Variety Trials

Effect of Cultivar and Site on Fruit Quality as Demonstrated by the NE-183 Regional Project on Apple Cultivars

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SUMMARY. Cultivar and planting site are two factors that often receive minimal attention, but can have a significant impact on the quality of apple (*Malus × domestica*) produced. A regional project, NE-183 The Multidisciplinary Evaluation of New Apple Cultivars, was initiated in 1995 to systematically evaluate 20 newer apple cultivars on Malling.9 (M.9) rootstock across 19 sites in North America. This paper describes the effect of cultivar and site on fruit quality and sensory attributes at a number of the planting sites for the 1998 through 2000 growing seasons. Fruit quality attributes measured included fruit weight, length:diameter ratio, soluble solids concentration (SSC), titratable acidity (TA), flesh firmness, red overcolor, and russet. Fruit sensory characteristics rated included crispness, sweetness, and juiciness, based on a unipolar intensity scale (where 1 = least and 5 = most), and acidity, flavor, attractiveness, and desirability based on a bipolar hedonic scale (where 1 = dislike and 5 = like extremely). All fruit quality and sensory variables measured were affected by cultivar. The two-way interaction of cultivar and planting site was significant for all response variables except SSC, TA, russet, crispness, and sweetness ratings. The SSC:TA ratio was strongly correlated with sweetness and acidity sensory rating, but was weakly correlated with flavor rating. The results demonstrate that no one cultivar is ideally suited for all planting sites and no planting site is ideal for maximizing the quality of all apple cultivars.

Quality in apples is an important attribute for consumer acceptance and grower profitability (Harker et al., 2003). However, quality is a vague term meaning different things to different people. Quality as defined by an apple grower may differ significantly from quality as described by an apple processor or the consumer (Barritt, 2001). Quality can be described by objective measures such as surface color, size, flesh firmness, SSC, or acidity (Westwood, 1978). In addition, quality can be used to indicate freedom from blemishes caused by diseases, insects, or physiological disorders (e.g., surface russet, corking, etc.). Quality may also be used to describe subjective attributes such as crispness, juiciness, flavor, or attractiveness (Barritt, 2001).

Apple quality is affected by many factors (Westwood, 1978). Growers are keenly aware of the effect that temperature, moisture, light exposure, or pest control practices, for example, have on the quality of apples at harvest. For some of these factors, such as pest control or canopy light exposure, growers have an opportunity to alter their management practices each growing season to positively affect the quality of fruit at harvest. In contrast, the opportunity to impact some quality factors is quite limited. Cultivar and site are two factors that affect fruit quality where a grower's opportunity to influence that quality may be limited. A single decision made before the orchard is even planted regarding site and cultivar may have a profound affect on fruit quality throughout the life of the planting.

There have been many reports describing the impact of site and

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
4.4482	lbf	N	0.2248
28.3495	oz	g	0.0353

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rootstock on yield and tree growth (Al-Hinai and Roper, 2004; Autio et al., 1990; Barritt et al., 1995; Rogers, 1946; Schupp, 1995; Unrath, 2003), but few reports to describe the effect of site and cultivar on apple quality (Autio et al., 2001; Konishi and Barritt, 1999; Parry, 1977). Autio et al. (2001) found that site had a significant effect on fruit size, as well as tree size and yield, when four apple cultivars were planted on five dwarfing rootstocks across 12 widely differing sites in the U.S. Parry (1977) also reported site effects on fruit size of 'Cox's Orange Pippin' and 'Worcester Pearmain' grown on a range of sites. Other than effects on fruit size, these earlier studies have not addressed a number of fruit quality attributes.

Systematic evaluation of apple cultivars across a broad range of soil and climatic conditions has been quite limited. Evaluations of performance of new cultivars and selections are often limited to those of the plant breeder at a few test sites or observations by growers and/or nursery personnel in the field (Ballard, 2002; Brown et al., 1999; Greene, 1998; Stebbins and Norton, 1991). In 1994, Regional Project NE-183, titled "Multidisciplinary Evaluation of New Apple Cultivars," was initiated to systematically evaluate the performance of new apple cultivars in replicated trials under a wide range of climatic and edaphic conditions. Description and background information on the NE-183 Regional Project is provided by Greene et al. (2004). The fruit quality performance of 19 cultivars on M.9 rootstock at 13 sites in the NE-183 Project has been reported by Miller et al. (2004). Hampson et al. (2004) reported the performance of three cultivars on two rootstocks across 19 of the planting sites in the NE-183 Regional Project. This paper reports on the interaction of cultivar and site, as preharvest factors, on apple quality using data gleaned from the NE-183 Regional Project. Cooperators at 16 locations (Table 1), representing 17 planting sites, provided fruit quality and/or sensory data to this report.

