Phenotypic Variation of Length of Bud Dormancy in Apple Cultivars and Related *Malus* Species

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Abstract. The chilling requirements (CR) to break bud dormancy in a broad range of apple cultivars (*Malus × domestica* Borkh.) and related *Malus* spp. were assessed by periodic sampling and forcing of field-grown shoots as a function of chill unit (CU) accumulation and/or by the total growing degree hours (GDH) accumulated from leaf fall until the time of budbreak under a simulated subtropical winter. The mean number of CU required to break dormancy of field overwintered shoots varied between 218 ± 113 for 'Anna' and 1516 ± 113 for 'Wright #1'. However, most genotypes had CR between 800 and 1200 CU. Much wider variation for the length of bud dormancy was observed in plants growing under simulated subtropical winter conditions. Genotypes that had shown the lowest CR values under Geneva, N.Y., winters generally had the highest year-to-year variation in CR estimates. Cultivar bud CR values obtained under cold winters are related to field-observed CR estimates in a subtropical environment, but absolute values may differ markedly. Furthermore, several genotypes that show reasonable adaptation to the subtropics have similar or higher CR than apple cultivars with standard CR under Geneva conditions. In addition, enough CU accumulated under the simulated subtropical winters to break dormancy of standard apple cultivars. However, complete dormancy removal was observed only in cultivars well-adapted to a subtropical environment. This result indicates that in addition to CU accumulation, there are important interactions among cultivars and environmental factors that are responsible for terminating bud dormancy. Several cultivars and wild species have shown resistance to delayed foliation. Among the species, *M. brevipes*, *M. rockii*, *M. spectabilis*, and *M. turesii* are more tolerant than *M. baccata* and its hybrids, which are recognized for their adaptation to the subtropic environment.

Apple budbreak occurs promptly and uniformly in the spring in genotypes that are adapted to the environment; this is what normally occurs in temperate-zone climates. However, dormancy symptoms may persist if winter is neither long enough nor cold enough to break dormancy. "Delayed foliation" or "extended rest" are names commonly given to a series of aberrations observed when deciduous fruit trees are grown under mild winter conditions that do not allow for a complete rest release (Black, 1952; Ruck, 1975). The effects can be observed in every aspect of the growth cycle of the plant; the intensity of the symptoms is related to the amount of chilling that is lacking. This lack is the main limiting climatic factor governing the distribution of woody species of the temperate zones in the tropics and subtropics.

Wide variation among cultivars, wild species, and interspecific hybrids for the length of the bud dormancy period under field conditions has been reported (Chandler and Brown, 1957; Crossa-Raynaud, 1955; Lloréns, 1967; Mazzochi and Pucci, 1963; Miller and Baker, 1982; Oppenheimer and Slor, 1968; Ruck, 1975; Samish and Lavee, 1962; Stebbins and Walheim, 1981). In only a few cases have variability studies been conducted under more controlled conditions (Eggert, 1951; Pasternak, 1983; Petropoulou, 1985; Shaltout and Unrath, 1983; Swartz and Powell, 1981; Young and Werner, 1985). A few genotypes adapted to subtropic conditions have been developed (Oppenheimer and Slor, 1968; Ruck, 1975).

The purpose of our study was to determine the variability of the length of the bud dormancy period in apple cultivars and

related *Malus* spp. and to verify how these values are related to the behavior of the genotypes under various environmental conditions. The relationships among the different indices used to estimate the end of dormancy (Hauagge and Cummins, 1991a) and the variability of the apple bud dormancy pattern throughout the season (Hauagge and Cummins, 1991b) are subjects of companion papers.

Materials and Methods

Field sampling. Previous season's apple shoots 15 to 25 cm long having terminal flower buds were collected periodically from trees growing at the New York State Agricultural Experiment Station, Geneva, during 1984-85 (20 sampling times between 22 Oct. 1984 and 27 Mar. 1985), 1985-86 (16 sampling times between 24 Sept. 1985 and 28 Apr. 1986), and 1986-87 (12 sampling times between 14 July 1986 and 13 Apr. 1987) fall/winter seasons. Leaves were removed when necessary and shoots were forced in continuous light and constant temperature ($23 \pm 1^\circ\text{C}$ in 1984-85 and 1985-86; $19 \pm 1^\circ\text{C}$ in 1986-87). Shoots with terminal buds removed were also used on five sampling dates in the 1986-87 experiments.

