

# Regional differences in performance of Canadian-bred apple cultivars and implications for breeding

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Hampson, C. R., McNew, R., Cline, J., Embree, C., Zandstra, J. and Wilson, K. 2009. **Regional differences in performance of Canadian-bred apple cultivars and implications for breeding.** Can. J. Plant Sci. **89**: 81–91. To evaluate their commercial potential in several major production regions of Canada, 10 Canadian breeding selections and two standard cultivars of apple (*Malus × domestica* Borkh.) were planted at four locations: one in British Columbia, two in Ontario and one in Nova Scotia. Subsidiary objectives of the trial were to determine whether wider testing of promising apple selections was warranted, and to accumulate information to help guide breeders in selecting apples for widespread adaptation. At each site the planting was arranged in a randomized complete block design with eight replicates. Individual trees were the unit of replication. Data were collected for 7 yr (5 cropping years). The measures of orchard performance recorded were: tree survival, trunk-cross sectional area, final tree height and canopy spread, precocity, times of bloom and harvest, yield, yield efficiency, and average fruit size. The effects of location, genotype and genotype × location interaction were statistically significant for all response variables. The two standard cultivars, Royal Gala and Summerland McIntosh, were intermediate to high in precocity, tree vigour, yield and fruit size. No single cultivar was superior in these characteristics at all locations. Among the test selections, S23-06-153 and 8S-27-43 had the most consistently good performance with regard to tree survival, tree vigour, yield, yield efficiency, pre-harvest fruit drop and fruit size. 8S6923 (Aurora Golden Gala™) and Silken also performed well, except that fruit size was smaller in eastern Canada. Many of the selections took fewer days to reach maturity in Nova Scotia and Ontario than they did in British Columbia. The results obtained suggest that regional testing is highly desirable for characteristics such as tree survival, yield, pre-harvest drop and climatic suitability (e.g. dates of bloom and harvest), all of which profoundly affect the commercial desirability of the cultivar. If the present results can be generalized, breeding and selection of new genotypes at one location are probably adequate for tree vigour, relative order of bloom and harvest, and precocity, despite the genotype × environment interaction demonstrated. For these characteristics, the modest changes in rank among cultivars from location to location do not have great practical or economic consequences. Selection at one location may also be effective for fruit size and percentage of over colour, if the breeder takes location effects into account (smaller fruit in Ontario and Nova Scotia, less colour on early-harvest apples in British Columbia).

**Key words:** Fruit breeding, cultivar testing

Hampson, C. R., McNew, R., Cline, J., Embree, C., Zandstra, J. et Wilson, K. 2009. **Variation régionale du rendement des cultivars canadiens de pommier et implications eu égard à leur amélioration.** Can. J. Plant Sci. **89**: 81–91. Les auteurs ont planté dix sélections canadiennes et deux cultivars ordinaires de pommier (*Malus x domestica* Borkh.) à quatre endroits (1 en Colombie-Britannique, 2 en Ontario et 1 en Nouvelle-Écosse) en vue d'en évaluer le potentiel commercial dans plusieurs grandes régions productrices du Canada. Les objectifs secondaires étaient d'établir s'il vaudrait la peine d'élargir les essais sur les sélections prometteuses et de glaner plus d'informations afin d'aider les améliorateurs à choisir des pommiers qui s'acclimateront mieux. Les arbres ont été plantés en blocs totalement aléatoires à chaque endroit, avec huit répétitions. Un pommier constituait l'unité de réplication. Les données ont été recueillies pendant 7 ans (5 saisons culturales). Pour déterminer le rendement du verger, les auteurs ont mesuré le taux de survie des arbres, la surface transversale du tronc, la hauteur finale de l'arbre et l'envergure de la frondaison, la précocité, le moment de la floraison et de la récolte, le rendement, l'efficacité du rendement et le calibre moyen des fruits. Les effets de l'emplacement, du génotype et de l'interaction génotype x emplacement sont statistiquement significatifs pour toutes les variables-réactions. Les deux cultivars ordinaires, Royal Gala et Summerland McIntosh, se caractérisent par une précocité, une vigueur et un rendement intermédiaires à élevés, comme c'est le cas du calibre des fruits. Aucun cultivar n'a dépassé les autres à tous les endroits

**Abbreviations:** CS, Cedar Springs; KE, Kentville; SM, Simcoe; SSC, soluble solids content; SU, Summerland; TCSA, trunk cross-sectional area

pour ces caractéristiques. Parmi les sélections, S23-06-153 et 8S-27-43 ont toujours donné une bonne performance eu égard au taux de survie des arbres, à la vigueur des arbres, au rendement, à l'efficacité du rendement, à la chute prématurée des fruits et au calibre des fruits. Les sélections 8S6923 (Aurora Golden Gala<sup>MC</sup>) et Silken ont également donné de bons résultats, si ce n'est que leurs fruits étaient plus petits dans l'est du Canada. Beaucoup de sélections sont parvenues plus rapidement à maturité en Nouvelle-Écosse et en Ontario qu'en Colombie-Britannique. Ces résultats laissent croire qu'il serait bon d'effectuer des essais régionaux pour vérifier les caractères, tels la survie des arbres, le rendement, la chute prématurée des fruits et la convenance du climat (à savoir les dates de floraison et de récolte), qui affectent considérablement la valeur commerciale du cultivar. Si l'on peut généraliser les résultats de l'étude, l'amélioration et la sélection de nouveaux génotypes à un seul endroit convient sans doute pour la vigueur des arbres, l'ordre relatif au niveau de la floraison et de la récolte, et la précocité, en dépit d'une interaction évidente entre le génotype et l'environnement. Pour ces caractéristiques, les modestes variations de classement entre les cultivars, d'un endroit à l'autre, ne présentent pas de grandes conséquences pratiques ni économiques. La sélection à un seul endroit pourrait aussi avoir son utilité pour le calibre des fruits et l'intensité de la pigmentation rouge lorsque l'améliorateur prend en compte les effets de l'emplacement (fruits plus petits en Ontario et en Nouvelle-Écosse, fruits hâtifs moins colorés en Colombie-Britannique).

**Mots clés:** Amélioration des arbres fruitiers, essais de cultivar

Apple (*Malus × domestica* Borkh.) is the most widely grown tree fruit in Canada, worth \$127 272 000 in 2005 (Statistics Canada 2006) with most of the commercial plantings in Ontario, British Columbia, Nova Scotia and Quebec. Tree fruit producers in all provinces are interested in diversifying varietal assortment in order to capture consumer demand for novel and exciting varieties (e.g., Honeycrisp and Ambrosia). Some apple cultivars, such as Golden Delicious, seem to have widespread adaptation in the world, while others, like Honeycrisp or McIntosh, perform well only in a restricted range of climates (Crassweller et al. 2005). While a given variety will have a characteristic fruit texture and flavour, many aspects of adaptation that are important to commercial success have been inconsistent from location to location in previous continent-wide trials (Miller et al. 2004, 2005, 2007; Crassweller et al. 2005, 2007). Because of the high costs of replanting an orchard, choosing a poorly performing apple cultivar is a costly mistake for a grower. Unlike peaches or bananas, apples are sold in the market by cultivar, and hence demand is cultivar-specific.

Unlike field crop breeders, Canadian tree fruit breeders have no organized regional testing prior to commercial release because of the high costs of such trials. Growers are understandably reluctant to plant a new cultivar that has not been tested for adaptation in their region. Our immediate objective was to test the horticultural performance and adaptation of promising apple selections from Agriculture and Agri-Food Canada breeding programs in Kentville, Nova Scotia, and Summerland, British Columbia, in locations representing the major apple-producing regions of Canada. The selections were evaluated specifically for possible commercial use at each location. Our broader objectives were to obtain information useful to breeders for guiding selection, and to demonstrate whether regional testing of promising tree fruit selections within Canada is warranted.