Materials and methods

Details regarding the planting, cultural maintenance, and data collection for the NE-183 Project plantings are presented by Crassweller et al. (2005), Hampson et al. (2004), and

Miller et al. (2004, 2005). Briefly, trees representing 20 apple cultivars (Table 2) were propagated on M.9 T337 rootstock by Adams County Nursery (Aspers, Pa.) in 1993. The cultivars Braeburn and Golden Delicious were also propagated on Mark rootstock (note: data for this tree/rootstock combination were only used in the results illustrated in Fig. 2). The 1-year-old trees were dug in Fall 1994 and planted at the designated sites located in the U.S. and Canada in Spring 1995. The experimental design was a randomized block with five replications and a single tree of each cultivar per block. Trees were planted in north-south rows, when possible, at a spacing of 2.5 × 4.3 m. Plantings had the primary designation of either horticultural or pest suscep-

tibility. Horticultural (H) plantings were dedicated to answering questions of horticultural characteristics such as growth, yield, flowering, or fruit and sensory quality. Pest (P) plantings were dedicated to examining the disease and insect susceptibilities of the various cultivars. Data from both the H and P plantings at the WV site were included in this report since the pest protocol for the study (disease evaluation from 1996 to 1999 and insect evaluation beginning in 2000) had had a negligible overall effect on fruit quality and tree growth/viability (as judged by several independent NE-183 project cooperators) and all horticultural data had been collected. Data for all other sites in this report represent only H plantings.

Fruit quality data presented here

Table 1. Locations and cooperators in the 1995 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)
AR	Fayetteville, Ark.	C. Rom
BC	Summerland, B.C.	C. Hampson
MA	Belchertown, Mass.	D. Greene, J. Clements
ME	Monmouth, Maine	R. Moran, J. Schupp
NJ	Pittstown, N.J.	W. Cowgill
NYG	Geneva, N.Y.	S. Brown
NYH	Highland, N.Y.	J. Schupp, E. Stover
NYI	Ithaca, N.Y.	I. Merwin
OH	Wooster, Ohio	D. Miller
ON	Simcoe, Ont.	J. Cline
PAB	Biglerville, Pa.	G. Greene
PAR	Rock Springs, Pa.	R. Crassweller
VT	Burlington, Vt.	E. Garcia, L. Burkett
WA	Wentachee, Wash.	B. Barritt
WI	Sturgeon Bay, Wis.	T. Roper
WV	Kearneysville, W. Va.	S. Miller
WVP ^z	Kearneysville, W. Va.	S. Miller

^zWVP represents the W.Va. NE-183 planting dedicated to the pest objective for the regional project but, from which horticultural data was collected using the prescribed protocol for the project's horticultural objective. Data for all other planting sites were collected from test plantings designated for the horticultural objective of the regional project.

Table 2. Apple cultivars and selections evaluated for quality and selected sensory characteristics in the 1995 NE-183 "Multidisciplinary Evaluation of New Apple Cultivars" Regional Project.^z

Arlet (Swiss Gourmet)	Golden Supreme
Braeburn	GoldRush (originally Co-op 38)
Cameo (originally Carousel)	Honeycrisp
Creston (originally BC8M15-10)	NY75414-1
Enterprise (originally Co-op 30)	Orin
Fortune (originally NY 429)	Pristine (originally Co-op 32)
Fuji Red Sport #2	Shizuka
Gala Supreme	Suncrisp (originally NJ 55)
Ginger Gold	Sunrise
Golden Delicious, Gibson strain	Yataka Fuji

^zPhotographs of apple cultivars are available (Clements and Cowgill, 2003).

represent apples harvested for the years 1998 to 2000. The goal was to harvest fruit when the average starch index (SI) rating fell within the range 4 to 6 (considered optimum maturity) based on the Cornell Generic Starch-Iodine Index Chart (Blanpied and Silsby, 1992). Objective quality characteristics were determined on a 10-apple sample per tree and included fruit weight, diameter, length, flesh firmness, SSC, and TA. Details regarding methods used to measure objective fruit quality variables have been presented by Miller et al. (2004). Subjective measures of fruit quality that were rated included percent red overcolor, surface russet (based on total percent surface exhibiting russet), and various sensory attributes to include crispness, sweetness, acidity, juiciness, flavor, attractiveness, and desirability. Crispness, sweetness, acidity, and juiciness were rated on a five-point unipolar intensity scale and flavor, attractiveness, and desirability were rated using a bipolar five-point hedonic scale (Miller et al., 2005). Attractiveness was defined as the outward appearance of the apple considering the background and overcolor, shape, uniformity, and finish (russet, lenticels, etc.). Cooperators were asked to rate desirability considering all factors while asking two questions: would this apple be acceptable to commercial growers in their area's production/marketing system; and would consumers be likely to purchase this apple?

Because of the large volume of data and the size of some of the individual data sets in this project, only selected quality attributes and in some instances only a portion of the data set for a given attribute will be used to illustrate the effect of cultivar and site on fruit quality. The cultivar Yataka Fuji was found to be overmature (mean SI above 6.5 SI rating) when harvested at all planting sites except one and was deleted from all quality analyses except for individual fruit weight.

