Journal of the American Pomological Society 61(2):97-114 2007

Performance of Apple Cultivars in the 1999 NE-183 Regional Project Planting. II. Fruit Quality Characteristics

S. Miller, R. McNew, R. Crassweller, D. Greene, C. Hampson, A. Azarenko, L. Berkett, W. Cowgill, E. Garcia, T. Lindstrom, M. Stasiak, J. Cline, B. Fallahi, E. Fallahi, and G. Greene II

Abstract

The fruit quality performance of 23 apple (*Malus* x *domestica* Borkh.) cultivars and numbered selections on Malling 9 (M.9 T337) rootstock was evaluated over four growing seasons at 12 locations across North America as part of the NE-183 Regional Project, "Multidisciplinary Evaluation of New Apple Cultivars." At each site, trees were planted in 1999 in five randomized blocks with single-tree plots. 'Golden Delicious' served as the standard cultivar for comparison. 'Minnewashta' (Zestar!®) was the earliest maturing cultivar being harvested an average of 43 days before 'Golden Delicious'. 'Cripp's Pink' was the latest cultivar to mature and was harvested an average of 29 days after 'Golden Delicious'. The selection NY 79507-49 had the largest diameter fruit at 8.6 cm followed closely by 'Runkel', 'Hampshire' and 'Co-op 29' ('Sundance™'). The British Columbia planting location produced the largest fruit averaged across all cultivars. The highest length/diameter (L:D) ratio was recorded for 'Delblush' ('Tentation™'). CQR10T17 had the firmest flesh at 10 of 11 reporting locations, but its average firmness of 11.1 kg at harvest would make it too firm for immediate fresh consumption. Average fruit soluble solids concentration (SSC) across all cultivars and locations was 14.5% indicating most cultivars in this test had excellent sugar levels. BC-8S-26-50 had the highest average SSC at 17.0% followed closely by 'Delblush' and then 'Golden Delicious'. Utah recorded the highest mean SSC at 16.5 %. Cultivar mean surface color ratings for NJ 90, 'Chinook' and 'Co-op 39' ('Crimson Crisp™') were 88% to 90% surface red color. Skin russet generally affected about 10% to 15% of the surface of BC-8S-26-50, 'Golden Delicious', and 'Co-op 29' ('Sundance™'). Results support the need for widespread testing of new apple cultivars.

Apple quality is a complex of both physical and visual characteristics as well as chemical composition (39). More than ever, consumers are seeking high quality apples that provide a pleasant eating experience (1,18). Growers know that high quality apples result in a high level of customer satisfaction (9) and produce the best returns (38). Developing and selecting high quality apple cultivars is a goal of breeders and nurserymen. Producing fruit of the highest quality is a universal goal among apple growers.

Quality involves many attributes including, but not limited to, such characteristics as appearance, size, flesh firmness, sugar and acid levels, freedom from defects, flavor, and texture. Large, well colored apples with firm flesh that exhibit a uniform characteristic shape and are free from defects are generally considered to be of "high quality". Recent studies and consumer taste panels identify flavor, taste, and texture as highly important in consumer preference and buying habits for apples (15,17,32). Market surveys consistently show that consumers prefer apples that are crisp and juicy (16,27,36) with a good balance of acid and sugar (10). Large apples are preferred to medium or extra-large size fruit (37). Appearance is also an important factor in consumer buying habits for apples (33). Brightly colored apples have greater appeal than those with a dull color (35).

Characteristics such as fruit size, flesh firmness, soluble solids concentration (SSC), and titratable acidity are objective measures that can be used to identify quality fruits. These characteristics all play significant roles in achieving a level of sensory quality (texture, flavor, crispness, juiciness, etc.) that meets consumer expectations for apples. Wills et al. (40) reported that changes in flavor and texture were highly correlated with

the overall quality ratings for 'Delicious' apples by a taste panel. In their study, flesh firmness and titratable acidity declined when apples were stored at selected temperatures. As these quality attributes declined hedonic ratings for texture and flavor declined. The change in flavor and texture was correlated with a loss in overall taste panel rating and consumer acceptability (40). Studies with 'Golden Delicious' showed a positive correlation between taste panel flavor ratings and SSC, but a negative correlation with yield in four of the five seasons tested (8).

Interest in new high quality apple cultivars with unique characteristics has increased in recent years (2,22,29). Successful introduction of new cultivars that will meet the needs of both growers and consumers requires detailed systematic evaluation across a broad range of soil and climatic conditions. Until recently, such a system for evaluating the performance of new apple cultivars was limited. In 1994 Regional Project NE-183, titled "Multidisciplinary Evaluation of New Apple Cultivars," was initiated with the goal of providing producers with information on the horticultural performance and pest susceptibility of new apple cultivars and selections across a number of apple growing regions in North America. Description and background information on the NE-183 Regional Project has been published (11,12). The results of the evaluation from the 1995 NE-183 horticulture plantings have been summarized and published (4,5,11,14,23,24,25). The objective of this paper is to report the horticultural fruit quality performance for the 23 new apple cultivars and breeding selections in the 1999 NE-183 horticulture planting.

Materials and Methods

General details regarding the identification and selection of the 23 cultivars for the 1999 NE-183 planting, and propagation, planting, and cultural maintenance are provided by Greene et al. (12). 'Golden Delicious' was included in the planting as the commercial standard of comparison. Additional specific details concerning cultural maintenance procedures and protocols used in harvesting fruit and in data collection for the NE-183 plantings can be found in earlier publications by Crassweller et al. (5), Hampson et al. (14), and Miller et al. (23,25).

Most cooperators removed all bloom that appeared in 1999 and 2000 to encourage tree

Table 1. Locations and cooperators in the 1999 NE-183 apple cultivar evaluation trial who supplied fruit quality data for their trees to this report.

Location code	Test planting location city, state/province	Cooperator(s)
BC	Summerland, B.C.	C. Hampson
ID	Parma, Id.	E. Fallahi, B. Fallahi
MA	Belchertown, Mass.	D. Greene
NJ	Pittstown, N.J.	W. Cowgill
ON	Simcoe, Ont.	J. Cline
OR	Corvallis, Ore.	A. Azarenko
PAB	Biglerville, Pa.	G. Greene
PAR	Rock Springs, Pa.	R. Crassweller
UT	Kayesville, Ut.	T. Lindstrom
VT	Burlington, Vt.	E. Garcia, L. Berkett
WI	Sturgeon Bay, Wis.	M. Stasiak
WV	Kearneysville, W. Va.	S. Miller

growth. Fruit quality data presented here represent apples harvested for the years 2001 (third-leaf) through 2004. Cooperators at 12 locations (Table 1) provided fruit quality data for this report. A standard protocol was developed for collecting fruit quality data. Quality variables were determined on a 10-fruit sample per replicate tree as previously described (23). Fruit were harvested when the average starch index (SI) rating fell within the range of 4 to 6 (considered optimum maturity) based on the Cornell Generic Starch-Iodine Index Chart (3). If the mean SI for a given cultivar-location-year was lower than 3.5 or higher than 6.5, the data were excluded from the statistical analysis. Objective data were collected on the following variables: fruit weight, length, and diameter, flesh firmness, soluble solids concentration (SSC), and titratable acidity (TA) as percent malic acid. Prior to destructive measurements, each fruit was subjectively rated for surface russet and percent red overcolor. A description and details of the methods used to measure quality variables has been provided by Miller et al. (23).

Data from 2001 to 2004 inclusive were analyzed with the SAS statistical software package (release 8.2, SAS Institute, Cary NC), using a mixed linear model (MIXED procedure). The Satterthwaite option was used for determining the degrees of freedom, and estimates of the variance components for random effects were REML estimates. Location, cultivar and their interaction were deemed fixed effects. Block, replicate nested within cultivar, year, and all interaction terms that included year, were considered random effects. Generalized least squares means for cultivar within location were compared if the P-value of the F test for cultivar x location was less than 0.01. Pairwise comparisons were made with multiple t tests, each using a significance level of 0.05. No LSD can be given because all comparisons have different standard errors.

Results and Discussion

Location effect was not significant for length/diameter ratio (L:D) and fruit russet rating, but cultivar and the cultivar (C) x location (L) interaction were significant for L:D ratio (Table 2). The C x L interaction for fruit russet was not significant. For all other response variables, both main effects and the interaction between C and L were significant. The data presented here will focus on results within a location and broad, general responses. Tables 4 to 11 show two-way means, with mean separation within the indicated location. Because of unbalanced data, mean separation letters may not run continuously for some groupings.

Apple maturity. The mean SI rating at the time of harvest and the mean number of days deviation from the mean harvest date

Table 2. *P*-values from the mixed-model analysis of variance for the main-factor effects and interactions of cultivar and planting location on experimental response variables.

Response variable	Cultivar (C)	Planting location (L)	C x L
Fruit weight	<0.001	0.002	<0.001
Fruit diameter	<0.001	0.005	<0.001
Length:diameter ratio	<0.001	0.120	0.027
Flesh firmness	<0.001	0.002	0.001
Soluble solids	<0.001	<0.001	<0.001
Titratable acidity	<0.001	0.010	<0.001
Red overcolor	<0.001	<0.001	<0.001
Russet rating	<0.001	0.076	0.060

Table 3. Mean starch index (SI) rating at the time of harvest for 23 apple cultivars on Malling 9 T337 rootstock at 12 planting sites in North America in the NE-183 Apple Cultivar Evaluation Project for the years 2001 through 2004.