## MATERIALS AND METHODS

### Plant Material

Ten test selections were chosen for the trial based on the suggestions of H. Quamme (Summerland, BC) and C. Deslauriers (Kentville, NS), the apple breeding program leaders in 1996. The selections and their parentages were: 8NE-07-72 (Maigold × Splendour); 8S-26-50, 8S-27-73, 8S6923 and Chinook [all with parentage Splendour × Gala (Kidd's D.8 strain)]; S14-15-72 [(Mother × Rome Beauty) × Scotia]; S23-06-153 {Julyred × [(Melba × (Wealthy × Star)) × NJ12]}; S43-43-79 (Ohlsen open-pollinated × Nova Easygro); S47-23-100 [(Cortland × JerseyMac) × (NJ25 × S80ER16T50)]; Silken (Honeygold × Sunrise). Cultivar descriptions are available for 8S6923 (Hampson et al. 2005), Chinook (Quamme et al. 1999a) and Silken (Quamme et al. 1999b). Information from the breeders indicated that 8S6923 and Silken were yellow-skinned; selection S23-06-153 had a 40% rosy pink blush over yellow, and S43-43-79 had 10–20% orange blush over yellow; the others were all predominantly red over a yellow or green ground colour. Selections S43-43-79 and S47-23-100 were the only scab-resistant selections, but 8S-26-50 was resistant to fire blight. Harvest period ranged from early September to late October. The comparators were McIntosh (Summerland strain), whose parentage is unknown, and Gala (Royal strain) whose parentage is Kidd's Orange Red × Golden Delicious. All trees were budded in August 1997 at Misty Meadows Nursery (Cloverdale, BC) by staff from the Pacific Agri-Food Research Centre (PARC), Summerland on virus-free Budagovsky 9 (B.9) rootstock.

### Planting Sites

One-year-old whip trees were planted at five locations in the spring of 1999. The sites were Summerland (BC), Cedar Springs (ON), Clarksburg (ON), Simcoe (ON) and Kentville (NS). The Ontario locations were chosen to represent different climatic regions in that province.

The Clarksburg location later discontinued the trial due to a change in employment of the cooperator at that location. We were unable to secure a collaborator in Quebec.

#### *Cedar Springs (CS)*

The trees were planted at the Ridgetown Campus of the University of Guelph. The soil was a Fox gravelly loam (47.8% sand; 38.1% silt; 14.1% clay) and was not fumigated prior to planting. The area had been in grass for the previous 10 yr. Prior to planting the soil was treated with glyphosate (3 L ha<sup>-1</sup>). The trees were drip-irrigated.

#### *Simcoe (SM)*

The trees were planted at the Horticultural Experiment Station at Simcoe. The soil was a Brady sandy loam (aquatic hapludalf) of mainly lacustrine sand and sandy loam. The area had been planted to apples previously but was fallow for several years prior to replanting. No fumigant was used and the trees were not irrigated.

#### *Kentville (KE)*

Trees were planted at the Agriculture and Agri-Food Canada research centre at Kentville, NS. The soil was a dark reddish brown, friable and well-drained sandy loam overlying a yellowish-red sandy loam. The field had previously been planted to a general hay mix and had not been cultivated for a number of years. It was not fumigated prior to planting.

#### *Summerland (SU)*

Trees were planted at the Agriculture and Agri-Food Canada research centre at Summerland, BC. The soil was a Naramata orthic brown sandy loam with coarse texture and low organic matter (Wittneben 1986). The area had previously been planted to grass and was fumigated in the autumn of 1998 with Vapam (Amvac Chemical Corp., Los Angeles, CA) at 657 L ha<sup>-1</sup>. Irrigation consisted of two drip emitters (0.5 m from the trunk on both sides) operating from April through September annually. The amount of water applied ranged from 24 L per tree per week in April to 112 L per tree per week in July (total application 1360 L per tree each season).

### **Planting Design and Cultural Care**

Each planting was a randomized complete block with eight blocks and 12 apple selections. Individual trees were the unit of replication. Guard trees were supplied by the individual cooperators. Spacing was 2.5 m in-row and 4.3 m between rows. A 1.8-m vegetation-free strip under the trees was maintained with herbicides, and the alleys were seeded to grass. The trees were supported with posts and trained as spindles. Pest control and fertilization regime followed provincial commercial recommendations in each area. The trees were dor-

mant-pruned annually but not summer-pruned. Trees were de-fruited in 1999 and 2000 to encourage the development of the tree structure. In subsequent years, fruit were thinned to a spacing of 15–20 cm, and singled to one fruit per spur (normally the king fruit).

### **Data Collection and Analysis**

Data collection followed the experimental protocols used in the USDA NE-183 regional research project (Greene et al. 2007), which are detailed in Crassweller et al. (2005, 2007) and Miller et al. (2004, 2007). The survival status of each tree was recorded annually after harvest as 0 = dead, 1 = alive, 2 = sick. The “sick” category was used for trees that were alive but their performance was severely compromised by disease. Trunk diameter or circumference was measured annually at 30 cm above the bud union and reported as trunk cross-sectional area (TCSA). The number of blossom clusters was counted in 2001 as a measure of precocity. Floral density (no. of flowers cm<sup>-2</sup> TCSA) was calculated to account for differences in tree size. From 2001 to 2005, the date of full bloom (defined as 90% of king flowers open) was recorded for each tree and the bloom was rated on a 0 to 5 scale, where 0 = no bloom, 1 = one or two blooms, 2 = more than a few blooms but not sufficient for a full crop, 3 = sufficient bloom for a full crop, 4 = more than sufficient bloom for a full crop, 5 = “snowball” bloom, tree covered with flowers (Crassweller et al. 2007). Maximum tree height and canopy spread (average of across-row and in-row measurements for the latter) were measured at the end of the experiment and the height:spread ratio was calculated for analysis.

Fruit maturity was monitored at each site and fruit were harvested when the starch index reached 4 to 6 on the eight-point Cornell University starch-iodine index chart (Blanpied and Silsby 1992). The date of harvest, number of days between full bloom and fruit picking (“days to maturity”), and fruit number were recorded. Average fruit weight was obtained by dividing the total weight of picked fruit by the number of fruit. Fruit that dropped prior to harvest were counted but not weighed, to obtain the percent fruit drop. Annual yields were summed to get cumulative yield. A sample of 10 fruit per cultivar was collected at harvest and the starch index (Blanpied and Silsby 1992) and flesh firmness (by penetrometer) were recorded. The percent soluble solids (measured by refractometer) and the percent red over-color (estimated visually to the nearest 10%) were recorded at some of the locations as optional data.

Variance was analyzed with a mixed linear model (procedure MIXED of SAS software) using the REML method to estimate variance components for random effects; degrees of freedom were calculated with the Satterthwaite option (SAS Institute, Inc., Cary NC). In the analysis, blocks and all interaction terms containing block were deemed random effects, and cultivar and location were fixed effects. For repeated measures (such

as average fruit weight), year and interaction terms with year were also deemed random effects. Our original intent was to perform stability analysis (Crassweller et al. 2005, 2007), but because of the small number of sites, the standard errors of the stability variance estimates were about as large as the estimates. Therefore, the SLICE procedure was used to test for equality of cultivars within sites (Littell et al. 1996, Marini et al. 2006). Generalized least-squares means for cultivar within location were separated using PDIFF (equivalent to multiple *t*-tests), which is the only option available with the MIXED procedure. No LSD can be given because the comparisons have different standard errors. "Sick" trees (status = 2) were excluded from the analysis.