Bud development stage (BDS) (1984-85 and 1985-86), percent terminal budbreak (BB) on the 21st day of forcing (1985-86), and the day on which 50% of the shoots had terminal buds broken (D50), were based on fitted linear and quadratic equations as functions of CU accumulation and are described in Hauagge and Cummins (1991a). Seven BDS classes were assigned on the 21st day of forcing, based on Chapman and Catlin (1976). Dormancy was considered over when the indices BB, BDS, and D50 reached the values 50%, 1.5 and 15 days, respectively, as the result of CU accumulation (Hauagge and Cummins, 1991a). CU accumulated at the sampling time was

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Abbreviations: BB, percent terminal budbreak; BDS, bud development stage; CR, chilling requirement; CU, chill unit; D50, number of days for 50% terminal budbreak; GDH, growing degree hours.

determined by the formula, $CU = 0.2770 + 0.1940t - 0.0124t^2$ (A. Lakso, personal communication) fitted from Shaltout and Unrath's (1983) data, where t is the hourly recorded temperature. GDH (Anderson et al., 1986) was calculated assuming optimum (25C) and base (4C) temperatures for apple growth.

Experiments conducted in 1984–85 were intended to facilitate a broad assessment of the variation of the length of bud dormancy in the apple germplasm. More detailed studies were conducted in 1985–86 and 1986–87. Cultivars were selected based on previous knowledge of their behavior, time of budbreak, genealogy, and branching growth habit in the field. Shoots were completely randomized, with each observation unit consisting of two shoots replicated three times in 1984–85 and four shoots replicated four times in 1985–86 and 1986–87.

Overwintering under alternating temperature regime. An environment imitating subtropical winter conditions was used to test genotypic behavior under those conditions. On 30 May 1985, at least eight recently grafted plants of each of 43 apple cultivars and *Malus* spp. were planted in the New York Agricultural Experiment Station greenhouse facilities, Geneva, in 1500-cm³ containers, which allowed 90 cm² of surface area per plant. Plants were grown under 16 h of light at a 20C minimum. Hardening and dormancy induction started 180 days later by a process modified from Stushnoff (personal communication). In 1985, only natural light was supplied after 11 Nov. Temperature was maintained at $14 \pm 2C$, $8 \pm 2C$, and $14 \pm 2C$ for 20, 40, and 14 days, respectively.

The low reached $-4C$ for 3 h during two mornings in the 8th week. At the end of the dormancy induction treatment, 80% to 95% of the leaves on all plants had abscised or were in an advanced stage of senescence. Plants were then submitted to an alternating temperature regime similar to that which normally occurs in the winter in subtropical areas, where bud dormancy in standard apple cultivars is not completely broken. The temperature was maintained at $5 \pm 2C$ for 9 h at night and then raised to $14 \pm 3C$ during the day. Temperatures as high as 24C occurred a few times for short periods (<2 h). After 100 days in 1986 and after 70 days in 1987, the minimum was raised to 12C and the maximum to $20 \pm 2C$. There was no additional accumulation of CU after this time. Both CU (Shaltout and Unrath, 1983) and GDH (Anderson et al., 1986) were calculated based on hourly recorded temperatures. Accumulation of CU and GDH was started simultaneously when 80% to 95% of the leaves had abscised or were in an advanced stage of senescence. Plants were checked every fifth day for budbreak. On 2 June 1986, they were evaluated for the degree of adaptation, an index based on the intensity of delayed foliation symptoms shown by the plants after budbreak. Degree of adaptation varied between 0, the least adapted, and 5, the most adapted. The classes were based on the number of buds broken, uniformity of budbreak, and internode elongation (Fig. 1).

Results and Discussion

Phenotypic variation for the CU required to terminate bud dormancy from field sampling. The mean number of CU required to break bud dormancy (i.e., CR) under the experimental conditions varied between the extremes of 218 ± 113 for 'Anna' and 1526 ± 113 for 'Wright #1' (Tables 1 and 2). However, most of the genotypes had CR between 800 and 1200 CU. 'Delicious' and its subclones require ≈ 1200 CU to break dormancy (Shaltout and Unrath, 1983). The possible differences expressed here were related to the parameters chosen to express the end of the bud dormancy period (Hauagge and Cummins,

Fig. 1. Degree of adaptation based on the number of buds broken, uniformity of budbreak, and internode elongation. Classes varied from (left) 0 to (right) 5. Degree of adaptation is an index based on the intensity of delayed foliation symptoms shown by the plant after budbreak.