Cultivar	SI rating[z]	Days deviation from harvest date for 'Golden Delicious'
Ambrosia	5.0	-2[y]
Autumn Gold	6.4	+9
BC 8S-26-50	4.7	+5
Chinook	4.7	+14
Co-op 29	4.8	+12
Co-op 39	5.9	-12
CQR10T17	5.6	-5
CQR12T50	7.2[x]	-20
Cripp's Pink	4.3	+29
Delblush	5.0	+8
Golden Delicious	5.4	0
Hampshire	4.9	+3
Jubilee Fuji	6.4	-7
McIntosh	6.4	-25
Minnewashta	4.3	-43
NJ 109	4.4	-24
NJ 90	4.5	-5
NY 65707-19	5.4	+2
NY 75907-49	4.8	-12
NY 75907-72	5.8	-18
Pinova	4.8	-4
Runkel	5.1	+1
Silken	4.4	-27
Mean for all cultivars	5.1	-5

[z] Average SI rating for harvested fruit from all replicate trees within a site determined to fall within the range 3.5 to 6.5; SI 1 = fully immature, SI 8 = fully over-mature.
[y] Calculated from mean harvest date for each cultivar across all sites; - indicates before 'Golden Delicious' and + indicates after 'Golden Delicious'
[x] Mean SI fall outside the acceptable range; not included in the overall cultivar average

for 'Golden Delicious' for all cultivars from across the 12 planting sites for the years 2001 – 2004 are presented in Table 3. Cultivars harvested when the average SI rating indicated the fruit were well below target maturity (mean SI $\leq$ 3.4) or above target maturity (mean SI $\geq$ 6.6) were deleted from the statistical analysis since fruit at these maturity levels were not considered representative of the cultivar. For a cultivar to be dropped from an individual site, the average of all replicates at that site had to be outside the acceptable SI range. Among the 23 cultivar/selections evaluated, only one selection, CQR12T50, had an overall mean SI rating outside the target range. Using SI rating as the indicator of optimum maturity, 'Pinova' was almost always harvested at the proper stage. Similarly, cultivars 'Delblush' and 'Chinook' and selections NY 65707-19 and NY 79507-72 were generally harvested (about 85% of the time) at an acceptable stage of maturity (data not shown). In contrast, selection CQR12T50 was seldom harvested (less than 30% of the time) at the proper stage of maturity and most locations harvested this selection when

SI was above the target level (SI 6.5) (data not shown). The reason why CQR12T50 was often harvested late is not readily apparent. Conversion of starch to sugar can be delayed in some cultivars followed by a sudden and rapid degradation as the fruit reach full maturity (21). This may account for the late harvest of CQR12T50. Also, harvesting at an SI of 4 to 6 may not be the best time to harvest all cultivars at all locations (23,24,25). The cultivars 'Autumn Gold' and 'Jubilee Fuji' were only harvested about half of the time within the target range of SI rating (data not shown). When harvested outside the target range, these two cultivars were harvested above 6.5 on the SI rating scale. Excluding CQR12T50, 'Jubilee Fuji' was harvested at the highest mean SI while 'Cripp's Pink' was harvested with the lowest mean SI within the target SI range. The late maturity of 'Cripp's Pink' may have contributed to the lower SI rating at harvest, as some locations may have harvested on the early side to avoid the possibility of fruit freezing on the tree before harvest. As in the previous study of apple cultivar performance (23), this difference in mean SI at time of harvest is probably a reflection of inherent differences in the rate of starch hydrolysis among cultivars (21).

'Minnewashta' matured 43 days before the mean maturity date for 'Golden Delicious' (Table 3) and was the earliest maturing cultivar among the 23 evaluated. 'Cripp's Pink', the latest maturing cultivar, matured a mean of 29 days after 'Golden Delicious'. Thirteen of the 23 cultivars matured before 'Golden Delicious' and nine cultivars matured after 'Golden Delicious' (Table 3). Nine of the cultivars matured within one week of 'Golden Delicious'.

Fruit weight and size. No one cultivar was consistently the largest, in terms of fruit weight, across the 11 reporting locations (Table 4). Based on the 10-apple sample selected for quality measurements NY 79507-49, CQR10T17 and 'Runkel' were generally the largest cultivars, averaging about 250 g or more per fruit. 'Co-op 29' and 'Hampshire' were also among the largest selections at several locations which agrees with published descriptions for these cultivars (12,18). 'Runkel' was the largest cultivar at the OR, PAB, PAR, and VT planting locations. However, when fruit weight was averaged across all planting locations, NY 79507-49 had the largest mean fruit weight among the 23 cultivars evaluated (Table 4). 'Chinook' was planted at 10 of the 11 reporting locations and had the lowest fruit weight. The mean fruit weight of 140 g for 'Chinook' was 36 g less than the next smallest cultivar, 'Silken' which had a mean weight of 176 g. 'Chinook' is described as a small to medium size apple with a reported mean weight of 152 g to 184 g over two growing seasons when tested in BC (29). 'Silken' is described as a medium size apple with a mean weight of 172 g to 204 g in two test seasons in BC (31).

Average fruit weight for the 10-apple sample collected in this paper agrees closely with average fruit weight for whole tree samples reported by Crassweller et al. (6) for 17 test locations in the 1999 NE-183 Regional Planting. In their report, NY 75907-49 had an average fruit weight of 254 g followed by 'Runkel' at 241 g per fruit. The smallest fruits were 'Chinook' at 129 g followed by 'Cripp's Pink' at 149 g per fruit (6). When fruit weight was averaged across all cultivars at a location, apples growing at the BC location had the highest average fruit weight followed by the UT location. The MA and WV locations had the lowest average fruit weight across all cultivars.

As might be expected, based on the results from fruit weight, NY 79507-49 and 'Runkel' also had the largest fruit diameters at several sites (VT, WI and WV and PAB and PAR respectively) (Table 5). At the MA, OR and UT locations, 'Hampshire' had the largest fruit diameter while in BC and NJ the largest fruit diameter was recorded for 'Co-op 29'. Across 10 reporting locations, NY 79507-49 had the largest average fruit diameter (Table 5). At six of 10 reporting locations, 'Chinook' was the smallest diameter fruit. 'Delblush' was

Table 4. Generalized least-squares means for fruit weight among 23 apple cultivars grown at 11 planting locations for the years 2001 through 2004.

Cultivar	Mean fruit weight (g)											Cultivar mean
	BC[z]	MA	NJ	ON	OR	PAB	PAR	UT	VT	WI	WV	
Ambrosia	284 d-g[y]	197 b-e	205 d-i	-[x]	248 a-d	206 abc	198 cd	227 e-h	213 bcd	180 cde	175 c-g	213
Autumn Gold	317 a-d	176 def	262 abc	-	224 a-f	210 abc	npw	-	np	205 a-e	212 a-d	230
BC 8S-26-50	np	211 a-d	268 ab	265 a	268 abc	211 abc	216 bc	253 d-g	192 c-f	-	218 abc	233
Chinook	np	143 f	165 i	131 g	162 i	135 d	123 h	178 i	123 h	129 g	109 h	140
Co-op 29 (Sundance™)	344 a	178 e	272 a	222 a-e	273 a	-	206 cd	256 def	213 b-e	199 bcd	201 b-e	236
Co-op 39 (Crimson Crisp™)	233 j	169 ef	203 d-i	-	207 e-h	183 bcd	161 efg	np	193 cdeg	174 cdeg	173 efg	188
CQR10T17	315 a-d	238 a	259 a-d	-	232 a-e	232 ab	242 ab	240 d-g	240 b	250 a	232 ab	247
CQR12T50	240 hij	-	-	np	np	214 abc	np	303 abc	202 b-f	np	-	240
Cripp's Pink (Pink Lady®)	227 j	np	np	np	197 e-i	167 cd	159 fg	203 ghi	np	166 def	143 g	178
Delblush	289 def	144 f	218 c-g	213 b-e	201 e-i	174 cd	184 c-g	199 hi	160 fh	156 eg	165 fg	191
Golden Delicious (Gibson)	298 cde	198 a-e	229 b-g	-	195 e-i	177 bcd	176 d-g	228 e-h	185 def	161 deg	181 def	204
Hampshire	302 b-e	228 ab	248 a-f	258 abc	232 b-e	218 abc	237 ab	307 a	210 b-e	186 b-e	232 ab	240
Jubilee Fuji	298 cde	-	-	-	222 b-g	-	191 c-f	236 efg	187 c-f	179 cde	190 c-f	216
Minnewashta (Zestar!®)	263 fgh	202 b-e	198 ghi	-	164 hi	189 a-d	204 cd	224 e-h	179 c-f	221 ab	175 d-g	202
McIntosh	np	np	209 e-h	200 def	np	np	np	np	np	np	np	204
NJ 90	250 ghj	193 cde	245 a-f	210 b-e	174 ghi	160 cd	193 cde	248 d-g	188 b-f	200 bcf	185 def	204
NJ 109	274 e-h	174 ef	175 hi	208 cef	-	184 bcd	173 d-g	219 fgh	146 fgh	198 a-e	166 efg	195
NY 65707-19	240 hj	np	246 a-g	251 abd	217 def	-	205 cd	259 cde	206 b-e	208 abc	np	227
NY 79507-49	322 abc	np	264 ab	-	np	np	240 ab	296 ab	285 a	240 a	235 a	269
NY 79507-72	253 ghj	195 cde	207 fgh	213 b-e	172 f-i	163 cd	182 c-g	249 d-g	212 b-e	214 abc	174 efg	205
Pinova	271 efgi	171 ef	np	166 eg	226 cde	np	196 cd	np	192 cde	np	np	203
Runkel	330 ab	219 abc	257 a-e	-	278 ab	240 a	259 a	274 bcd	221 bc	215 abc	230 ab	253
Silken	np	166 ef	209 e-h	-	168 f-i	167 cd	155 g	np	175 ef	166 de	204 a-f	176
Mean all cultivars	282	188	228	212	214	190	195	244	196	192	189	