## RESULTS AND DISCUSSION

### Tree Survival

In general, tree survival was good. Out of the 96 trees planted at each location, 95 survived in SU, 94 in SM, 93 in KE and 91 in CS. The cause of death could not be ascertained in most cases, but in KE, anthracnose (*Neofabrea* spp.) cankers were observed on some trees. The cultivar with the poorest survival was S43-43-79 (four trees lost over three sites), followed by 8NE-07-72 (three sites losing one tree each). In CS, a number of trees became sick starting in summer 2004. The symptoms were weak annual growth with small, pale leaves. One tree was dug up and the major roots appeared short and thickened. Death from crown rot [*Phytophthora cactorum* (Leb. and Cohn.) Schroet] or fire blight [*Erwinia amylovora* (Burr.) Winslow] was ruled out, but the cause was never identified. It did not appear to be cultivar-specific or spatially patterned, but by 2005, 40 trees were excluded from data analysis due to illness, including some of each cultivar. Because of fewer trees, the standard errors of estimates for CS are larger than at other sites in the data (Tables 1 to 9).

For all response variables analyzed with the MIXED procedure, the effects of location, selection and location  $\times$  selection interaction were significant ( $p \leq 0.05$ ), and therefore the following discussion will highlight commonalities and cultivar differences within sites.

### Tree Growth

Overall, trees were largest at SM and smallest at SU and CS, as estimated by TCSA (Table 1). Previous studies have confirmed that above-ground tree size is well-correlated with TCSA (Barden and Marini 2001; Hampson et al. 2004). Selection 8NE-07-72 ranked first and S43-43-79 ranked last for TCSA at all four locations. The standards, Gala and McIntosh did not differ significantly from each other in TCSA at any of the sites, and were moderate in vigour at all sites. Few of the other selections differed significantly from Gala or McIntosh, and when present, such differences were not consistent from location to location. A trend was

observed for 8S-26-50 and S14-15-72 to be among the least vigorous trees at two or more locations.

Tree height tended to be greatest in KE and SM and smallest in CS (Table 2). A severe hail storm damaged and broke trees at CS in 2001, setting back the planting a year. The range in tree heights was fairly narrow within each location. Gala and McIntosh did not differ significantly from each other at any site and were in the tallest group at all sites. S43-43-79 was shorter than Gala or McIntosh at SU, KE and SM, and Chinook, S14-15-72 and Silken were smaller than the standards at SM.

Canopy spread was widest in SM and narrowest in British Columbia overall (Table 3). The CS location did not rank last, confirming that the tree height difference observed (Table 2) was probably attributable to hail damage rather than climatic conditions. McIntosh trees had wider canopies than Gala trees at all locations but SU, and these two standards also tended to have among the widest canopies at most locations. In keeping with TCSA measurements, S43-43-79 had smaller canopies than McIntosh at all locations, and 8NE-07-72 was in the largest group for canopy size, except in CS. Selections 8S-26-50 and S14-15-72 were also smaller than the standards at two or more locations. Trees with smaller canopies can be planted at higher density to increase yield per unit area.

The height:spread ratio was also calculated and analyzed (data not shown). This ratio was not informative, but rather obscured the cultivar differences evident in the separate measurements of height and spread. None of the test selections differed from the two standards at KE and SM. At SU and CS, only one or two selections differed from the standards, but the selections in question were not the same at both sites.

Taken together, the data indicate that 8NE-07-72 was a vigorous cultivar, producing larger trees than Gala or McIntosh in several cases, while the opposite was true for S43-43-79, 8S-26-50 and S14-15-72. These latter selections may need a less dwarfing rootstock to produce vigour sufficient for commercial orchards. Trees of Chinook and 8S-26-50 were also among the least vigorous in the 1999 USDA NE-183 trial (Crassweller et al. 2007). Our Gala and McIntosh standards were of intermediate vigour with wide canopies, and most of the other selections were similar to these standards, although exceptions occurred at each site.

### Flowering

Floral density was recorded in 2001, the first year of cropping, as an estimate of earliness of bearing. Data were not collected at CS due to the hail storm mentioned previously. Earliness of bearing is of economic importance to growers, who require an early return on capital investment after replanting an orchard. Floral density was similar in SU and SM, but lower in KE for most selections (Table 4); presumably this phenomenon was related to environmental conditions because the measurement accounts for tree size differ-

**Table 1. Least-squares means and standard errors (SE) for trunk cross-sectional area (cm<sup>2</sup>) in 2005 for healthy trees of 12 apple clones at five locations**

Selection	Summerland, BC	Cedar Springs, ON	Kentville, NS	Simcoe, ON	Selection mean
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
8NE-07-72	20.6 ± 1.7a	23.4 ± 2.0a	22.5 ± 1.8a	35.1 ± 1.8a	30.0 ± 0.8
S23-06-153	16.0 ± 1.7bc	14.9 ± 2.3b	21.3 ± 1.7ab	24.4 ± 1.7b	21.6 ± 0.8
S47-23-100	15.5 ± 1.7bcd	12.7 ± 3.1b	17.0 ± 1.7cd	23.1 ± 1.7b	18.6 ± 0.9
8S6923	16.6 ± 1.7ab	15.8 ± 2.3b	16.7 ± 1.7cd	23.5 ± 1.7b	18.4 ± 0.8
Gala	15.4 ± 1.7bcd	14.8 ± 1.9b	17.3 ± 1.7bcd	18.1 ± 1.7c	17.6 ± 0.8
McIntosh	11.8 ± 1.7def	13.2 ± 2.0b	18.9 ± 1.7abc	17.9 ± 1.7cd	17.1 ± 0.8
Silken	16.3 ± 1.7b	13.9 ± 1.8b	16.9 ± 1.8cd	15.2 ± 1.7cd	16.0 ± 0.8
8S-27-43	13.0 ± 1.7bcde	12.4 ± 2.6b	15.5 ± 1.7cd	18.0 ± 1.7cd	15.3 ± 0.8
S14-15-72	11.9 ± 1.8cdef	13.6 ± 2.0b	14.5 ± 1.7de	16.2 ± 1.7cd	14.8 ± 0.8
Chinook	11.9 ± 1.7def	11.5 ± 2.3b	14.7 ± 1.7de	17.5 ± 1.7cd	14.1 ± 0.8
8S-26-50	10.2 ± 1.7ef	11.8 ± 2.3b	15.4 ± 1.8cd	13.9 ± 1.7de	13.5 ± 0.8
S43-43-79	7.8 ± 1.7f	8.3 ± 4.4b	11.1 ± 1.7e	10.1 ± 1.8e	9.7 ± 1.1
Location mean	13.9 ± 0.9	13.9 ± 1.0	16.8 ± 0.9	19.4 ± 0.9	

a-f Selection means within a location that are followed by the same letter are not significantly different according to the SAS procedure PDIF (equivalent to multiple t-tests at  $P \leq 0.05$ )

ences by dividing by TCSA. Simcoe had the greatest range in floral density among selections (20.4 clusters·cm<sup>2</sup> TCSA). Silken had among the highest floral density at all three locations, as it did in the USDA NE-183 trial (Crassweller et al. 2007). Again, the two comparators were intermediate at each site, and most of the test selections did not differ significantly from these standards. 8S-26-50 ranked last at SM and KE; it was also low in SU, but there it ranked ahead of 8S-27-43. 8S-26-50 was among the least floriferous selections in a previous trial in the United States of America (Crassweller et al. 2007). Other differences were inconsistent across the three sites.