1991a). The values were similar when compared within comparable conditions (data not shown).

Many wild species and interspecific hybrids have lower CR than *Malus × domestica* apple cultivars. However, this characteristic was not observed either in cultivars or New York selections in which *M. floribunda* Sieb. or *M. prunifolia* Willd. were involved in the pedigree (Black, 1952) (Table 1), which could be the result of selections for later budbreak throughout the generations.

Clones that had shown the lowest CR values generally had the highest variation in year-to-year CR estimations (coefficients of variation of the means, Table 1). This variation could indicate that accumulation of CU, as defined in this study, is not the only factor responsible for the release of bud dormancy in these cultivars. Variation of cultivars in adapting to subtropical conditions is correlated with and generally expressed in relation to the CU accumulation during the dormancy season. However, the CR values we obtained cannot be directly compared with them. For instance, 'Dorsett Golden' and 'Ein Shemer' are known to behave normally with 250 to 450 h of chilling (Miller and Baker, 1982). Nevertheless, they have shown termination of bud dormancy under our conditions only after 814 ± 99 and 986 ± 76 CU accumulation, relatively close to the values observed for cultivars that do not behave well under subtropical conditions. Furthermore, one group of cultivars, including 'Coast' (1037 ± 94 CU), 'Fuji' (1077 ± 74 CU), 'Gala' (1064 ± 61 CU), 'Granny Smith' (1049 ± 150 CU), 'Hume' (1035 CU), 'Melrose' (1063 ± 50 CU), and 'Winter Banana' (1088 ± 79 CU), could not be distinguished, in terms of their CR, from a second group of cultivars, including 'Delicious' (1093 ± 108 CU), 'Golden Delicious' (1049 ± 150 CU), 'McIntosh' (1086 ± 44 CU), and others. This first group has been reported to have superior adaptation to mild winter conditions (Black, 1952; Chandler and Brown, 1957; Hill and Campbell, 1949; Miller and Baker, 1982; Ruck, 1975). In addition, cultivars such as 'Anoka' (1137 ± 49 CU), 'Beverly Hills' (1152 ± 45 CU), 'Yellow Newtown' (1216 ± 79 CU), and 'Wolf River' (1217 CU), which also behave better under subtropical conditions (Boyton, 1959; Chandler and Brown, 1957; Overcash and Murphy, 1959; Ruck, 1975), have even shown some tendency to have a longer bud dormancy period.

Table 1. Estimated CU accumulation required (i.e., CR) to break bud dormancy in apple cultivars and related *Malus* spp. in three seasons.