[z] Locations: See Table 1 for explanation of location codes
[y] Means within a location not sharing a common letter are significantly different by pairwise t tests from the analysis of the mixed model ($p \leq 0.05$)
[x] - = no data were taken, the cultivar was lost at this location, or the mean starch index rating fell outside the acceptable range of 3.5 to 6.5
[w] np = the cultivar was not planted at this location

Table 5. Generalized least-squares means for fruit diameter among 23 apple cultivars grown at 10 planting locations for the years 2001 through 2004.

Cultivar	Mean fruit diameter (cm)										Cultivar mean
	BCz	MA	NJ	OR	PAB	PAR	UT	VT	WI	WV	
Ambrosia	8.5 a-f[y]	7.6 b-e	7.4 d-h	7.0 e	7.7 abc	7.6 d-g	7.9 def	7.9 bcd	7.5 cde	7.1 efg	7.6
Autumn Gold	8.7 abc	7.3 c-g	6.5 hi	7.1 de	7.6 abc	np[x]	- [w]	np	7.8 a-e	7.7 bcdf	7.5
BC 8S-26-50	np	7.7 b-e	8.5 a	6.8 e	7.6 abc	7.8 b-g	8.0 cd	7.5 cde	-	7.9 abc	7.7
Chinook	np	6.9 fg	7.2 gh	6.9 e	6.7 c	6.4 i	7.2 f	6.7 f	6.7 f	6.2 h	6.8
Co-op 29 (Sundance™)	9.1 ab	7.5 cde	8.5 ab	8.2 ab	-	7.8 c-f	8.3 bcd	8.0 bc	7.7 bcd	7.6 b-e	8.1
Co-op 39 (Crimson Crisp™)	7.9 f	7.3 d-g	7.6 bcdfg	7.5 b-e	7.5 abc	7.2 gh	np	7.6 bcd	7.3 c-f	7.2 deg	7.5
CQR10T17	8.5 cde	8.0 abc	8.1 abcdfg	8.2 ab	7.9 ab	7.9 b-e	8.1 bcd	8.0 bcd	8.2 abc	7.8 bcd	8.1
CQR12T50	8.0def	-	-	np	7.8 abc	np	8.6 a-d	7.9 bcd	np	-	8.1
Cripp's Pink (Pink Lady®)	7.8 f	np	np	7.0 e	7.2 bc	7.0 hi	7.6 def	np	7.2 def	6.7 gh	7.2
Delblush	8.3 c-f	6.7 g	7.8 cdfg	7.0 e	7.1 bc	7.3 fgh	7.4 ef	7.0 ef	6.9 ef	7.1 eg	7.2
Golden Delicious (Gibson)	8.6 a-e	7.8 a-e	7.9 abcdf	7.9 bc	7.3 bc	7.4 e-h	8.0 cde	7.6 cd	7.3 def	7.5 b-e	7.7
Hampshire	8.8 abc	8.3 a	7.2 fgh	8.5 a	8.1 ab	8.3 abc	9.0 a	8.0 bc	7.7 a-e	8.2 ab	8.2
Jubilee Fuji	8.6 a-e	-	-	6.8 e	-	7.6 d-g	8.2 bcd	7.4 b-f	7.5 cde	7.5 cde	7.7
Minnewashta (Zestar!®)	8.7 a-d	7.9 a-d	8.0 a-d	7.4 cde	7.9 ab	8.0 bcd	8.4 a-d	8.0 bcd	8.5 a	7.7 a-e	8.1
McIntosh	np	np	8.2 abce	np	np	np	np	np	np	np	8.2
NJ 90	8.4 b-f	7.9 a-d	8.4 ab	7.4 cde	7.4 bc	7.8 b-f	8.5 a-d	7.8 b-e	8.0 abc	7.6 b-e	7.9
NJ 109	8.4 c-f	7.3 def	6.4 i	-	7.5 abc	7.3 e-h	8.0 b-e	7.1 def	7.7 a-e	7.0 eg	7.4
NY 65707-19	8.1 ef	np	8.3 a-d	7.7 bcd	7.6 abc	7.9 b-e	8.4 a-d	8.0 bc	8.0 abc	np	8.0
NY 79507-49	9.1 a	np	7.4 dfgh	np	np	8.4 ab	8.9 a	9.1 a	8.5 a	8.4 a	8.6
NY 79507-72	8.5 cde	8.0 abc	7.9 abcdf	7.2 cde	7.3 bc	7.7 b-h	8.6 abc	8.3 ab	8.3 ab	7.7 b-e	7.9
Pinova	8.4 cde	7.3 ef	np	8.1 ab	np	7.6 d-g	np	7.6 bcd	np	np	7.8
Runkel	9.1 ab	8.1 ab	8.4 abc	8.3 ab	8.5 a	8.6 a	8.7 ab	8.2 b	8.2 ab	8.1 ab	8.4
Silken	np	7.2 efg	7.7 cdfg	7.1 cde	7.2 bc	7.0 h	np	7.4 cde	7.3 def	7.5 b-e	7.3
Mean all cultivars	8.5	7.6	7.8	7.5	7.6	7.7	8.2	7.8	7.7	7.5	

[z] Locations: See Table 1 for explanation of location codes
[y] Means within a location not sharing a common letter are significantly different by pairwise t tests from the analysis of the mixed model ($p \leq 0.05$)
[x] np = the cultivar was not planted at this location
[w] - = no data were taken, the cultivar was lost at this location, or the mean starch index rating fell outside the acceptable range of 3.5 to 6.5

the smallest diameter fruit at the MA location and was the second smallest fruit at four other locations (Table 5). Averaged across all locations 'Chinook' had the smallest fruit diameter followed by 'Cripp's Pink' and 'Delblush'. In the cultivar release, Cripps et al. (7) characterized 'Cripp's Pink' as a medium to large apple which they indicated was 7.0 to 7.5 cm. 'Cripp's Pink' averaged 7.2 cm across seven planting locations in this study (Table 5). When all cultivars were averaged at a location, BC had the largest diameter fruit and WV and OR had the smallest diameter fruit. The tendency for smaller diameter fruit at the OR location is somewhat surprising since apples grown in the Pacific Northwest region are often larger than from other locations in the U.S. The OR planting site was west of the Cascades where spring can be cooler and this may explain the smaller fruit size. Fruit sizes of 7.5 cm represent a box size of at least 125 count fruit and nearly 113 count (apple tray pack sizes, Durand-Wayland, LaGrange, GA), which would be commercially acceptable.

Fruit size (weight and diameter) is affected by crop load with fruit size generally decreasing as crop load increases. Crassweller et al. (6) reported 'Chinook' had the highest average crop load [6.1 fruit per cm^{-2} trunk cross-sectional area (TCSA)] among the 23 cultivars evaluated across 17 locations in this study and an average fruit diameter of 6.8 cm (Table 5). 'Golden Delicious', the standard for comparison, had a crop load of 4.4 fruit/ cm^{-2} TCSA with an average fruit weight of 183 g (5) and an average fruit diameter of 7.7 cm (Table 5). In contrast, 'Cripp's Pink' and 'Delblush', two of the smaller cultivars in terms of diameter (both 7.2 cm) (Table 5) and fruit weight (Table 5) (6), had moderate to low crop loads (3.8 and 3.0 fruit/ cm^{-2} TCSA, respectively) (6). This suggests that 'Cripp's Pink' and 'Delblush' may be inherently small and will require aggressive thinning and other cultural practices to obtain commercially acceptable fruit size.