Date of full king bloom (Table 5) was earliest in SU (average day 122 = May 02) and latest in KE (average day 150 = May 30), with the other two sites being about the same (day 141 = May 21). The SU data were skewed by getting 2 yr of record-setting early bloom during the

trial, as the 50-year average date of full bloom for McIntosh is May 10 at Summerland according to weather records (R. MacDonald, Agriculture and Agri-Food Canada, Summerland, unpublished data). Bloom was more compressed at KE and CS (range of 2 and 4 d, respectively) than at SU and SM (range of 6 to 7 d). The significant location × cultivar interaction indicated that cultivars varied inconsistently across sites, but there were some commonalities. The earliest cultivar to bloom at all locations was Silken, which bloomed significantly earlier than McIntosh (except at KE) and Gala. Other early-blooming genotypes were 8NE-07-72 and McIntosh. Bloom time is important for choosing appropriate pollinizers, and in some areas, early-blooming cultivars are at a greater risk for frost damage. However, no important bloom frosts occurred at any of the locations during this trial. Gala and S43-43-79 tended to bloom latest. McIntosh bloomed significantly

**Table 2. Least-squares means and standard errors (SE) for tree height (m) in 2005 of 12 apple clones at four locations**

Selection	Summerland, BC	Cedar Springs, ON	Kentville, NS	Simcoe, ON	Selection mean
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
8NE-07-72	2.49 ± 0.10ab	2.12 ± 0.12a	2.91 ± 0.11ab	3.05 ± 0.11a	2.64 ± 0.05
S47-23-100	2.39 ± 0.10abc	1.99 ± 0.20ab	3.06 ± 0.10a	3.04 ± 0.10a	2.62 ± 0.07
8S-27-43	2.49 ± 0.10a	2.10 ± 0.16ab	2.81 ± 0.10abc	2.88 ± 0.10ab	2.57 ± 0.06
Gala	2.46 ± 0.10ab	1.84 ± 0.11ab	2.94 ± 0.10ab	2.99 ± 0.10a	2.56 ± 0.05
S23-06-153	2.45 ± 0.10ab	1.91 ± 0.14ab	2.83 ± 0.10abc	2.89 ± 0.10ab	2.52 ± 0.06
McIntosh	2.44 ± 0.10ab	1.85 ± 0.12ab	2.84 ± 0.10abc	2.83 ± 0.10ab	2.49 ± 0.05
Silken	2.52 ± 0.10	2.03 ± 0.11ab	2.84 ± 0.11abc	2.53 ± 0.10c	2.48 ± 0.05
8S6923	2.43 ± 0.10a	1.86 ± 0.14ab	2.69 ± 0.10bc	2.72 ± 0.10bc	2.43 ± 0.06
Chinook	2.30 ± 0.10abc	1.75 ± 0.14b	2.84 ± 0.10abc	2.52 ± 0.10c	2.35 ± 0.06
8S-26-50	2.22 ± 0.10bc	1.88 ± 0.14ab	2.62 ± 0.11c	2.66 ± 0.10bc	2.34 ± 0.06
S14-15-72	2.27 ± 0.11abc	2.02 ± 0.12ab	2.61 ± 0.10c	2.46 ± 0.10c	2.34 ± 0.05
S43-43-79	2.13 ± 0.10c	2.00 ± 0.28ab	2.26 ± 0.10d	2.00 ± 0.11d	2.10 ± 0.08
Location mean	2.38 ± 0.03	1.95 ± 0.05	2.77 ± 0.03	2.71 ± 0.03	

a-c Selection means within a location that are followed by the same letter are not significantly different according to the SAS procedure PDIF (equivalent to multiple t-tests at  $P \leq 0.05$ )

**Table 3. Least-squares means and standard errors (SE) for canopy spread (m) in 2005 of 12 apple clones at four locations**

Selection	Summerland, BC	Cedar Springs, ON	Kentville, NS	Simcoe, ON	Selection mean
	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE
McIntosh	1.70 $\pm$ 0.09 <sup>ab</sup>	2.40 $\pm$ 0.11 <sup>a</sup>	2.11 $\pm$ 0.09 <sup>a</sup>	2.28 $\pm$ 0.09 <sup>abc</sup>	2.12 $\pm$ 0.05
8NE-07-72	1.83 $\pm$ 0.09 <sup>a</sup>	2.07 $\pm$ 0.11 <sup>b</sup>	1.97 $\pm$ 0.09 <sup>abc</sup>	2.49 $\pm$ 0.09 <sup>a</sup>	2.10 $\pm$ 0.05
S23-06-153	1.82 $\pm$ 0.09 <sup>a</sup>	2.09 $\pm$ 0.12 <sup>ab</sup>	1.97 $\pm$ 0.09 <sup>ab</sup>	2.39 $\pm$ 0.09 <sup>ab</sup>	2.07 $\pm$ 0.05
S47-23-100	1.75 $\pm$ 0.09 <sup>a</sup>	2.12 $\pm$ 0.17 <sup>abc</sup>	2.02 $\pm$ 0.09 <sup>ab</sup>	2.19 $\pm$ 0.09 <sup>bc</sup>	2.02 $\pm$ 0.06
Silken	1.81 $\pm$ 0.09 <sup>a</sup>	2.05 $\pm$ 0.09 <sup>b</sup>	1.93 $\pm$ 0.09 <sup>abcd</sup>	2.22 $\pm$ 0.09 <sup>bc</sup>	2.00 $\pm$ 0.05
Gala	1.81 $\pm$ 0.09 <sup>a</sup>	2.03 $\pm$ 0.10 <sup>b</sup>	1.86 $\pm$ 0.09 <sup>bcd</sup>	2.13 $\pm$ 0.09 <sup>cd</sup>	1.96 $\pm$ 0.05
8S6923	1.73 $\pm$ 0.09 <sup>a</sup>	2.08 $\pm$ 0.12 <sup>b</sup>	1.69 $\pm$ 0.09 <sup>e</sup>	2.32 $\pm$ 0.09 <sup>abc</sup>	1.95 $\pm$ 0.05
Chinook	1.49 $\pm$ 0.09 <sup>bc</sup>	1.86 $\pm$ 0.12 <sup>bc</sup>	1.84 $\pm$ 0.09 <sup>bcd</sup>	2.12 $\pm$ 0.09 <sup>cd</sup>	1.83 $\pm$ 0.05
8S-27-43	1.43 $\pm$ 0.09 <sup>c</sup>	1.86 $\pm$ 0.14 <sup>bc</sup>	1.67 $\pm$ 0.09 <sup>e</sup>	2.20 $\pm$ 0.09 <sup>bc</sup>	1.79 $\pm$ 0.05
S14-15-72	1.63 $\pm$ 0.09 <sup>abc</sup>	1.94 $\pm$ 0.11 <sup>bc</sup>	1.69 $\pm$ 0.09 <sup>e</sup>	1.87 $\pm$ 0.09 <sup>e</sup>	1.78 $\pm$ 0.05
8S-26-50	1.16 $\pm$ 0.09 <sup>d</sup>	1.70 $\pm$ 0.12 <sup>c</sup>	1.71 $\pm$ 0.09 <sup>de</sup>	1.91 $\pm$ 0.09 <sup>de</sup>	1.62 $\pm$ 0.05
S43-43-79	1.41 $\pm$ 0.09 <sup>c</sup>	1.11 $\pm$ 0.24 <sup>d</sup>	1.74 $\pm$ 0.09 <sup>cde</sup>	1.84 $\pm$ 0.09 <sup>e</sup>	1.53 $\pm$ 0.07
Location mean	1.63 $\pm$ 0.03	1.94 $\pm$ 0.05	1.85 $\pm$ 0.03	2.16 $\pm$ 0.03	

*a-e* Selection means within a location that are followed by the same letter are not significantly different according to the SAS procedure PDIF (equivalent to multiple *t*-tests at  $P \leq 0.05$ )

earlier than Gala at all locations but KE, where bloom was very compressed. The time of full bloom and the duration of bloom are strongly influenced by temperature, and for this reason are variable from year to year. As an example, the date of full bloom for McIntosh ranged from April 22 to May 08 over the period 2002 to 2005 in SU (data not shown). Cultivars usually bloom in the same relative order, but the bloom period is compressed in warm years.