Cultivar/species	1984-85 Season ^z	1985-86 Season ^y	1986-87 Season ^y	Mean $\pm$ SD	CV ^x
Anna	280	287	88	218 $\pm$ 113	51.72
Anoka	1102		1172	1137 $\pm$ 49	4.35
Arkad Zimnji	1062	1110	1231	1134 $\pm$ 87	7.68
Beverly Hills	1185	1100	1170	1152 $\pm$ 45	3.94
Blairmont	1130	1051	1065	1082 $\pm$ 42	3.90
Chihuahua Gold	1195		1118	1156 $\pm$ 54	4.70
Coast		971	1104	1037 $\pm$ 94	9.06
Delicious	1031	1031	1218	1093 $\pm$ 108	9.88
Dorsett Golden	719	916	806	814 $\pm$ 99	12.13
Early McIntosh	1111	1143	1292	1182 $\pm$ 97	8.17
Ein Shemer	1039	895	1024	986 $\pm$ 79	8.03
Elstar	1017	1071	992	1027 $\pm$ 40	3.93
Empire	1108	1055	1073	1079 $\pm$ 27	2.50
Fuji	1152	1003	1077	1077 $\pm$ 74	6.92
Gala	1104	994	1094	1064 $\pm$ 61	5.71
Golden Delicious	1037	1046	1066	1050 $\pm$ 15	1.41
Governor Carr	795	848	1059	901 $\pm$ 140	15.51
Granny Smith	1078	886	1183	1049 $\pm$ 151	14.36
Honeygold	1032	996	1026	1018 $\pm$ 19	1.90
Hyslop	1018	1088	955	1020 $\pm$ 66	6.52
Idared	1100	941	1011	1017 $\pm$ 80	7.83
Ikorocavka Alaja	1045	897	1114	1019 $\pm$ 111	10.89
Joan	1004	892	1106	1001 $\pm$ 107	10.69
June Wealthy	881	915	1138	978 $\pm$ 140	14.27
Kerr	880	947	931	919 $\pm$ 35	3.81
Khashabi	711	678		694 $\pm$ 23	3.35
King Kole	874	978	1029	960 $\pm$ 79	8.23
Koningszuur	1480	1551	1328	1453 $\pm$ 119	7.84
Lennoxville	731	853		792 $\pm$ 86	10.90
Leyda	1022	813	1191	1009 $\pm$ 189	18.78
Liberty	1016	1034	1108	1053 $\pm$ 49	4.64
<i>M. baccata</i> Ge24408	1027	1021	903	984 $\pm$ 70	7.11
<i>M. baccata</i> Ge24911	843	823	1067	911 $\pm$ 135	14.87
<i>M. baccata</i> DE#98	1080	878	1075	1011 $\pm$ 115	11.39
<i>M. baccata</i> PI 392301	1172	769	776	906 $\pm$ 231	25.47
<i>M. baccata columnaris</i>	774	917	856	849 $\pm$ 71	8.46
<i>M. baccata</i> 'Nertschinsk'	731	859	856	815 $\pm$ 73	8.97
<i>M. brevipes</i>	0	627	585	404 $\pm$ 350	86.76
<i>M. baccata mandshurica</i>	794	900	1045	913 $\pm$ 126	13.80
<i>M. prunifolia</i> DE#229	875	1206	1185	1089 $\pm$ 185	17.02
<i>M. prunifolia</i> 'Sikora I'	981	908	976	955 $\pm$ 41	4.27
<i>M. prunifolia xanthocarpa</i>	787	1012	999	933 $\pm$ 126	13.54
<i>M. prunifolia rinkii</i>	1122	1101	1159	1127 $\pm$ 29	2.61
<i>M. rockii</i>	0	696	1032	526 $\pm$ 526	91.39
<i>M. spectabilis</i>	0	707	735	481 $\pm$ 416	86.64
<i>M. sylvestris</i> PI 392302	914	735	893	847 $\pm$ 99	11.54
<i>M. x arnoldiana</i>	1003	942	816	920 $\pm$ 95	10.37
<i>M. x magdeburgensis</i>		733	664	698 $\pm$ 49	6.99
<i>M. x robusta</i> DE#485	1048	877	951	959 $\pm$ 86	8.95
<i>M. x robusta</i> 'Korea'	895	1016	903	938 $\pm$ 68	7.22
<i>M. x robusta</i> 'R5'	712	860	927	833 $\pm$ 110	13.21
<i>M. x scheideckeri</i>	979	496	900	792 $\pm$ 259	32.73
<i>M. yunnanensis</i> 'Vilmorin'	1167	1185	1119	1157 $\pm$ 34	2.95
<i>M. zumi calocarpa</i>	1136	952	893	994 $\pm$ 127	12.75
Maribor	1151	1014	1037	1067 $\pm$ 73	6.88
McIntosh	1118		1055	1086 $\pm$ 44	4.10
Medina	1024	958	1013	998 $\pm$ 35	3.55
Melrose		1028	1099	1063 $\pm$ 50	4.72
Minkler		959	1035	997 $\pm$ 53	5.39
N.H. 9		1034	1162	1098 $\pm$ 90	8.24
N.J. 88		1018	1007	1012 $\pm$ 8	0.77
Northern Spy	1189	1284	1212	1228 $\pm$ 50	4.04
NY 330	1066	1003		1034 $\pm$ 44	4.30
NY 454	982	1010	985	992 $\pm$ 15	1.55

(continued)

Table 1. (continued)