Fruit shape can be characterized by a fruit's length/diameter (L:D) ratio. 'Golden Delicious', characterized as a round-conic apple (26) had an L:D ratio of 0.93 when averaged across 10 locations (Table 6). True conic or oblong shaped apples would be expected to have an L:D ratio greater than 'Golden Delicious'. 'Delblush', 'Cripp's Pink', NJ 109, and 'Autumn Gold' all had L:D ratios above 0.93 (Table 6). Published descriptions for 'Cripp's Pink' and 'Autumn Gold' support our findings regarding fruit shape (7,13). At seven of 10 locations 'Delblush' had the highest L:D ratio. At two locations NJ 109 had the highest L:D ratio, while at the MA location 'Delblush' and NJ 109 had equally high L:D ratios. Fruit with an L:D ratio of about 0.85 or below could be characterized as oblate or flat. In the present study one selection, NY 79507-72, had the lowest L:D ratio across all locations with an average L:D ratio of 0.77. Field observations of NY 79507-72 would support a description of flat for this selection. When averaged over all cultivars, the BC location produced fruit with the highest L:D ratio. The lowest L:D ratio averaged across all cultivars occurred at the WV and PAB locations. In the previous study of 19 different apple cultivars (23) the BC location had the highest L:D ratio and the WV location had the lowest L:D ratio. The WV planting was located at the most southern latitude among the 10 locations reporting L:D ratio while the BC location was the most northern latitude. Temperatures during early fruit development can affect fruit shape, and high temperatures during this period are known to reduce fruit elongation (34). While the previous evaluation of apple cultivars (23) supports the premise that the most southern planting locations are likely to have fruit with a low L:D ratio, in the present study the lack of a location main treatment effect and a significant C x L interaction (Table 2) indicates locations responded differently and the same conclusion may not be justified.

Flesh quality. Objective measures of flesh quality in this study included flesh firmness, SSC and TA. Mean flesh firmness for the

Table 6. Generalized least-squares means for fruit length/diameter (L:D) ratio among 23 apple cultivars grown at 10 planting locations for the years 2001 through 2004.

Cultivar	Mean fruit L:D ratio										Cultivar mean
	BC[z]	MA	NJ	OR	PAB	PAR	UT	VT	WI	WV	
Ambrosia	0.95 def[y]	0.90 bcd	0.94abc	0.93 cde	0.87 b-e	0.90 def	0.91 bcef	0.90 cde	0.91 b-f	0.88 c-f	0.91
Autumn Gold	1.01 ab	0.95 ab	0.98 a	0.96 abc	0.89 a-f	np[x]	-[w]	np	0.93 abc	0.92 abc	0.95
BC 8S-26-50	np	0.92 bc	0.93 bc	0.94 b-e	0.91 a-d	0.91 cde	0.94 ab	0.87 def	-	0.89 cd	0.91
Chinook	np	0.86 e	0.88 de	0.88 fg	0.83 d-g	0.85 ghi	0.89 c-g	0.86 efg	0.87 dfghi	0.83 gh	0.86
Co-op 29 (Sundance™)	0.95 def	0.88 de	0.89 cde	0.88 fg	-	0.87 efg	0.88 fg	0.87 def	0.91 bce	0.85 d-g	0.89
Co-op 39 (Crimson Crisp™)	0.94 ef	0.89 cde	0.91 b-e	0.89 ef	0.85 c-g	0.86 fgh	np	0.88 cde	0.91 b-g	0.89 cde	0.89
CQR10T17	0.98 bcd	0.91 bcd	0.94 abc	0.94 bcd	0.91 abc	0.93 bcd	0.87 fgh	0.89 cde	0.93 a-d	0.90 bc	0.92
CQR12T50	0.89 hi	-	-	np	0.84 c-g	np	0.88 e-h	0.82 fgh	np	-	0.86
Cripp's Pink (Pink Lady®)	1.01 ab	np	np	0.98 ab	0.92 ab	0.94 abc	0.95 abc	np	0.97 a	0.93 ab	0.96
Delblush	1.03 a	0.97 a	0.99 a	0.99 a	0.95 a	0.97 a	0.96 a	1.02 a	0.97 a	0.91 abc	0.98
Golden Delicious (Gibson)	0.99 bc	0.90 b-e	0.96 ab	0.93 cd	0.89 a-d	0.91 cde	0.94 abd	0.91 c	0.95 ab	0.90 bc	0.93
Hampshire	0.89 hi	0.82 fg	0.86 ef	0.85 ghi	0.81 e-h	0.83 hij	0.82 ij	0.82 gh	0.85 ghjk	0.82 ghi	0.84
Jubilee Fuji	0.93 fg	-	-	0.91 def	-	0.86 fgh	0.85 ghi	0.87 c-g	0.87 e-j	0.85 efg	0.88
Minnewashta (Zestar!®)	0.89 hi	0.85 ef	0.85 ef	0.88 fg	0.81 fgh	0.84 ghi	0.84 hij	0.82 fgh	0.85 hj	0.83 f-i	0.85
McIntosh	np	np	0.80 gh	np	np	np	np	np-	np	np	0.80
NJ 90	0.85 i	0.80 gh	0.85 ef	0.84 hi	0.80 gh	0.80 jk	0.80 jk	0.80 ghi	0.80 kl	0.79 i	0.81
NJ 109	1.01 ab	0.97 a	0.98 a	-	0.91 abc	0.96 ab	0.93 abce	0.97 b	0.99 a	0.95 a	0.96
NY 65707-19	0.94 efg	np	0.86 efg	0.87 fgh	0.84 c-g	0.86 ghi	0.90 cef	0.87 def	0.89 c-h	np	0.88
NY 79507-49	0.91 gh	np	0.82 fg	np	np	0.82 ij	0.84 hi	0.82 gh	0.87 fghj	0.80 hi	0.84
NY 79507-72	0.81 j	0.76 h	0.78 h	0.80 i	0.75 h	0.77 k	0.76 k	0.76 i	0.78 l	0.74 j	0.77
Pinova	0.96 cde	0.88 de	np	0.94 cd	np	0.90 de	np	0.90 cd	np	np	0.92
Runkel	0.89 hi	0.82 fg	0.89 cde	0.87 fgh	0.79 gh	0.83 hij	0.85 ghi	0.79 hi	0.83 jk	0.83 gh	0.84
Silken	np	0.92 bcd	0.91 cd	0.90 d-g	0.90 a-d	0.89 def	np	0.91 bc	0.91 bce	0.93 abc	0.91
Mean all cultivars	0.94	0.88	0.90	0.90	0.86	0.88	0.88	0.87	0.89	0.86	

[z] Locations: See Table 1 for explanation of location codes
[y] Means within a location not sharing a common letter are significantly different by pairwise t tests from the analysis of the mixed model ($p \leq 0.05$)
[x] np = the cultivar was not planted at this location
[w] - = no data were taken, the cultivar was lost at this location, or the mean starch index rating fell outside the acceptable range of 3.5 to 6.5

Table 7. Generalized least-squares means for flesh firmness among 23 apple cultivars grown at 12 planting locations for the years 2001 through 2004.

Cultivar	Mean flesh firmness (kg)												Cultivar mean
	BC[z]	ID	MA	NJ	ON	OR	PAB	PAR	UT	VT	WI	WV	
Ambrosia	7.9 efg[y]	8.1 cde	8.8 e	8.0 b-f	-[x]	7.1 egh	8.4 b-e	8.0 def	9.0 cd	8.4 b-f	8.2 cde	7.7 d-h	8.1
Autumn Gold	7.4 g	7.0 def	8.3 efg	6.8 efg	-	6.2 h	9.5 bcd	npw	-	np	7.5 efg	7.3 ghi	7.5
BC 8S-26-50	np	8.6 cd	8.7 e	7.2 efg	7.6 cd	7.1 e-h	8.2 b-f	7.5 efg	8.7 def	8.4 b-f	-	7.4 fgh	7.9
Chinook	np	-	10.0 cd	9.1 b	9.5 a	8.1 bcdf	9.8 b	9.9 bc	10.8 a	9.2 b	9.1 bcd	8.3 c-f	9.4
Co-op 29 (Sundance™)	8.7 cde	-	10.9 b	8.5 bcd	8.4 abc	8.2 bcd	-	9.9 bc	9.7 bc	8.9 bc	9.9 ab	8.5 bcd	9.2
Co-op 39 (Crimson Crisp™)	9.3 bc	10.3 ab	10.7 bc	9.4 b	-	9.1 bc	8.8 b-e	10.9 ab	np	8.6 b-e	10.0 ab	9.2 b	9.6
CQR10T17	10.8 a	11.4 a	12.0 a	11.2 a	-	10.4 a	12.0 a	11.1 a	11.8 a	10.4 a	10.3 ab	10.7 a	11.1
CQR12T50	8.2 d-g	7.9 cde	-	-	np	np	7.9 c-g	np	10.5 ab	8.4 b-g	np	-	8.6
Cripp's Pink (Pink Lady®)	10.0 ab	-	np	np		np9.0 b	8.5 b-e	10.0 abc	10.7 ab	np	10.6 a	8.5 bcd	9.6
Delblush	8.3 def	8.9 bc	10.1 bcd	7.8 cde	8.0 bc	8.1 cdf	9.5 bc	8.8 d	9.8 bc	8.5 b-e	9.0 bcd	8.3 cde	8.8
Golden Delicious (Gibson)	7.4 g	7.2 def	7.3 fgh	6.9 efg	-	7.0 gh	7.7 d-g	7.9 def	7.5 gh	7.0 h	7.8 ef	7.5 e-h	7.4
Hampshire	7.5 fg	7.9 cde	8.4 ef	6.4 g	7.8 b-e	7.2 eg	8.6 b-e	8.2 de	8.2 d-g	6.8 h	8.2 cde	7.5 e-h	7.7
Jubilee Fuji	7.2 g	6.8 ef	-	-	-	6.7 gh	-	7.9 def	7.8 fgh	-	7.3 ef	6.9 hi	7.2
Minnewashta (Zestar!®)	5.9 h	5.6 fg	7.2 h	7.4 e-g	-	6.4 gh	6.6 fg	6.5 g	6.9 hi	6.5 h	6.1 g	6.3 i	6.5
McIntosh	np	np	np	7.1 efg	6.5 de	np	np	np	np	np	np	np	6.8
NJ 90	8.0 e-g	-	7.8 fgh	7.3 efg	7.8 b-e	6.6 gh	7.4 efg	7.4 efg	7.7 gh	-	7.6 ef	6.9 hi	7.4
NJ 109	6.0 h	4.3 g	7.5 gh	7.6 def	6.4 e	-	6.4 g	7.0 fg	6.3 i	6.9 gh	6.5 fg	6.8 hi	6.5
NY 65707-19	7.9 efg	np	np	6.8 efg	7.8 b-e	7.0 gh	7.7 d-g	8.7 d	7.9 efg	7.3 gh	8.1 de	np	7.7
NY 79507-49	7.8 fg	np	np	8.5 bcd	-	np	np	8.9 cd	8.7 def	7.8 c-h	8.2 cde	8.0 c-g	8.3
NY 79507-72	9.1 bcd	7.9 cde	9.7 d	8.8 bc	9.1 ab	8.6 bcd	9.6 b	10.4 ab	8.9 cde	8.7 bcd	9.2 bc	8.8 bc	9.1
Pinova	7.6 fg	7.0 def	8.8 e	np	7.1 cde	7.9 de	np	8.1 de	np	7.5 fgh	np	np	7.7
Runkel	7.5 g	-	8.3 efg	6.4 fg	-	6.7 gh	7.3 efg	7.6 ef	7.8 fgh	7.5 e-h	7.6 ef	7.2 ghi	7.4
Silken	np	6.8 ef	8.4 efg	8.7 bc	-	8.4 b-e	7.5 efg	8.8 d	np	7.6 d-h	7.4 ef	7.5 d-h	7.9
Mean all cultivars	8.0	7.7	9.0	7.9	7.8	7.7	8.4	8.7	8.8	8.0	8.3	7.9	