The majority of cultivars averaged between 2 and 3 on the six-point bloom rating scale (Table 6), indicating sufficient bloom production for a full crop, but not excessive. Ratings for Gala were significantly higher than for McIntosh in SU and SM, the two were not different in CS, and in KE McIntosh ratings were higher than for Gala. This illustrates the cultivar

inconsistency across locations that resulted in significant genotype  $\times$  environment interaction. Bloom ratings for 8S-26-50 were low except in SM; this cultivar tends to alternate-bear, at least in British Columbia. Gala, 8S6923 and 8NE-07-72 were among the genotypes with the highest bloom ratings at three out of four locations.

#### Yield

Five-year cumulative yields were similar for SU, KE and SM, but lower for CS (Table 7), in accordance with the lack of harvestable fruit at CS in 2001 from the hail storm. Gala was significantly more productive than McIntosh at all locations but CS, where they were similar. Silken was the only other cultivar with higher cumulative yield than McIntosh at all locations. 8S-26-50, S43-43-79 and

**Table 4. Least-squares means and standard errors (SE) for floral density<sup>2</sup> of 12 apple clones in 2001 at three locations**

Selection	Summerland, BC	Kentville, NS	Simcoe ON	Selection mean
	Mean $\pm$ SE <sup>2</sup>	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE
Silken	12.87 $\pm$ 1.42 <sup>abcd</sup>	8.97 $\pm$ 1.42 <sup>a</sup>	25.70 $\pm$ 1.42 <sup>a</sup>	15.84 $\pm$ 0.82
Gala	13.90 $\pm$ 1.42 <sup>abc</sup>	4.41 $\pm$ 1.52 <sup>bcd</sup>	19.22 $\pm$ 1.42 <sup>b</sup>	12.51 $\pm$ 0.84
Chinook	16.36 $\pm$ 1.42 <sup>a</sup>	5.19 $\pm$ 1.42 <sup>abc</sup>	14.78 $\pm$ 1.42 <sup>c</sup>	12.11 $\pm$ 0.82
S47-23-100	15.60 $\pm$ 1.42 <sup>ab</sup>	3.91 $\pm$ 1.42 <sup>bcd</sup>	13.02 $\pm$ 1.42 <sup>cde</sup>	10.84 $\pm$ 0.82
8S6923	13.75 $\pm$ 1.42 <sup>abc</sup>	7.30 $\pm$ 1.42 <sup>ab</sup>	10.82 $\pm$ 1.42 <sup>def</sup>	10.62 $\pm$ 0.82
McIntosh	12.52 $\pm$ 1.42 <sup>bcd</sup>	4.86 $\pm$ 1.42 <sup>bcd</sup>	13.89 $\pm$ 1.42 <sup>cd</sup>	10.43 $\pm$ 0.82
S43-43-79	12.38 $\pm$ 1.42 <sup>bcd</sup>	3.75 $\pm$ 1.42 <sup>bcd</sup>	14.22 $\pm$ 1.42 <sup>cd</sup>	10.12 $\pm$ 0.82
8NE-07-72	10.34 $\pm$ 1.42 <sup>cde</sup>	3.10 $\pm$ 1.42 <sup>cd</sup>	9.51 $\pm$ 1.42 <sup>efg</sup>	7.63 $\pm$ 0.82
8S-27-43	7.47 $\pm$ 1.42 <sup>e</sup>	2.02 $\pm$ 1.42 <sup>cd</sup>	11.32 $\pm$ 1.42 <sup>cdef</sup>	6.94 $\pm$ 0.82
S23-06-153	9.87 $\pm$ 1.42 <sup>de</sup>	2.06 $\pm$ 1.42 <sup>cd</sup>	8.84 $\pm$ 1.42 <sup>fgh</sup>	6.93 $\pm$ 0.82
S14-15-72	9.83 $\pm$ 1.42 <sup>de</sup>	2.62 $\pm$ 1.52 <sup>cd</sup>	5.26 $\pm$ 1.42 <sup>h</sup>	5.90 $\pm$ 0.84
8S-26-50	7.66 $\pm$ 1.42 <sup>e</sup>	1.00 $\pm$ 1.52 <sup>d</sup>	6.62 $\pm$ 1.42 <sup>gh</sup>	5.09 $\pm$ 0.84
Location mean	11.88 $\pm$ 0.55	4.10 $\pm$ 0.55	12.77 $\pm$ 0.55	

<sup>2</sup>Number of flower clusters  $\text{cm}^{-2}$  trunk cross-sectional area

*a-h* Selection means within a location that are followed by the same letter are not significantly different according to the SAS procedure PDIF (equivalent to multiple *t*-tests at  $P \leq 0.05$ )

**Table 5. Least-squares means and standard errors (SE) for day of year of full king bloom (2001–2005) of 12 apple clones at four locations**

Selection	Summerland, BC	Cedar Springs, ON	Kentville, NS	Simcoe, ON	Selection mean
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
8S-26-50	123 ± 2.5bc	143 ± 2.5ab	151 ± 2.9ab	142 ± 3.6bc	140 ± 1.5
Gala	124 ± 2.5a	143 ± 2.5ab	151 ± 2.9abc	142 ± 3.6b	140 ± 1.5
S23-06-153	123 ± 2.5bc	142 ± 2.5cd	151 ± 2.9a	142 ± 3.6b	140 ± 1.5
S43-43-79	124 ± 2.5ab	143 ± 2.6a	151 ± 2.9ab	144 ± 3.6a	140 ± 1.5
8S-27-43	123 ± 2.5c	142 ± 2.5abc	150 ± 2.9abc	140 ± 3.6d	139 ± 1.5
Chinook	121 ± 2.5d	142 ± 2.5bc	151 ± 2.9abc	141 ± 3.6c	139 ± 1.5
8S6923	122 ± 2.5d	141 ± 2.5de	150 ± 2.9abc	139 ± 3.6de	138 ± 1.5
McIntosh	120 ± 2.5e	141 ± 2.5ef	150 ± 2.9bcde	140 ± 3.6de	138 ± 1.5
S14-15-72	122 ± 2.5d	141 ± 2.5ef	150 ± 2.9abcd	139 ± 3.6ef	138 ± 1.5
S47-23-100	121 ± 2.5d	141 ± 2.5ef	150 ± 2.9cde	142 ± 3.6bc	138 ± 1.5
8NE-07-72	120 ± 2.5e	140 ± 2.5f	149 ± 2.9de	138 ± 3.6f	137 ± 1.5
Silken	118 ± 2.5f	139 ± 2.5g	149 ± 2.9e	137 ± 3.6g	136 ± 1.5
Location mean	122 ± 2.5	141 ± 2.5	150 ± 2.9	141 ± 3.6	

*a-g* Selection means within a location that are followed by the same letter are not significantly different according to the SAS procedure PDIF (equivalent to multiple *t*-tests at  $P \leq 0.05$ ). Values were rounded to the nearest day, resulting in some selections having different letters for the same apparent mean (e.g., 8S-26-50 and 8S-27-43 in Summerland).