Cultivar/species	1984-85 Season ^z	1985-86 Season ^y	1986-87 Season ^y	Mean $\pm$ SD	CV ^x
NY 480	1072	1137	1110	1106 $\pm$ 33	2.96
NY 485	1096	1014	1027	1046 $\pm$ 44	4.22
NY 506	1071	1058	1131	1087 $\pm$ 39	3.58
NY 543	1063	1154	1116	1111 $\pm$ 46	4.11
NY 615	1063	1102	1156	1107 $\pm$ 47	4.22
NY 701	1102	1136	1097	1112 $\pm$ 21	1.91
NY 702	1160	1164	1188	1171 $\pm$ 15	1.29
NY 724	936	882	955	924 $\pm$ 38	4.10
NY 725		919	1156	1037 $\pm$ 168	16.15
Ottawa 7	855	880	828	854 $\pm$ 26	3.04
Prima	1168	945	1103	1072 $\pm$ 115	10.70
Priscilla	1078	1059	1033	1057 $\pm$ 23	2.14
Rome Beauty			1163		
Rosedale	601	813	790	735 $\pm$ 116	15.83
Rozovoe		1128	1092	1110 $\pm$ 25	2.30
Starkspur Golden Delicious	1145		1185	1165 $\pm$ 28	2.43
Toba	1144	1167	1270	1194 $\pm$ 67	5.62
Transcendent	870	918	891	893 $\pm$ 24	2.70
Vienna		829	1002	915 $\pm$ 122	13.36
Winter Banana	1014	1078	1172	1088 $\pm$ 79	7.31
Wright #1	1496	1651	1431	1526 $\pm$ 113	7.40
Yellow Newtown	1163		1275	1219 $\pm$ 79	6.50
Zabaoani	802	654	1051	836 $\pm$ 201	24.00

^zCR for buds to achieve 1.5 mean developmental stage after 21 days of forcing (Eggert, 1951).

^yCR for D50 at the 15th day of forcing (Eggert, 1951).

^xCoefficient of variation of the mean.

Mild winter conditions are characterized not only by a shorter period of time at low temperature, but also by wide temperature fluctuations during the dormancy season. This situation suggests that there are important interactions among cultivars and environmental factors other than CU accumulation alone that are responsible for terminating bud dormancy. Differences could relate to specific cultivar response in relation to the stimulation and negation effects of temperatures that by themselves do not have a known dormancy-breaking effect (Couvillon and Erez, 1985; Samish and Lavee, 1962). Some of the known "low-chilling" cultivars definitively have both pattern and depth of bud dormancy different from those of standard apple cultivars (Hauagge and Cummins, 1991b). Consequently, it is difficult to develop a universal model to accurately describe the development and termination of bud dormancy for various genotypes growing under diverse environments. Such a model might be developed, however, for individual cultivars or groups of cultivars having similar characteristics.

Interaction between the efficiency of constant temperature (6, 9, 12, and 15°C) on dormancy termination and the cultivars Beverly Hills, Gala, and Golden Delicious could not be detected (Table 3).

Phenotypic variation for the length of bud dormancy in plants overwintering under an alternating-temperature regime. CU accumulated during dormancy induction treatment and before leaf fall was not taken into consideration in the CU calculations. This did not affect the expected behavior of grafted plants that were chilled at 6 ± 1 °C for various periods. Chilling treatments started just after the dormancy induction treatment (Fig. 2).

An interval of 177 days between the first and the last cultivar to show budbreak was observed when they were overwintered under an alternating-temperature regime. Although 1380 and 1010 CU were accumulated for the 1986 and 1987 experiments, respectively, dormancy was not completely bro-

ken in the standard apple cultivars, as shown by the values for "degree of adaptation" (Table 4). These observations again indicate the importance of factors other than chilling (Shaltout and Unrath, 1983) on the termination of apple bud dormancy under subtropical conditions. There was no further accumulation of CU after GDH reached 15,000 and 8000 units in 1986 and 1987, respectively. GDH accumulated on an average rate of 300 GDH/day thereafter. Fewer CU accumulated in 1987 (1010 CU), but budbreak was relatively faster and better than in 1986 (1380 CU). Wide differences for dormancy periods occurred among the tested genotypes (Table 4). Only genotypes in which budbreak occurred around 12,000 GDH or earlier in 1986 had a reasonable adaptation to the simulated subtropical environment.

The order of budbreak and of blossoming is directly related to the CR of the genotypes in conditions where chilling is a limiting factor (Chandler and Brown, 1957; Lesley, 1944; Miller and Baker, 1982; Oppenheimer, 1962; Samish and Lavee, 1962). This relationship remains constant from year to year and is less visible when the amount of chilling accumulated is considerably larger than the needs of the cultivar. Based on this pattern, determination of CR under field conditions in locations that have mild winters is made by comparing budbreak or bloom dates with known standards (Miller and Baker, 1982). Indeed, cultivar GDH values that accumulated from leaf fall until the time of budbreak under alternating temperatures were closely related to CR determined in subtropical conditions (Miller and Baker, 1982) (Fig. 3). GDH is also linearly related to the degree of adaptation (Fig. 4), which is an index based on the intensity of delayed foliation symptoms shown by the plant after budbreak. Both observations reinforce the value of the method for evaluating apple germplasm for adaptation to subtropical environments.

