frost occurs can depend on the degree of acclimation of the plant tissue at the time of frost. In some crops, tissue death may not occur until temperatures are as low as  $-4.4^{\circ}\text{C}$  (7). Warmund and Krumme in 2005 (19) investigated several different models for estimating rest completion in erect blackberries and found that the model with a chilling inception temperature of  $-2.2^{\circ}\text{C}$  estimated chilling most accurately. This model also used weighted chilling hours with temperatures between 0 and  $2.4^{\circ}\text{C}$  being weighted more heavily. Warmund and Krumme (19) found weighted chilling hours to be more accurate for estimating chilling in blackberry than the Utah peach chilling model (17). In light of this new research, the use of weighted chilling hours and a chilling inception temperature of  $-2.2^{\circ}\text{C}$  would likely have reduced variability in our data.

Despite variability in the studies, overall we believe our findings were reflective of chilling requirement for several cultivars. For instance, 'Arapaho' consistently had significant increases in budbreak at 400-500 h, and this parallels the field observations that it breaks buds more evenly in areas receiving less chilling than northwest Arkansas, namely Poplarville, Miss. (C. Gupton, personal communication), and Monticello, Fla. (P. Andersen, personal communication). Budbreak for 'Navaho' in Experiment 1 fluctuated at the lower chill levels but the data indicated that chilling requirement appeared to be fulfilled at 800-900 hours. Though our data for 'Navaho' are based on just one experiment, field observations in Mississippi, north Florida, and Hope, Ark., have shown reduced budbreak in 'Navaho' compared to 'Arapaho' in years when chilling was 500-600 h, thus corroborating our findings of a higher chilling requirement. Therefore for the two cultivars with the largest amount of field testing, our findings substantiate field

observations.

'Choctaw' has also been reported to be lower in chilling requirement in Central Mexico (J. Rodriguez, personal communication), where very little to no chill is experienced. However, a low chilling requirement could not always be discerned from our data. The reasons for this variability in chilling response are not clear. In Experiment 2, it is possible that some winter injury could have damaged the buds in the field due to the severe cold experienced in Fayetteville in late December and January of 2001, thereby reducing budbreak on the collected cuttings. However, we do not believe any winter injury was experienced at Hope during the winter of 2001-2002, and therefore the reasons for data variability at this location are not clear. In recent years, field observations of 'Kiowa' have indicated good budbreak in southern Georgia (G. Krewer, personal communication) where chilling is usually 400-600 h. Reliable fruiting has also been observed in an area of very little to no chill in Guatemala (R. Castaneda, personal communication). 'Kiowa' has also consistently broken buds evenly at Hope, Ark. in many trials there. Our data reflect a lower chilling requirement for 'Kiowa' compared to any other genotypes in our studies, which parallels field observations.

Our data for 'Shawnee' from Experiments 2 and 3 show rather consistent increases in budbreak between 400 and 500 h, and 500 and 600 h. 'Shawnee' was released in 1983 and has been widely planted in the southern U.S. Most of the southern U.S. receives at least 400 to 600 hours of chilling in most or every year, and we have not had reports of poor budbreak for 'Shawnee' at any location. We feel our findings are very reflective of the actual chilling requirement of 'Shawnee' as observed in the field. Finally, the primocane-fruiting cultivars 'Prime-Jan'<sup>®</sup> and 'Prime-Jim'<sup>®</sup> showed the lowest chilling requirements of any genotypes tested in Experiments 3 and 4. We noticed that at Hope,

Ark. these cultivars retained their leaves all winter in the field and never appeared to become fully dormant. Further investigation will be conducted to learn more about the chilling requirement, if any, of these new unique blackberries. It should be emphasized that our data were collected on floricanes of all cultivars, and that the primocanes require no chilling to fruit during the current growing season.

Another area of interest in our studies was the use of stem cuttings for determining chilling requirement fulfillment. Whole plants used in chilling requirement studies are expensive and often difficult to manage. We are encouraged that the forced-stem approach gave positive and generally consistent results. The age of plant material sampled did not affect the amount of budbreak observed in stem cuttings. However, field observations of 'Chickasaw' and 'Apache' suggest that age may be a factor in the amount of budbreak under field conditions and this requires further investigation. Although the stem cutting technique did not work as well for a few genotypes, it did appear to give general chilling responses for a range of genotypes. We will use this technique for further screening of cultivars and breeding selections with the goal to have earlier information on chilling requirement for blackberry cultivars to provide for growers in a wider range of climates.

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