S14-15-72 were less productive than Gala at all locations, perhaps because of their small canopy size. In contrast, 8NE-07-72 and S47-23-100 were also generally less productive than Gala, despite having vigorous trees with large canopies. Sometimes excess vigour is associated with low yields. More resources are available for vegetative growth when crop loads are light. The other cultivars were inconsistent across locations. The cultivars with the greatest range in yield across locations (i.e. most inconsistent) were 8S-27-43 and 8NE-07-72 (Table 7), while S43-43-79 and S23-06-153 had the narrowest range. From a breeder’s viewpoint, high yield and low range is the most desirable combination; here Silken and S23-06-153 best fit that pattern. Selections S43-43-79, S47-23-100

and 8S-26-50, the only disease-resistant cultivars in the trial, all tended to be very unproductive.

Our yield figures excluded fruit that dropped prior to harvest. Pre-harvest drop was significant (over 25%) each year for S14-15-72 at all locations and was consistent for S47-23-100 at some locations (data not shown) even when the fruit was picked at the proper maturity or even before starch index reached 4.0. This provides another reason for the low apparent yield of S14-15-72. McIntosh, Chinook and 8NE-07-72 had significant pre-harvest drop (over 20%) in some years or at some locations. Pre-harvest drop is commercially undesirable because such fruit either cannot be sold (because of food safety regulations) or are of extremely

**Table 6. Least-squares means and standard errors (SE) for bloom ratings<sup>2</sup> (2002–2005) of 12 apple clones at four locations**

Selection	Summerland, BC	Cedar Springs, ON	Kentville, NS	Simcoe, ON	Selection mean
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
8S6923	4.1 ± 0.3a	2.1 ± 0.4bc	3.1 ± 0.5ab	3.8 ± 0.3a	3.3 ± 0.2
Silken	3.5 ± 0.3bcd	3.0 ± 0.3a	3.3 ± 0.5a	3.2 ± 0.3bcd	3.3 ± 0.2
8NE-07-72	3.7 ± 0.3abc	2.3 ± 0.3bc	3.0 ± 0.5abc	3.8 ± 0.3a	3.2 ± 0.2
Gala	3.9 ± 0.3ab	2.6 ± 0.3ab	2.5 ± 0.5bcd	3.8 ± 0.3a	3.2 ± 0.2
Chinook	3.9 ± 0.3ab	2.3 ± 0.3bc	2.4 ± 0.5cd	3.7 ± 0.3ab	3.1 ± 0.2
S23-06-153	3.4 ± 0.3cd	2.9 ± 0.3a	2.2 ± 0.5d	3.6 ± 0.3ab	3.0 ± 0.2
McIntosh	3.1 ± 0.3d	2.2 ± 0.3bc	3.2 ± 0.5a	3.0 ± 0.3d	2.9 ± 0.2
8S-27-43	3.5 ± 0.3bcd	1.3 ± 0.4de	2.4 ± 0.5cd	3.7 ± 0.3a	2.8 ± 0.2
S14-15-72	2.5 ± 0.3e	1.8 ± 0.3cd	2.6 ± 0.5abcd	3.2 ± 0.3bcd	2.5 ± 0.2
S43-43-79	2.1 ± 0.3e	2.1 ± 0.4bc	2.4 ± 0.5cd	3.3 ± 0.3abcd	2.5 ± 0.2
S47-23-100	3.3 ± 0.3cd	1.9 ± 0.4cd	2.0 ± 0.5d	3.1 ± 0.3cd	2.5 ± 0.2
8S-26-50	2.4 ± 0.3e	1.0 ± 0.3e	1.9 ± 0.5d	3.6 ± 0.3abc	2.2 ± 0.2
Location mean	3.3 ± 0.3	2.1 ± 0.3	2.6 ± 0.4	3.5 ± 0.3	

<sup>2</sup>Rating scale 0 = no bloom; 1 = a few flowers; 2 = flowers present but insufficient to support a full crop; 3 = sufficient flowers to support a full crop; 4 = more than enough flowers for a full crop; 5 = “snowball” bloom.

*a-d* Selection means within a location that are followed by the same letter are not significantly different according to the SAS procedure PDIF (equivalent to multiple *t*-tests at  $P \leq 0.05$ ). Values were rounded off, resulting in some selections having different letters for the same apparent mean.

**Table 7. Least-squares means and standard errors (SE) for five-year cumulative yield per tree (kg) from 2001 to 2005 inclusive for 12 apple clones at four locations**

Selection	Summerland, BC	Cedar Springs, ON	Kentville, NS	Simcoe, ON	Selection mean
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Silken	61.7 ± 2.9 <sup>a</sup>	54.0 ± 3.1 <sup>a</sup>	60.7 ± 3.1 <sup>a</sup>	55.1 ± 2.9 <sup>b</sup>	57.9 ± 1.5
8S6923	53.3 ± 2.9 <sup>b</sup>	44.1 ± 4.1 <sup>ab</sup>	48.1 ± 2.9 <sup>b</sup>	69.2 ± 3.1 <sup>a</sup>	53.7 ± 1.7
Gala	52.5 ± 2.9 <sup>bc</sup>	38.6 ± 3.4 <sup>bc</sup>	59.7 ± 3.1 <sup>a</sup>	57.0 ± 2.9 <sup>b</sup>	52.0 ± 1.6
8S-27-43	44.8 ± 2.9 <sup>c</sup>	24.2 ± 4.8 <sup>def</sup>	36.8 ± 2.9 <sup>c</sup>	51.5 ± 2.9 <sup>b</sup>	39.3 ± 1.7
McIntosh	26.2 ± 2.9 <sup>ef</sup>	42.4 ± 3.7 <sup>b</sup>	50.3 ± 2.9 <sup>b</sup>	28.8 ± 3.1 <sup>de</sup>	36.9 ± 1.6
Chinook	30.1 ± 2.9 <sup>de</sup>	29.0 ± 4.7 <sup>cde</sup>	37.2 ± 2.9 <sup>c</sup>	49.8 ± 4.1 <sup>b</sup>	36.5 ± 1.9
S23-06-153	37.0 ± 2.9 <sup>d</sup>	35.5 ± 4.1 <sup>bcd</sup>	32.4 ± 2.9 <sup>c</sup>	38.1 ± 2.9 <sup>c</sup>	35.8 ± 1.6
8NE-07-72	48.9 ± 2.9 <sup>bc</sup>	24.8 ± 3.7 <sup>ef</sup>	30.1 ± 3.1 <sup>cd</sup>	19.9 ± 4.7 <sup>ef</sup>	30.9 ± 1.9
8S-26-50	27.4 ± 2.9 <sup>e</sup>	20.4 ± 4.1 <sup>ef</sup>	29.9 ± 3.4 <sup>cd</sup>	36.1 ± 3.1 <sup>cd</sup>	28.4 ± 1.7
S14-15-72	17.7 ± 3.1 <sup>g</sup>	15.5 ± 3.7 <sup>f</sup>	29.3 ± 3.1 <sup>cd</sup>	33.8 ± 2.9 <sup>cd</sup>	24.1 ± 1.6
S47-23-100	19.2 ± 2.9 <sup>fg</sup>	15.7 ± 5.8 <sup>ef</sup>	24.2 ± 3.1 <sup>d</sup>	14.9 ± 2.9 <sup>f</sup>	18.5 ± 2.0
S43-43-79	12.4 ± 2.9 <sup>g</sup>	9.6 ± 8.1 <sup>f</sup>	11.1 ± 2.9 <sup>e</sup>	N/A <sup>z</sup>	11.0 <sup>x</sup>
Location mean	35.9 ± 1.3	29.5 ± 1.7	37.5 ± 1.3	41.3 <sup>y</sup>	

<sup>z</sup>N/A = yield data for all replicate trees of this selection missing in 2003, so value cannot be calculated.