In spite of the considerable differences between the behavior of some apple cultivars in relation to the length of bud dormancy

Table 2. Estimated CU accumulation required (i.e., CR) to break bud dormancy in apple cultivars and related *Malus* spp. sampled in the 1984–85 season only.²

Cultivar/species	CR
Almey	842
Beacon	1122
Bellefleur Record	1145
Britemac	1129
Chestnut Crab	838
Columbia Crab	890
Cowichan	1044
Democrat	1066
Dolgo	966
Edgar	1127
Freedom	1213
Gloster	1119
Golden Gem	998
Gravenstein	1118
Hume	1035
Jerseymac	1120
Jonalicious	1174
Jonamac	1133
Kendall Kitaika	828
Lemoine	1112
Malling 7	1151
Malling 9	1026
<i>M. baccata costata</i>	1102
<i>M. bracteata</i>	1125
<i>M. florentina</i>	1059
<i>M. floribunda</i>	830
<i>M. fusca</i> cv. F2	1193
<i>M. glabrata</i>	1163
<i>M. glaucescens</i> DE#162	1117
<i>M. halliana</i>	1066
<i>M. ioensis</i>	1197
<i>M. prunifolia dulcis</i>	846
<i>M. pumila niedzwetzkyana</i>	1266
<i>M. sieboldii</i>	1144
<i>M. sikkimensis</i>	1049
<i>M. × atrosanguinea</i>	1029
Macfree	1210
Marin Oufroy	1423
McLicious	1090
Melba	1099
Midget Ge181544	1213
Midget Ge24618	1172
Milton	1160
Minjon	1290
Minn. 1527	1153
Minnehaha	1110
Malling-Merton 106	1246
Malling-Merton 111	1419
Morden 357	1049
Newtosh	1153
Nova Easygro	849
NoVole	938
NY 330	1066
NY 380	1140
NY 394	1045
NY 433	1082
NY 473	1123
NY 488	1140
NY 537	1059
NY 614	1114
NY 644	1142
NY 651	1167
NY 652	1143
NY 657	1149
NY 667	1119

(continued)

Table 2. (continued)

Cultivar/species	CR
NY 680	1120
NY 62315-4	1165
NY 62316-34	1183
NY 72703-10	1321
NY 72709-7	1161
NY 72711-111	1235
NY 72732-112	1269
NY 72732-32	1054
NY 72741-189	1164
NY 73732-85	1216
Oporto	1123
Orleans	1075
Ottawa 292	827
Quinte	1061
Red Crimson Beauty	962
Red Ralls	1185
Redford	1054
Redfree	1148
Shear N°1	1464
Spartan	1117
Summerred	999
Tasty	1020
Tayeshnoe	1197
Viking	1082
Vista Bella	968
Wabiskaw	819
Wealthy	1169
Wellington	965
White Angel	892
Wolf River	1217

²CR for buds to achieve the 1.5 developmental stage after 21 days of forcing (Hauagge and Cummins, 1991a).

Table 3. Analysis of variance table for the effect of four constant overwintering temperatures (6, 9, 12, and 15°C) on the break of bud dormancy of the apple cultivars Beverly Hills, Gala, and Golden Delicious. Bud dormancy intensity was assessed by the I_{50} index.

Source	df	Mean square	F value
Cultivar	2	2781.20	1.33 ^{NS}
Temperature	3	12557.82	6.01***
Hours	4	77186.04	36.79***
Cultivar × temperature	6	1393.98	0.66 ^{NS}
Experimental error	177	2098.00	

¹ I_{50} dormancy index value was equal to 50 if budbreak occurred in the first day of forcing, and then it decreased by 1 for every subsequent day.

^{NS},***Nonsignificant or significant at $P = 0.001$, respectively.

in cold climates and adaptation to subtropical conditions, the two responses are related, in general terms (Fig. 5). However, the deviations were persistent.

In general terms, CR values for the cultivars in both years were similar, but some genotypes seemed to be markedly advanced ('Beverly Hills', 'Davilla Spur Red Delicious', 'Governor Car', 'Hume', *M. baccata* Ge24408, *M. baccata* DE#98, 'Transcendent') or delayed (Goldsmith PI319847 and *M. spectabilis*) in the order of budbreak in the 1985–86 experiment. This inconsistency could be related to the unequal susceptibility of the various cultivars to small differences in the temperature regimes of both years.