[z] Locations: See Table 1 for explanation of location codes
[y] Means within a location not sharing a common letter are significantly different by pairwise t tests from the analysis of the mixed model ($p \leq 0.05$)
[x] - = no data were taken, the cultivar was lost at this location, or the mean starch index rating fell outside the acceptable range of 3.5 to 6.5
[w] np = the cultivar was not planted at this location

23 cultivars at 12 locations is presented in Table 7. CQR10T17 was the firmest cultivar at 10 of 11 locations that reported data for this selection. 'Cripp's Pink' was the firmest cultivar at the WI location followed closely by CQR10T17. No data were reported for CQR10T17 at the ON location and 'Cripp's Pink' was not planted at this location where 'Chinook' had the firmest flesh. Averaged over all locations CQR10T17 had the highest flesh firmness among the 23 cultivars evaluated followed by 'Cripp's Pink', 'Co-op 39', and 'Chinook'. Janick et al. (20) reported 'Co-op 39' averaged 7 to 10 kg firmness. In our study, 'Co-op 39' averaged 9.6 kg flesh firmness. In the cultivar release paper, Cripps et al. (7) indicated 'Cripp's Pink' had a flesh firmness of about 8.4 kg at harvest and generally about 0.3 kg greater than 'Golden Delicious'. Our results show 'Cripp's Pink' with an average flesh firmness of 9.6 kg and about 2.2 kg firmer than 'Golden Delicious'. Small fruit size is often associated with higher flesh firmness readings. CQR10T17 was a large fruit, averaging 8.1 cm in diameter (Table 5) while 'Chinook' had smaller fruit (average 6.8 cm diameter) as did 'Cripp's Pink', but 'Co-op 39', a rather dense flesh cultivar, averaged almost 7.5 cm (about 3 inches) in diameter, a 113 box size (apple tray pack sizes, Durand-Wayland, LaGrange, GA), not small by commercial standards.

'Minnewashta' was the least firm cultivar at 6 of 11 locations. NJ 109 was the least firm at four locations and together with 'Minnewashta', they were the least firm cultivars averaged over all locations. Early maturing cultivars can lack good flesh firmness. 'Minnewashta' was the earliest maturing cultivar in this study maturing an average of 43 days before 'Golden Delicious' and NJ 109 averaged 24 days before 'Golden Delicious'. When averaged across all cultivars, the MA location produced the firmest fruit and the ID and OR sites produced fruit with the lowest average flesh firmness (Table 7). Average flesh firmness does not appear to be closely related to fruit size in this study since the OR location, along with the WV location, produced the smallest fruit (Table 5). BC, which produced the largest size fruit on average, had a medium level flesh firmness. The average for flesh firmness across all cultivars and all locations was 8.2 kg (18.1 lb) at harvest suggesting good to excellent flesh firmness for many cultivars in this test. However, this average is skewed somewhat by the unusually high flesh firmness for CQR10T17 and the high firmness associated with many of the smaller sized cultivars. A flesh firmness reading between 7.3 and 8.2 kg at harvest would be considered good for most cultivars. In our test, 10 of 23 cultivars fell within this range of flesh firmness, 8 cultivars averaged above this range in firmness and only four cultivars fell below this firmness range (Table 7).

Results for mean SSC for the 23 cultivars at 12 locations are presented in Table 8. SSC ranged from a high of 19.3% for BC 8S-26-50 at the PAR location to a low of 11.4% for CQR12T50 at the PAB location. 'Delblush' had the highest SSC at five locations and 'Delblush' and/or BC 8S-26-50 produced the highest SSC at all but two of the 12 reporting locations (WI and ID). CQR10T17, CQR12T50, 'Autumn Gold', 'Chinook', 'Jubilee Fuji' and NY 65707-19 were among the cultivars with the lowest SSC, but no single cultivar consistently produced the lowest SSC. CQR10T17 was the most often identified as having the lowest SSC (Table 8). When averaged across all locations BC 8S-26-50 followed by 'Delblush' had the highest SSC and the two CQR selections had the lowest SSC. 'McIntosh' was among the cultivars with a lower SSC (13.3%), but it was represented at only 2 locations in the study. SSC averaged across all cultivars and all locations was 14.5%, suggesting most of these cultivars have good to excellent sugar levels. Only two locations, BC and WV, reported results for fruit TA (Table 9). TA for most cultivars was about twice as high at the BC location compared to the same cultivar grown at the WV location. At both locations the cultivars producing the highest TA were 'Cripp's

Table 8. Generalized least-squares means for soluble solids concentration (SSC) among 23 apple cultivars grown at 12 planting locations for the years 2001 through 2004.