<sup>y</sup>Arithmetic mean calculated without the data for S43-43-79.

<sup>x</sup>Arithmetic mean calculated without the data for Simcoe, ON.

*a-g* Selection means within a location that are followed by the same letter are not significantly different according to the SAS procedure PDIF (equivalent to multiple *t*-tests at  $P \leq 0.05$ ).

low value (if sale is permitted for juice or animal feed). Certain chemical “stop-drop” treatments can ameliorate this tendency, but will increase the cost of production. The fruit can also be picked earlier, before it starts to drop, but fruit eating quality may suffer if it is immature at harvest.

When cumulative yield was adjusted for tree size (i.e. cumulative yield efficiency), Silken ranked highest at all locations, but Gala was not significantly different except in CS (data not shown). No selection ranked last consistently, but S47-23-100 and S43-43-79 tended to be low in efficiency. Gala and McIntosh were again intermediate among the genotypes; Gala was more yield-efficient than McIntosh in SU, KE and SM, but

the reverse was true at CS. There were many other instances of cross-over interaction i.e. reversals in rank from location to location amongst the cultivars. Cultivars that are biennial-bearing or subject to pre-harvest drop will have low yield efficiency.

### Maturity Time

Most cultivars were picked at the appropriate maturity stage (starch index 4 to 6), except that S43-43-79 was harvested slightly later than the target time at SU, KE and SM (data not shown), and 8S-26-50 and sometimes Chinook slightly under-mature. Some selections never reached horticultural maturity in KE [e.g. 8S-26-50 (index 1.4) and Chinook (index 2.0), were picked as late as

**Table 8. Least-squares means and standard errors (SE) for days to maturity<sup>z</sup>, for 2003 to 2005 inclusive, for 12 apple clones at three locations**

Selection	Summerland, BC	Cedar Springs, ON	Simcoe, ON	Selection mean
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Chinook	175 ± 2.8 <sup>a</sup>	136 ± 2.9 <sup>a</sup>	151 ± 3.6 <sup>b</sup>	154 ± 1.8
8NE-07-72	163 ± 2.8 <sup>b</sup>	136 ± 2.9 <sup>a</sup>	155 ± 3.5 <sup>a</sup>	151 ± 1.8
8S-27-43	160 ± 2.8 <sup>c</sup>	134 ± 2.9 <sup>a</sup>	156 ± 3.5 <sup>a</sup>	150 ± 1.8
8S-26-50	160 ± 2.8 <sup>c</sup>	131 ± 2.9 <sup>b</sup>	144 ± 3.5 <sup>c</sup>	145 ± 1.8
8S6923	152 ± 2.8 <sup>d</sup>	127 ± 2.9 <sup>c</sup>	135 ± 3.5 <sup>d</sup>	138 ± 1.8
S23-06-153	141 ± 2.8 <sup>e</sup>	130 ± 2.9 <sup>b</sup>	135 ± 3.5 <sup>d</sup>	135 ± 1.8
S43-43-79	116 ± 2.8 <sup>i</sup>	120 ± 3.7 <sup>de</sup>	147 ± 3.6 <sup>c</sup>	128 ± 2.0
McIntosh	132 ± 2.8 <sup>f</sup>	119 ± 2.9 <sup>e</sup>	122 ± 3.5 <sup>e</sup>	125 ± 1.8
Gala	125 ± 2.8 <sup>g</sup>	121 ± 2.8 <sup>d</sup>	119 ± 3.5 <sup>ef</sup>	122 ± 1.8
S47-23-100	130 ± 2.8 <sup>f</sup>	120 ± 2.9 <sup>de</sup>	117 ± 3.5 <sup>f</sup>	122 ± 1.8
Silken	131 ± 2.8 <sup>f</sup>	120 ± 2.8 <sup>de</sup>	112 ± 3.5 <sup>g</sup>	121 ± 1.8
S14-15-72	120 ± 2.8 <sup>h</sup>	113 ± 3.0 <sup>f</sup>	114 ± 3.5 <sup>g</sup>	115 ± 1.8
Location mean	142 ± 2.7	125 ± 2.9	134 ± 3.4	

<sup>z</sup>Defined as the number of days from 90% king bloom to harvest.

*a-g* Selection means within a location that are followed by the same letter are not significantly different according to the SAS procedure PDIF (equivalent to multiple *t*-tests at  $P \leq 0.05$ ).

**Table 9.** Least-squares means and standard errors (SE) for average fruit weight (g) of 12 apple clones over five cropping years (2001–2005) at three locations

Selection	Summerland, BC	Kentville, NS	Simcoe, ON	Selection mean
	Mean ± SE <sup>z</sup>	Mean ± SE	Mean ± SE	Mean ± SE
8S-26-50	302 ± 9.3a	192 ± 10.6a	207 ± 9.3ab	234 ± 5.6
8S-27-43	291 ± 9.2a	185 ± 9.4a	226 ± 9.2a	234 ± 5.4
8NE-07-72	280 ± 9.2a	155 ± 9.7b	191 ± 9.6bc	209 ± 5.4
S23-06-153	210 ± 9.2b	146 ± 9.3bc	176 ± 9.3cd	177 ± 5.4
McIntosh	190 ± 9.2bcd	149 ± 9.3bc	191 ± 9.3bc	176 ± 5.3
Gala	205 ± 9.2bc	151 ± 9.3bc	174 ± 9.2cd	176 ± 5.3
8S6923	202 ± 9.2bc	118 ± 9.3d	165 ± 9.3d	162 ± 5.4
S14-15-72	191 ± 9.3bcd	129 ± 9.5cd	166 ± 9.3d	162 ± 5.4
S43-43-79	178 ± 9.4d	154 ± 9.3b	148 ± 14.5de	160 ± 6.5
S47-23-100	183 ± 9.2cd	113 ± 9.7d	165 ± 9.3d	154 ± 5.4
Silken	205 ± 9.2bc	114 ± 9.4d	138 ± 9.3e	152 ± 5.4
Chinook	176 ± 9.2d	105 ± 9.6d	123 ± 9.4e	135 ± 5.4
Location mean	218 ± 4.7	143 ± 4.7	172 ± 4.8	

*a–e* Selection means within a location that are followed by the same letter are not significantly different according to the SAS procedure PDIF (equivalent to multiple t-tests at  $P \leq 0.05$ ).

possible at day 295 (Oct. 22) and day 293 (Oct. 20), respectively], and are not well-suited to commercial production there.

Location × selection interaction for date of harvest was significant, but certain trends emerged. Harvest time was generally earliest in SU and latest in KE (data not shown). Silken, S14-15-72 and S43-43-79 were among the earliest-maturing cultivars (except S43-43-79 in SM), and Chinook, 8NE-07-72, 8S-26-50 and 8S-27-43 among the latest. Gala and McIntosh were both fairly early and matured at about the same time, except in KE, where Gala was significantly later.