Several selections (502/1/A, 504/1/A, 7-11-B), cultivars ('Dorsett Golden', 'Elah', 'Ein Shemer', 'Khashabi', 'Maayan', 'Michal', 'Succari'), and species (*M. brevipes*, *M. rockii*, *M.*

Fig. 2. Degree of adaptation of apple cultivars and interspecific hybrids having different CR after chilling them at $6 \pm 1^\circ\text{C}$ and 12°C light for various periods of time and forcing them for 21 days at $22 \pm 1^\circ\text{C}$ and 16 h light. Means of eight 1-year-old grafted plants. Bars equal to SD of the mean.

spectabilis, *M. turesii* 34143) demonstrated very good adaptation in both years. The cited species seem to be less affected by oscillating-temperature regimes than *M. baccata* and some of its hybrids (*M. baccata* Ge24715, *M. baccata* Ge14408, *M. x robusta* (Carr.) Rehd. Ge24707, and 'Rosedale'). Some clones of these species and hybrids are known to do well in subtropical climates (Chandler and Brown, 1957; Popenoe and Benítez, 1965). Some other "domestic" types (3-11-B, 'Beverly Hills', 'Davilla Spur Golden Delicious', 'Governor Carr', 'Goldsmith', 'Granny Smith', 'Huerto los Gruellos', 'Hume', 'Wainweight', 'Wermeshock', and 'Winter Banana') have a considerably lower CR than 'Golden Delicious' and 'Gala' or the very high-CR cultivars ('Koningszuur' and 'Marin Oufroy'). 'Succari' may have been one of the parents used by Oppenheimer (1962) in his apple breeding program. 'Wermeshock' is involved in the pedigree of 'Drakstein', a cultivar that does well under 400 h chilling in South Africa (Hurter, 1981). 'Davilla Spur Golden Delicious' also performs well in Florida (Miller and Baker, 1982); this may be a 'Golden Delicious' somatic mutation. It is interesting to note that although 'Golden Delicious' and 'Gala' did not differ very much in relation to the time for budbreak, 'Gala' had considerably better lateral budbreak developing somewhat later, starting at the base of the plant.

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Table 4. Length of bud dormancy period of apple cultivars and related *Malus* spp. estimated by GDH accumulated from leaf fall until the time of budbreak. Plants were overwintered under an alternating temperature regime ($5 \pm 2^\circ\text{C}$ for 10 h/14 $\pm 2^\circ\text{C}$ for 14 h). Chilling accumulation was 1380 and 1010 CU for the 1986 and 1987 experiments, respectively.