Cultivar	Soluble solids concentration (%)												Cultivar mean
	BC[z]	ID	MA	NJ	ON	OR	PAB	PAR	UT	VT	WI	WV	
Ambrosia	14.7 b-e[y]	14.1 cde	12.9 c-f	12.1 ghi	-[x]	16.0 c-f	12.9 c-f	15.5 d-g	15.7 def	13.0 ef	13.4 cd	15.0 a-d	14.1
Autumn Gold	14.9 bcd	13.2 de	11.9 f	14.3 b-g	-	16.4 b-e	12.7 c-f	npw	-	np	14.0 bcd	12.5 g	13.7
BC 8S-26-50	np	16.7 abc	15.6 a	16.7 a	16.9 ab	18.3 a	17.5 a	19.3 a	18.6 a	14.8 bcd	-	15.2 ab	17.0
Chinook	np	-	13.0 c-f	14.4 cde	13.7 cd	16.6 bcd	13.3 b-f	17.0 bc	18.7 a	12.9 ef	14.5 bcd	14.2 b-f	14.8
Co-op 29 (Sundance™)	15.2 bcd	-	14.6 ab	14.4 b-f	15.8 a-d	14.2 gh	-	16.1 cde	16.8 bcd	13.7 def	14.0 bcd	14.4 b-e	14.9
Co-op 39 (Crimson Crisp™)	14.3 de	14.9 bcd	12.5 ef	13.9 b-i	-	14.8 fgh	14.2 bcd	14.9 e-i	np	14.1 cde	13.7 bcd	13.8 c-f	14.1
CQR10T17	14.5 cde	14.0 de	12.1 f	12.2 ghi	-	13.3 h	11.9 ef	13.9 i	13.9 g	13.2 ef	13.5 bcd	13.0 fg	13.2
CQR12T50	13.3 e	12.5 e	-	-	np	np	11.4 f	np	15.2 d-g	13.8 c-f	np	-	13.2
Cripp's Pink (Pink Lady®)	15.8 bc	-	np	np	np	15.4 d-g	15.5 ab	15.8 c-f	18.6 ab	np	14.8 bcd	14.9 abc	15.8
Delblush	17.8 a	16.2 abc	15.6 a	15.7 ab	17.8 a	17.4 ab	15.1 abc	18.1 ab	18.8 a	16.9 a	17.5 a	16.3 a	16.9
Golden Delicious (Gibson)	15.9 b	15.4 a-d	14.6 a-d	15.1 bc	-	16.4 b-e	14.0 b-e	18.0 ab	17.8 abc	15.8 ab	18.1 a	16.1 a	16.1
Hampshire	14.6 cde	14.7 b-e	12.8 def	12.2 i	14.0 cd	14.5 gh	12.9 c-f	14.8 f-i	16.5 cde	12.8 f	14.0 bcd	13.8 c-g	14.0
Jubilee Fuji	14.9 bcd	14.4 cd	-	-	-	17.4 abc	-	14.6 f-i	14.9 fg	13.9 c-f	13.2 d	13.6 d-g	14.6
Minnewashta (Zestar!®)	15.4 bc	17.4 a	13.9 bcd	14.6 b-e	-	15.3 efg	13.7 b-f	15.5 d-g	16.6 b-e	13.1 def	15.0 b	13.4 c-g	14.9
McIntosh	np	np	np	12.4 gi	14.3 cd	np	np	np	np	np	np	np	13.3
NJ 90	15.8 bc	-	13.0 c-f	12.2 i	14.6 cd	15.4 d-g	12.6 def	15.3 d-h	16.2 def	13.4 c-f	14.5 bcd	13.4 efg	14.2
NJ 109	14.9 b-e	15.1 a-d	13.2 c-f	14.7 bcd	15.6 bc	-	12.9 c-f	14.6 f-i	14.7 fg	12.8 def	15.2 bc	13.1 efg	14.3
NY 65707-19	14.8 bcd	np	np	13.1 defgi	13.8 d	14.6 gh	12.7 def	14.4 ghi	15.3 efg	12.5 f	14.1 bcd	np	13.9
NY 79507-49	14.2 de	np	np	13.1 e-i	-	np	np	15.6 d-g	16.6 b-e	13.8 c-f	13.9 bcd	12.9 fg	14.3
NY 79507-72	14.2 de	13.5 de	12.3 ef	14.0 c-h	14.2 cd	14.2 fgh	12.6 def	14.9 e-i	15.8 def	13.2 def	13.3 cd	12.9 fg	13.8
Pinova	15.9 b	16.6 ab	14.1 bc	np	14.4 cd	15.4 d-g	np	16.5 cd	np	15.3 bc	np	np	15.4
Runkel	15.4 bcd	-	13.0 c-f	13.3 c-i	-	14.5 fgh	11.9 def	14.6 f-i	16.6 b-e	13.3 ef	13.7 bcd	13.2 efg	14.0
Silken	np	15.0 bcd	13.6 b-e	13.0 fgi	-	14.3 fgh	3.4 b-f	14.2 hi	np	12.6 f	13.8 bcd	13.6 c-g	13.7
Mean all cultivars	15.1	14.9	13.5	13.8	15.0	15.5	13.4	15.7	16.5	13.7	14.4	14.0	

[z] Locations: See Table 1 for explanation of location codes
[y] Means within a location not sharing a common letter are significantly different by pairwise t tests from the analysis of the mixed model ($p \leq 0.05$)
[x] - = no data were taken, the cultivar was lost at this location, or the mean starch index rating fell outside the acceptable range of 3.5 to 6.5
[w] np = the cultivar was not planted at this location

Table 9. Generalized least-squares means for titratable acidity (TA) among 22 apple cultivars grown at 2 locations for the years 2001 through 2004.

Cultivar	Mean titratable acidity (% malic acid) BC[z]	WV	Cultivar mean
Ambrosia	0.54 i[y]	0.22 ij	0.38
Autumn Gold	0.56 i	0.22 ij	0.39
BC 8S-26-50	np[x]	0.29 hi	0.29
Chinook	np	0.40 defghj	0.40
Co-op 29 (Sundance™)	1.25 bc	0.59 abc	0.92
Co-op 39 (Crimson Crisp™)	1.16 cde	0.55 bcd	0.85
CQR10T17	0.94 fg	0.56 bcd	0.75
CQR12T50	1.35 bc	-[w]	1.35
Cripp's Pink (Pink Lady®)	1.64 a	0.68 ab	1.16
Delblush	1.41 ab	0.74 a	1.07
Golden Delicious (Gibson)	1.02 ef	0.48 c-f	0.75
Hampshire	0.78 gh	0.46 c-g	0.62
Jubilee Fuji	0.73 h	0.40 e-h	0.56
Minnewashta (Zestar!®)	1.19 cd	0.48 b-h	0.84
NJ 90	1.10 c-f	0.40 efghj	0.75
NJ 109	1.01 def	0.56 a-e	0.78
NY 65707-19	0.96 f	np	0.96
NY 79507-49	0.67 hi	0.36 f-i	0.52
NY 79507-72	0.80 gh	0.58 abc	0.69
Pinova	1.17 cde	np	1.17
Runkel	0.55 i	0.32 ghi	0.43
Silken	np	0.41 c-i	0.41
Mean all cultivars	0.99	0.46	

[z] Locations: See Table 1 for explanation of location codes
[y] Means within a location not sharing a common letter are significantly different by pairwise t tests from the analysis of the mixed model ($p \leq 0.05$)
[x] np = the cultivar was not planted at this location
[w] -= no data were taken, the cultivar was lost at this location, or the mean starch index rating fell outside the acceptable range of 3.5 to 6.5

Pink' and 'Delblush' while 'Ambrosia', 'Autumn Gold', and 'Runkel' produced fruit with the lowest TA. Compared to the standard, 'Golden Delicious', 'Cripp's Pink' and 'Delblush' had about 30% to 40% more acid and 'Ambrosia' and 'Autumn Gold' about 36% less acid. TA reported by Cripps et al. (7) ranged between 0.71% and 0.90%. In our study TA averaged 1.16% as malic acid, however, this is an average from only two locations. The level of TA is often a good indicator of the degree of tartness perceived in an apple's taste. The cultivars in this study with the higher TA including 'Cripp's Pink', 'Delblush', 'Pinova', 'Co-op 29', CQR12T50, NY 65707-19, and 'Minnewashta' could be characterized as somewhat tart to fully tart apples. Cultivars with the lowest TA values exhibited a sweet taste. The mean TA for all cultivars across both locations was 0.73% as malic acid. Ten cultivars averaged below the overall mean and 12 cultivars averaged above the overall mean indicating a good mix of sweet, tart or sweet/tart tasting apples in this group.

Red color and russet. Among the locations that reported red overcolor, only the WV and NJ planting sites were located in climatic re-

Table 10. Generalized least-squares means for surface red color among 23 apple cultivars grown at 9 planting locations for the years 2001 through 2004.

Cultivar	Red over color (%)[z]									Cultivar mean
	MA[y]	NJ	ON	OR	PAR	UT	VT	WI	WV[x]	
Ambrosia	70 c-e[w]	74 ab	-[v]	72 cd	80 cde	73 de	74 c	71 bcd	66 cd	73
Autumn Gold	0 hi	8 d	-	2 e	np[u]	-	np	36 e	-	11
BC 8S-26-50	80 bc	74 ab	92 a	95 a	84 a-e	88 abc	82 abc	-	67 cd	83
Chinook	77 b-d	84 a	100 a	93 a	93 abc	93 ab	83 abc	90 a	83 ab	88
Co-op 29 (Sundance™)	21 g	17 d	32 bc	17 e	32 g	14 g	24 e	32 e	-	24
Co-op 39 (Crimson Crisp™)	86 ab	88 a	-	94 a	92 abc	np	94 a	83 abc	78 abc	88
CQR10T17	65 e	69 ab	-	86 abc	72 ef	78 b-e	81 abc	83 abc	64 d	75
CQR12T50	-	-	np	np	np	12 gh	14 ef	np	-	13
Cripp's Pink (Pink Lady®)	np	np	np	63 d	84 a-e	100 ab	np	76 abc	70 bcd	79
Delblush	13 gh	9 d	39 b	7 e	22 gh	1 gh	15 ef	60 d	-	21
Golden Delicious (Gibson)	2 ghi	4 d	-	15 e	1 i	0 h	7 f	31 e	-	9
Hampshire	86 ab	85 a	93 a	85 abc	96 a	66 e	88 ab	90 ab	88 a	86
Jubilee Fuji	-	-	-	97 a	83 b-e	75 cde	83 abc	81 abc	61 d	80
Minnewashta (Zestar!®)	45 f	46 c	-	76 bcd	66 f	45 f	53 d	69 cd	38 e	55
McIntosh	np	47 c	92 a	np	np	np	np	np	np	70
NJ 90	95 a	83 a	92 a	96 a	95 ab	85 a-d	90 abc	89 a	89 a	90
NJ 109	4 hi	3 d	17 c	-	8 hi	2 gh	12 ef	26 ef	-	10
NY 65707-19	np	73 ab	90 a	90 ab	89 abc	87 abc	77 bc	91 a	np	85
NY 79507-49	np	60 bc	-	np	91 abc	90 ab	70 cd	83 abc	62 d	76
NY 79507-72	83 ab	83 a	93 a	91 ab	89 a-d	97 a	86 abc	85 ab	69 cd	86
Pinova	64 e	np	77 a	83 abc	77 def	np	72 c	np	np	75
Runkel	68 de	78 ab	-	95 ab	81 c-e	81 bcd	76 bc	76 abc	62 d	77
Silken	0 i	3 d	-	17 e	3 i	np	3 f	13 f	-	6
Mean all:										
red skin cultivars	74	73	91	87	85 76	75	82	69		
yellow skin cultivars	7	7	29	11	13 5	12	33	-		