The range in average date of harvest spanned 34 d, whereas date of bloom spanned only 2 to 7 d (Table 5), depending on location. Thus, date of harvest and days to maturity followed similar patterns, with S14-15-72 and Silken having the fewest days to maturity and Chinook, 8NE-07-72 and 8S-27-43 the most (Table 8). Nevertheless, the number of days to maturity for a given cultivar varied greatly among locations in some instances. For example, Chinook reached a starch index of 5.4 after 136 d in CS, but after 175 d, the starch index was only 2.8 in SU, a difference of almost 40 d. For McIntosh, which all locations picked within the desired starch index range, the number of days to maturity was 132 in SU, but only about 120 in CS and SM. In contrast, Gala matured in 125 d in SU and 121 d in CS, a difference of only 4 d. In SM, Gala was picked at 119 d after bloom, but it was already at a starch index of 6.5 (i.e., more advanced maturity than at SU and CS). In general, although cultivars bloomed earlier in SU, they took longer to reach maturity there. A similar observation was made in the NE-183 apple trial (Crassweller et al. 2005), where Braeburn, a very late cultivar, reached maturity after fewer days in Wisconsin (145 d) than it did in Arkansas (182 d). Perhaps cool night temperatures

stimulate ethylene production and hasten the onset of fruit ripening in some genotypes. Further study is needed on this phenomenon.

### Fruit Size

Average fruit weight across all cultivars was 52% greater in SU (218 g) than in KE (143 g) and 27% greater in SU than in SM (172 g, Table 9). Summerland also had larger fruit than most eastern North American locations, some of which were irrigated, in a previous study (Miller et al. 2007). The range in fruit size among cultivars was 90 to 100 g in KE and SM, and about 125 g in SU. From a breeding perspective, apple selections bred in SU, but intended for use in eastern Canada should have larger-than-ideal fruit size at SU. Selections 8S-26-50 and 8S-27-43 had among the largest fruit at each site, and Chinook always had among the smallest, regardless of thinning level. Gala and McIntosh were intermediate in fruit size and did not differ from each other at any location (Table 9). Chinook was considered too small for commercial use in the eastern United States of America (Miller et al. 2007) and the same is likely true in eastern Canada.

Apples with the most variable fruit size across locations are probably more responsive to climatic and management factors. In the present study we cannot separate management and climatic effects (together, the “environment”). However, the small average fruit size of Silken and 8S6923 in KE and SM over 5 cropping years was likely due at least partially to overcropping (due to unavailability of labour). Crop load on these cultivars in certain years was 10 to 17 fruit cm<sup>-2</sup> TCSA (data not shown); values greater than 6 to 9 fruit cm<sup>-2</sup> TCSA are usually considered the maximum in order not to compromise fruit size and return bloom (Lafer 1999). In other words, differences in the earliness and the

extent of thinning probably account for some of the site-to-site differences observed in these and other cultivars. Whether fruit size would have been sufficient at KE and SM with more stringent thinning cannot be stated from our data. Interestingly, the cumulative yield of Silken was about the same in SU (61.7 kg per tree) and KE (60.7 kg per tree) despite large differences in fruit size (Tables 7 and 9).

#### **Fruit Firmness, Soluble Solids and Red Colour**

Fruit quality data were measured annually on a 10-fruit sample pooled over all replications of a cultivar. Because there was no replication within a cultivar, these data could not be analyzed appropriately with the mixed-model ANOVA. In KE, many of the selections measured over 75 N flesh firmness (data not shown), perhaps related to the smaller fruit size there and the need to pick certain late-harvest selections prior to commercial maturity. As with other variables, cultivar performance was inconsistent in that changes in rank were evident across locations. For example, S43-43-79, 8NE-07-72 and S14-15-72 showed large site-to-site differences in firmness. McIntosh was consistently softer than Gala at all locations, and was among the softest cultivars in the trial at only 66 to 74 N. Regardless of their flavour preferences, consumers prefer firm, crisp, juicy texture in apple (Dailliant-Spinnler et al. 1996; Hampson et al. 2000).

Soluble solids content (SSC) was measured at SU, CS and SM. The range in SSC among cultivars at SU and SM was not large (13 to 16%) and was typical for apple (data not shown). The CS site had the highest overall SSC values, including several exceptionally high values ( $\geq 18.0\%$ ).

Only CS and SM recorded fruit colour. At these locations, colour was good (80 to 100%) on all the red-skinned cultivars, including both standards (data not shown). S23-06-153, described in Kentville breeding records as having 40% pink-red blush, had 30% red colour in SM but only 10% in CS. In SU, this selection had 0 to 5% pale orange blush (Hampson, personal observation), varying by year, perhaps because it ripened 20 d earlier, when the daytime temperature was still very warm. The observations suggest that if apples are being bred and selected in SU for fruit colour, they will probably have adequate colour in Ontario and Nova Scotia. However, some selections with poor colour in SU might have better colour in eastern Canada, and conversely, some good eastern selections may have poor colour in SU.

#### **Synthesis**

No single cultivar emerged as being superior in all regions. Some cultivars were very responsive to environment (e.g., the highly variable fruit size of Silken or yield of 8NE-07-72). On the other hand, cultivars with low vigour and yield tended to be low in these characteristics at all test sites. Some such cultivars may benefit from more vigorous rootstocks, but others may simply be too

weak or too unproductive. Only two new cultivars were identified with good to excellent yield at all locations (S23-06-153 and Silken). Cultivars with adequate to good performance in terms of survival, tree vigour, yield, pre-harvest drop and fruit size were the two standards, plus S23-06-153, and 8S-27-43. 8S6923 and Silken might be added to the list if they were re-tested in the east with more rigorous fruit thinning. The low apparent precocity and late maturity time of 8S-27-43 may be of concern in some situations. Naturally, consumer acceptance and fruit storage life, not tested here, would be other factors of paramount importance.

Regarding location effects, the SU or SM sites would be the best for testing overlap of bloom for cross-pollination data, because time of bloom was less compressed at these locations. A very interesting observation made here is that one cannot assume a cultivar will fail to mature in a climate with a shorter growing season, because the days to maturity were often fewer in eastern Canada than in British Columbia.

In this experiment, the first uniform cultivar trial for tree fruit in Canada, the effects of cultivar, location and their interaction were significant for all response variables analyzed. Although the cultivar  $\times$  location interaction was statistically significant, it was not always of practical importance. For the breeder, selection in one location is probably sufficient for some traits, such as tree vigour, precocity, and relative order of bloom and harvest, if the results from this trial can be generalized. With tree vigour, for example, the most and least vigorous genotypes were largely consistent across locations, and the observed changes in cultivar rank that did occur were not only modest, but would have little economic consequence to growers. Selection for fruit size and colour might be effective at one location provided that the effect of environment on fruit size (i.e., smaller fruit in the east) and colour (lower in British Columbia for early genotypes) is taken into account. On the other hand, it is difficult to see how one would successfully breed for a cultivar that only does well in a production region different from where it is bred. Alspach and Oraguzie (2002) likewise emphasize the distinction between statistical and biological significance in apple breeding. This distinction is particularly important for perennial fruit crops where trials require much labour and time, and trial costs exceed five figures.

In contrast, multi-site testing of advanced selections is warranted for tree survival, yield, pre-harvest drop, attractiveness of fruit (skin finish, russet, etc.) and possibly fruit firmness. One could effectively select against low yield at one site, but perhaps not in favour of high yield. Many cultivars with high yield seemed also to have high variability of yield in this trial. Environment and genotype  $\times$  environment effects on the traits listed above would have important consequences for commercial producers, and hence they are of both statistical and practical importance. Any future trials should concentrate on reporting these factors, plus fruit storage life and

climatic adaptation (tree hardiness, disease resistance, etc.), which also have profound commercial importance, but were not assessed in this trial. Consumer testing could then focus on the best selections at each location. Tree fruit trials are very costly, but most of the traits mentioned above are consistent for a cultivar within a site. Hence, costs might be reduced somewhat by using fewer replicate trees if the trial field is reasonably uniform, but detection of statistical differences would naturally become more difficult.

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