Cultivar/species	Degree of adaption ² $\pm$ SD	GDH $\pm$ SD (thousands)	
		1986	1987
3-11-B PI 483262	2.75 $\pm$ 1.04	15.6 $\pm$ 5.2	12.6 $\pm$ 3.3
502/1/A PI 483260	4.88 $\pm$ 0.16	8.2 $\pm$ 0.7	
504/1/A PI 483265	4.48 $\pm$ 0.29	7.1 $\pm$ 1.8	6.0 $\pm$ 0.8
7-11-B PI 483261	4.25 $\pm$ 0.35	6.1 $\pm$ 2.7	4.9 $\pm$ 0.3
Anna	4.55 $\pm$ 0.52	4.3 $\pm$ 1.8	4.7 $\pm$ 1.6
Beverly Hills	1.81 $\pm$ 1.25	23.4 $\pm$ 2.3	11.4 $\pm$ 2.1
Coast	3.00 $\pm$ 0.49	13.5 $\pm$ 1.1	9.2 $\pm$ 0.8
Davilla Spur Golden Delicious	2.76 $\pm$ 0.43	13.3 $\pm$ 2.7	10.2 $\pm$ 1.0
Davilla Spur Red Delicious	0.40 $\pm$ 0.89	26.6 $\pm$ 1.2	14.4 $\pm$ 2.8
Dorsett Golden	4.60 $\pm$ 0.47	6.1 $\pm$ 1.6	5.0 $\pm$ 0.5
Ein Shemer	3.99 $\pm$ 0.04	8.9 $\pm$ 2.6	9.2 $\pm$ 1.3
Elah	4.33 $\pm$ 0.83	8.0 $\pm$ 0.6	8.9 $\pm$ 2.0
Gala	0.60 $\pm$ 0.76	25.6 $\pm$ 4.4	19.8 $\pm$ 3.5
Golden Delicious	0.77 $\pm$ 0.72	24.5 $\pm$ 1.5	19.1 $\pm$ 3.0
Goldsmith	4.02 $\pm$ 0.87	11.9 $\pm$ 6.8	16.2 $\pm$ 1.2
Governor Carr	1.32 $\pm$ 0.71	20.4 $\pm$ 3.1	11.4 $\pm$ 2.5
Granny Smith	2.02 $\pm$ 1.10	13.1 $\pm$ 4.1	13.0 $\pm$ 2.2
Huerto los Gruellos	2.17 $\pm$ 0.90	15.5 $\pm$ 5.5	12.7 $\pm$ 4.3
Hume	2.25 $\pm$ 1.66	19.8 $\pm$ 4.3	9.0 $\pm$ 0.3
Khashabi	3.94 $\pm$ 0.30	5.2 $\pm$ 0.8	4.4 $\pm$ 0.4
Koningszuur	0.08 $\pm$ 0.20	28.1 $\pm$ 5.6	29.1 $\pm$ 4.4
Legana	0.50 $\pm$ 1.00	21.8 $\pm$ 6.8	18.2 $\pm$ 5.6
<i>M. baccata</i> Ge24408	0.33 $\pm$ 0.47	27.4 $\pm$ 5.3	11.7 $\pm$ 3.5
<i>M. baccata</i> DE#98	1.63 $\pm$ 0.92	21.4 $\pm$ 2.5	8.9 $\pm$ 1.6
<i>M. brevipes</i>	3.72 $\pm$ 0.83	10.2 $\pm$ 0.9	5.8 $\pm$ 1.1
<i>M. rockii</i>	5.00 $\pm$ 0.00	11.6 $\pm$ 1.3	7.2 $\pm$ 1.1
<i>M. spectabilis</i>	3.75 $\pm$ 1.06	3.9 $\pm$ 0	5.2 $\pm$ 0.2
<i>M. turesii</i> 34143	3.53 $\pm$ 0.56	10.0 $\pm$ 1.4	6.9 $\pm$ 1.3
<i>M. x robusta</i> DE#485	2.46 $\pm$ 1.22	16.4 $\pm$ 4.1	11.6 $\pm$ 1.4
Maayan	4.71 $\pm$ 0.62	10.4 $\pm$ 1.3	7.9 $\pm$ 0.5
Marin Oufroy	0.18 $\pm$ 0.22	25.6 $\pm$ 3.8	21.4 $\pm$ 1.1
Michal	4.24 $\pm$ 0.44	10.5 $\pm$ 2.8	8.9 $\pm$ 1.0
Rockwood	0.84 $\pm$ 0.55	19.1 $\pm$ 7.4	12.9 $\pm$ 3.7
Rosedale	2.89 $\pm$ 0.67	17.9 $\pm$ 4.3	13.0 $\pm$ 2.4
Shlomit	4.68 $\pm$ 0.6	10.4 $\pm$ 0.7	6.9 $\pm$ 1.1
Succari	3.53 $\pm$ 0.43	6.9 $\pm$ 0.6	6.2 $\pm$ 0.3
Transcendent	2.47 $\pm$ 1.26	18.0 $\pm$ 4.3	7.8 $\pm$ 0.6
Wainweight	3.08 $\pm$ 0.6	11.2 $\pm$ 1.3	8.5 $\pm$ 0.9
Wermeshock	3.17 $\pm$ 0.72	12.8 $\pm$ 2.4	10.3 $\pm$ 2.3
Winter Banana	2.52 $\pm$ 0.23	14.2 $\pm$ 1.2	10.2 $\pm$ 3.2

²Degree of adaptation was estimated on 2 June 1986. Values varied between 0 (least adapted) and 5 (most adapted).

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Fig. 3. Relationship between CU required for normal foliation and bloom in apple cultivars growing in Florida (after Miller and Baker, 1982) and GDH accumulated until the time of budbreak under an alternating-temperature regime.

Fig. 4. Relationship between GDH accumulation until the time of budbreak and degree of adaptation (0 = least adapted, 5 = most adapted) of apple cultivars and related *Malus* spp. Plants were overwintered under an alternating-temperature regime.

Fig. 5. Relationship between the apple genotype mean CU required to terminate bud dormancy (1984–85, 1985–86, and 1986–87 seasons) and the mean GDH accumulated until budbreak under an alternating-temperature regime (1986 and 1987).

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