[z] Visual rating to the nearest 5% surface red color to include blush on yellow skin cultivars
[y] Locations: See Table 1 for explanation of location codes
[x] Yellow skinned cultivars were not rated for red blush at this location
[w] Means within a location not sharing a common letter are significantly different by pairwise t tests from the analysis of the mixed model ($p \leq 0.05$)
[v] - = no data were taken, the cultivar was lost at this location, or the mean starch index rating fell outside the acceptable range of 3.5 to 6.5
[u] np = the cultivar was not planted at this location

gions where red color development can be a problem based on grower and research experience. The data support this supposition as WV had the lowest percent surface red color averaged over all red skin cultivars followed closely by NJ (Table 10). The highest percent red overcolor on red skin cultivars averaged across all cultivars was recorded at the ON location followed by the OR, PAR, WI locations, all of which had 82% red surface color or better. Among the 17 red skin cultivars, 13 averaged 75% surface red color or greater. No single cultivar was identified as consistently having the most surface red color and the cultivar with the highest percent surface red color varied from one location to another. NJ 90 had the most surface red color at two locations, MA and WV, and was the second best cultivar in terms of red skin color at three other locations, OR, PAR, and VT. 'Minnewashta' stood out among the red skin cultivars as having the least amount of red color. 'Minnewashta' is described as having 50% to 85% red stripe (28). In our evaluation at eight locations, 'Minnewashta' averaged 55% red color and four of those locations recorded less than 50% red color averaged over four harvest seasons (Table 10). WI and ON recorded the most red (or pink) blush on the yellow skin cultivars (Table 10). WI was one of the most northern planting locations in this study and could be expected to produce good red color. 'Co-op 29' and 'Delblush' had the most red blush among the yellow skin cultivars. Janick et al. (19) described 'Co-op 29' as occasionally having a mottled orange-red blush. In this study 'Co-op 29' had a mean of 24% surface blush averaged across 8 locations. 'Golden Delicious' produced 9% red blush. In the previous study, 'Golden Delicious' produced 8% red blush averaged over 14 planting locations (23).

The interaction of C x L for russet was not significant (Table 2), however, because the *P*–value was so close to the 5% level we have chosen to present the results for russet within each location (Table 11). Russet formation on the skin of some apple cultivars detracts from the apple's appearance and can reduce sales. The condition occurs with greater frequency in humid environments. Four locations, NJ, VT, WI, and WV, reported russet ratings for the 23 cultivars in this study (Table 11), a good contrast of humid and less humid environments. BC 8S-26-50 received the highest russet rating across all reporting locations followed by 'Golden Delicious' and 'Co-op 29'. An average russet rating of 3.5 for BC 8S-26-50 indicates this cultivar had about 12.5% of the surface covered by russet. 'Golden Delicious' rating was 2.9 indicating that about 10% of the surface on this cultivar was affected by russet. In the previous study 'Golden Delicious' received an average rating of 1.3, but the result was a mean of 9 planting locations. 'Co-op 29', with a russet rating of 2.7, was characterized by Janick et al. (19) as having russet in the basin that could extend to the side of the fruit. Observations in this study support their description. Several cultivars showed little tendency to form russet including NY 65707-19, NY 79507-72, 'Cripp's Pink', NJ 90, CQR10T17, 'Co-op 39', and 'Ambrosia'. The NJ and WV locations recorded the highest incidence of russeting averaged across all cultivars while the WI location reported the least amount of russet formation. The mean russet rating for all cultivars across all locations was 1.1 which was the identical overall mean russet rating for the 19 cultivars evaluated in the previous NE-183 study (23). This suggests that russet may be a problem for a few cultivars at specific locations, but in general, most of the cultivars evaluated have little tendency toward russet formation.

Conclusions

No one cultivar in the 1999 planting exhibited superior quality across all or a majority of locations. These findings are similar to the findings in the 1995 NE-183 planting (23). Likewise, no one cultivar was consistently superior in all or most of the quality attributes measured in this study. If large fruit size is an important characteristic for market-

Table 11. Generalized least-squares means for russet rating among 23 apple cultivars grown at four locations for the years 2001 through 2004.

Cultivar	Russet rating (scale, 1-5)[z]				Cultivar mean
	NJ[y]	VT	WI	WV	
Ambrosia	-[x]	0.6 fg[w]	0.3 cd	1.0 b	0.6
Autumn Gold	-	npv	0.7 bcd	1.0 b	0.9
BC 8S-26-50	5.0 a	2.6 abc	-	3.0 a	3.5
Chinook	3.6 b	0.7 efg	0.4 cd	0.8 b	1.4
Co-op 29 (Sundance™)	2.8 bcd	2.8 ab	1.7 b	3.6 a	2.7
Co-op 39 (Crimson Crisp™)	-	0.6 fg	0.4 bcd	0.9 b	0.6
CQR10T17	-	0.2 g	0.3 bcd	1.0 b	0.5
CQR12T50	-	0.8 d-g	np	-	0.8
Cripp's Pink (Pink Lady®)	np	np	0.1 cd	0.4 b	0.3
Delblush	1.4 cde	1.7 b-e	1.2 bcd	2.8 a	1.8
Golden Delicious (Gibson)	2.2 b-e	3.0 a	3.1 a	3.2 a	2.9
Hampshire	0.8 e	0.4 fg	0.6 bcd	0.7 b	0.6
Jubilee Fuji	-	0.5 efg	0.9 bcd	0.7 b	0.7
Minnewashta (Zestar!®)	1.4 de	0.4 efg	0.4 cd	0.7 b	0.7
NJ 90	0.9 e	0.1 fg	0.3 cd	0.4 b	0.4
NJ 109	1.1 e	0.9 d-g	1.1 bcd	1.0 b	1.0
NY 65707-19	-	0.1 g	0.1 cd	np	0.1
NY 79507-49	3.0 bc	0.3 efg	0.4 cd	0.8 b	1.1
NY 79507-72	1.2 de	0.0 g	0.1 d	0.1 d	0.4
Pinova	np	2.2 a-d	np	np	2.2
Runkel	-	0.7 efg	0.7 bcd	0.8 b	0.7
Silken	1.6 cde	1.5 c-f	1.2 bcd	1.2 b	1.4
Mean all cultivars	2.0	1.0	0.8	1.3	

[z] Russet rating, as percent surface covered: 0 = no russet, 1 = 0.1 to 5.0%, 2 = 5.1% to 10.0%, 3= 10.1% to 15.0%, 4 = 15.1% to 20.0% and 5 = over 20%

[y] Locations: See Table 1 for explanation of location codes

[x] - = no data were taken, the cultivar was lost at this location, or the mean starch index rating fell outside the accept able range of 3.5 to 6.5

[w] Means within a location not sharing a common letter are significantly different by pairwise t tests from the analysis of the mixed model ($p \leq 0.05$).

[v] np = cultivar not planted at this location

ing (37), NY 79507-49, 'Runkel', and 'Co-op 29' were among the largest cultivars evaluated. Among these three, 'Co-op 29' performed near the top in more quality variables than either NY 79507-49 or 'Runkel'. Results presented by Crassweller et al. (6), however, did show that 'Co-op 29' had a strong tendency toward biennial bearing and our results indicate russet could be a problem with this cultivar. NY 79507-49 may be a good candidate for processing based on its fruit size, flesh firmness, SSC, and time of maturity, but its release as a fresh market cultivar is uncertain (S. Brown, pers. communication). 'Hampshire' was also a large fruit with excellent color and a good SSC with very little russet. Its one quality weakness may be low flesh firmness. 'Chinook' was one of the poorer performing cultivars overall in terms of quality attributes. It is unfortunate that this cultivar was not included in the BC planting, since it originated at this location and probably would have performed much better under BC growing conditions. The same can be said for BC 8S-26-50 and Silken, neither of which was included in the BC planting. Considering all the quality factors evaluated in this study, several cultivars, in addition to

'Co-op 29', do appear to have above average potential over a fairly broad growing region, specifically 'Ambrosia', 'Cripp's Pink', and 'Pinova'. 'Ambrosia' had above average fruit weight, L:D ratio, and red surface color, average flesh firmness, and a low rating for surface russet compared to all other cultivars evaluated. 'Pinova' exhibited above average L:D ratio, SSC, and TA, average fruit diameter and red color and an acceptable level of flesh firmness. 'Pinova' was not planted in the three most southern locations, WV, PAB, and NJ, so performance in these areas is unknown. One negative exhibited by 'Pinova' was a high russet rating. Unfortunately, 'Ambrosia' and 'Pinova' (now named 'Piñata'™) have become "managed varieties" and therefore will have limited distribution especially among smaller size growing operations that focus on local retail sales. The other cultivar that ranked high, 'Cripp's Pink', had excellent flesh firmness, high SSC and TA, above average red surface color, and a very low russet rating. 'Cripp's Pink's' one negative was small fruit size.

The results confirm our use of 'Golden Delicious' as the standard of comparison, as noted by Crassweller et al. (6) in their results on growth and yield of the 1999 NE-183 planting. Results for quality variables in the 1995 planting were very similar to those in this study except in the present study SSC, TA, and skin russet were higher. These results reaffirm the need for widespread systematic testing of new apple cultivars across many sites in order to determine performance under different soil and climatic conditions.

Literature Cited

1. Barritt, B.H. 2001. Apple quality for consumers. Compact Fruit Tree 34:54-56.
2. Barritt, B.H. 2003. The apple world 2003 – present situation and developments for producers and consumers. Compact Fruit Tree 36:15-18.
3. Blanpied, G.D. and K.J. Silsby. 1992. Predicting harvest date windows for apples. Cornell Coop. Ext. Pub. Info. Bull. 221.
4. Cowgill, W.P., J.M. Clements, and NE183 Cooperators. 2001. NE-183 apple cultivar evaluation project. http://www.ne183.org
5. Crassweller, R.W., R. McNew, A. Azarenko, B. Barritt, R. Belding, L. Berkett, J. Cline, W. Cowgill, D. Ferree, E. Garcia, D. Greene, G. Greene, C. Hampson, I. Merwin, D. Miller, S. Miller, R. Moran, M. Parker, D. Rosenberger, C. Rom, T. Roper, J. Schupp, and E. Stover. 2005. Performance of apple cultivars in the 1995 NE-183 regional project planting: I. Growth and yield characteristics. J. Amer. Pomol. Soc. 59: 18-27.
6. Crassweller, R., R. McNew, D. Greene, S. Miller, A. Azarenko, B. Barritt, L. Berkett, S. Brown, J. Cline, W. Cowgill, E. Fallahi, B. Fallahi, E. Garcia, G. Greene, C. Hampson, T. Lindstrom, I. Merwin, J. Obermiller, M. Stasiak. 2007. Performance of apple cultivars in the 1999 NE-183 regional project planting. I. Growth and yield characteristics of apple cultivars in the 1999 NE-183 regional project planting. J. Amer. Pomol. Soc. 61: 84-96.
7. Cripps, J.E.L., L.A. Richards, and A.M. Mairata. 1993. 'Pink Lady' apple. HortScience 28:1057.
8. Gormley, T.R., D. Harrington and P.F. McDonnell. 1981. Quality of Golden Delicious apples grown in seven different orchard locations. Ir. J. Food Sci. Technol. 5:165-169.
9. Great American Publishing. 1995. Apple's appearance, inertia and crunch influence purchase. Great Lakes Fruit Grower News 34(3):54-55.
10. Greene, D.W. 2005. NE-183 Regional Project: Consumer survey of some of the most promising new apple varieties. Fruit Notes 70(3):1-6.
11. Greene, D., A. Azarenko, B. Barritt, B. Belding, L. Berkett, J. Cline, W. Cowgill, D. Ferree, E. Garcia, G. Greene, C. Hampson, R. McNew, I. Merwin, D. Miller, S. Miller, R. Moran, M. Parker, D. Rosenberger, C. Rom, T. Roper, J. Schupp, and E. Stover. 2004. Multidisciplinary evaluation of new apple cultivars: the NE-183 regional project. J. Amer. Pomol. Soc.58:61-64.
12. Greene, D., R. Crassweller, C. Hampson, R. McNew, S. Miller, A. Azarenko, B. Barritt, L. Berkett, S. Brown, W. Cowgill, J. Cline, C. Embree, E. Fallahi, B. Fallahi, E. Garcia, G. Greene, T. Lindstrom, I. Merwin, J.D. Obermiller, and M. Stasiak. 2007. Multidisciplinary evaluation of new apple cultivars: the NE-183 regional project 1999 planting. J. Amer. Pomol. Soc. 61: 78-83.
13. Greene, D.W., R.A. Norton, C.R. Rom, R.L. Stebbins, and R. Way. 1997. The Brooks and Olmo Register of Fruit and Nut Varieties. Third Edition. ASHS Press. Alexandria, Virginia.
14. Hampson, C.R., R. McNew, A. Azarenko, L. Berkett, B. Barritt, R. Belding, S. Brown, J. Clements, J. Cline, W. Cowgill, R. Crassweller, E. Garcia, D. Greene, G. Greene, I. Merwin, D. Miller, S. Miller, R. Moran, J.D. Obermiller, C. Rom, T. Roper, J. Schupp, and E. Stover. 2004. Performance of 'Braeburn', 'Golden Delicious and 'Yataka Fuji'

apple on Mark and M.9 rootstocks at multiple locations across north America. J. Amer. Pomol. Soc. 58:78-89.
15. Harker, R. 2002. Improve fruit quality to increase demand. Good Fruit Grower 53(3):27.
16. Harker, R. 2002. How people respond to apples Part 2: Eating quality. Good Fruit Grower 53(4):20.
17. Harker, R. 2002. Consumers like apples for health, taste, texture. Part 4: Beliefs, attitudes, and perceptions. Good Fruit Grower 53(6):16-17.
18. Harker, F. R., F. A. Gunson and S. R. Jaeger. 2003. The case for fruit quality: an interpretive review of consumer attitudes, and preferences for apples. Postharvest Biol Technol. 28:333-347.
19. Janick, J., J. C. Goffreda and S.S. Korban. 2004. 'Co-op 29' (Sundance™) apple. HortScience 39:450-451.
20. Janick, J., J. C. Goffreda and S.S. Korban. 2006. 'Co-op 39' (Crimson Crisp™) apple. HortScience 41:465-466.
21. Knee, M., S.G.S. Hatfield, and S.M. Smith. 1989. Evaluation of various indicators of maturity for harvest of apple fruit intended for long-term storage. J. Hort. Sci. 64:403-411.
22. Miller, S.S. 1991. Apple cultivars – current situation and trends around the world: an introduction. Fruit Var. J. 45:75-76.
23. Miller, S., R. McNew, R. Belding, L. Berkett, S. Brown, J. Clements, J. Cline, W. Cowgill, R. Crassweller, E. Garcia, D. Greene, G. Greene, C. Hampson, I. Merwin, R. Moran, T. Roper, J. Schupp, and E. Stover. 2004. Performance of apple cultivars in the 1995 NE-183 regional project planting: II. Fruit quality characteristics. J. Amer. Pomol. Soc. 58:65-77.
24. Miller, S., C. Hampson, R. McNew, L. Berkett, S. Brown, J. Clements, R. Crassweller, E. Garcia, D. Greene, and G. Greene. 2005. Performance of apple cultivars in the NE-183 regional project planting: III. Fruit sensory characteristics. J. Amer. Pomol. Soc. 59:28-43.
25. Miller, S. S., R. W. Mcnew, B. H. Barritt, L. Berkett, S. K. Brown, J. A. Cline, J. M. Clements, W. P. Cowgill, R. M. Crassweller, M. E. Garcia, D. W. Greene, G. M. Greene, C. R. Hampson, I. Merwin, D. D. Miller, R. E. Moran, C. R. Rom, T. R. Roper, J. R. Schupp, and E. Stover. 2005. Effect of cultivar and site on fruit quality as demonstrated by the NE-183 regional project on apple cultivars. HortTechnology 15:886-895.
26. Morgan, J. and A Richards. 1993. The book of apples. Ebury Press, London, UK.
27. Moxham, H. 2003. Consumer research 2003. Tree Fruit and Pome Fruit Austral. August, p. 12.
28. Norton, R. A. and R. D. Way. 1999. Register of new fruit and nut varieties list 39. Apple. HortScience 34:181-183.
29. O'Rourke, D. 2003. Changing dynamics of world fruit markets. Compact Fruit Tree 36(1):12-14.
30. Quamme, H.A., R.A. MacDonald, W.D. Lane, and C.R. Hampson. 1999. Chinook apple. Can. J. Plant Sci. 79:287-289.
31. Quamme, H.A., R.A. MacDonald, W.D. Lane, and C.R. Hampson. 1999. Silken apple. Can. J. Plant Sci. 79:295-297.
32. Redalen, G. 1988. Quality assessment of apple cultivars and selections. Acta Hort. 224:441-447.
33. Ricks, D., K. Heinze and J. Beggs. 1995. Consumer preference information related to Michigan apples. The Great Lakes Fruit Growers News 34(10):38-39.
34. Shaw, J.K. 1914. A study of variations in apple. Mass. Agr. Expt. Sta. Bull. 149. p. 29-36.
35. Shee, J. 2005. Build profits on what appeals most to shoppers. Penn. Fruit News 85(6):20, 22.
36. Stebbins, R. 1994. Consumers' tastes in apple varieties profiled. Good Fruit Grower 45(15):32-33.
37. Vance Publishing Co. 2004. Bigger is better in consumers' minds. The Grower 37(9):5.
38. van den Ende, B. 2006. Efficiency – key to survival. Tree Fruit (Pome Fruit Aust.). April, pp.26-27.
39. Watada, A.E. and J.A. Abbott. 1985. Apple quality influences of pre-and postharvest factors and estimation by objective methods. Pp.. 63-81. In: H. E. Pattee (Ed.) Evaluation of quality of fruits and vegetables, AVI, Westport, Conn.
40. Wills, R.B.H., P.A. Bambridge and K.J. Scott. 1980. Use of flesh firmness and other objective tests to determine consumer acceptability of Delicious apples. Aust. J. Exp. Agric. Anim. Husb. 20:252-256.