The factors in the statistical analysis of quality and sensory data are cultivar, site, block of the statistical design, and year. The analysis of each attribute was done using the MIXED procedure of SAS (version 8; SAS Institute, Cary, N.C.). The main effects and interaction effects of site and cultivar were the fixed effects in the model. The random effects, which were all nested within site, were the effects of block, year, block $\times$ cultivar,

Table 3. *P*-values from the mixed-model analysis of variance for the main-factor effects and interactions of cultivar and planting site on experimental response variables.

Response variable	Cultivar (C)	Planting site (Ps)	C $\times$ Ps
Average fruit weight	<0.001	<0.001	<0.001
Fruit diameter	<0.001	0.029	<0.001
Length:diameter ratio	<0.001	<0.001	<0.001
Flesh firmness	<0.001	<0.001	<0.001
Soluble solids	<0.001	0.788	0.776
Titrateable acidity	<0.001	0.060	0.823
Red overcolor	<0.001	<0.001	<0.001
Russet rating	<0.001	0.002	0.073
Crispness rating	<0.001	<0.001	0.582
Sweetness rating	<0.001	<0.001	0.058
Juiciness rating	<0.001	0.624	0.033
Acidity rating	<0.001	0.003	0.008
Flavor rating	<0.001	0.039	0.004
Attractiveness rating	<0.001	<0.001	<0.001
Desirability rating	<0.001	<0.001	<0.001

Fig. 1. Interaction of cultivar and planting site for fruit weight of eight cultivars and eight planting sites in the NE-183 Regional Project. For clarity, only a portion of the complete data set representing 20 cultivars at 17 planting sites is presented. BC = British Columbia; WA = Washington; ON = Ontario; OH = Ohio; MA = Massachusetts; WVP = West Virginia pest planting to test for disease and insect susceptibility; AR = Arkansas; NYG = Geneva, N.Y.; 1 g = 0.0353 oz.

block $\times$ year, and block $\times$ cultivar $\times$ year. Mean separation was done using the LSMEANS feature of MIXED, which involves multiple *t* tests, each at the 5% probability level. The relationship between selected instrumental measurements of fruit quality and sensory attributes (e.g., flesh firmness and crispness) was calculated using standard regression and correlation analysis and mean data.

Results and discussion

All the fruit quality and sensory response variables from the NE-183 Regional Project were affected by one or both of the main treatment effects and/or the two-way interaction (Table 3). There was a significant cultivar $\times$ planting site interaction (Table 3) when the mean fruit weight for the 20 cultivars was compared across all plant-

ing sites. The interaction is illustrated in Fig. 1 using eight selected cultivars from eight of the 17 planting sites. Among the 20 cultivars evaluated the BC planting site produced the largest fruit for 11 of the cultivars; the WA site had the largest fruit for six of the 20 cultivars (data not shown). The average difference in fruit weight between the largest and smallest fruit among the 20 cultivars was 122 g. The greatest range in fruit weight was 195 g for ‘Honeycrisp’, which occurred between the BC and AR planting sites. The smallest range in fruit weight difference was 60 g for ‘Pristine’ and occurred between the WA and PAB planting sites. A similar significant cultivar $\times$ planting site interaction was found for fruit diameter when 19 cultivars were compared over 13 planting sites (Table 3). The BC site produced the largest fruit diameter among 15 of 19 cultivars while eight different sites among 13 sites shared in producing the smallest fruit diameter for 19 cultivars (data not shown). Why many of the apple cultivars in this study were consistently larger when grown at the BC and WA sites cannot be determined, but it may be suggested that length of growing season, temperatures during the critical cell division stage, and/or light quantity and quality are more ideal in the Pacific Northwest than in other regions in this study.

Size (weight and/or diameter) is an important quality attribute since, within limits, larger apples generally command higher returns to the grower. While consumer surveys indicate that size is of minor importance among consumer buying decisions for apple (Ricks et al., 1995), surveys also suggest that consumers would prefer a range of sizes for specific uses (Moxham, 2003). Planting site had a significant effect on the size (measured by weight) of ‘Braeburn’ and ‘Golden Delicious’ apples grown on two rootstocks at 14 different sites in the NE-183 Regional Project (Hampson et al., 2004; Fig. 2). ‘Braeburn’ and ‘Golden Delicious’ grown at the BC site were significantly larger than when grown at all other planting sites. The PAR planting site produced the smallest ‘Braeburn’ and ‘Golden Delicious’ apples among the 14 sites reporting fruit weight. However, fruit size at the PAR planting site was not significantly different from size at the PAB, ON, WI, WVP, NYG, or

Fig. 2. The generalized least-squares means for fruit weight of ‘Braeburn’ and ‘Golden Delicious’ apples across 14 planting sites in the NE-183 Regional Project. Vertical mean bars followed by the same letter are not significantly different by t test at the 5% level. BC = British Columbia; NJ = New Jersey; NYI = Ithaca, N.Y.; NYH = Highland, N.Y.; ME = Maine; MA = Massachusetts; VT = Vermont; WV = West Virginia; NYG = Geneva, N.Y.; WVP = West Virginia pest planting to test for disease and insect susceptibility; WI = Wisconsin; ON = Ontario; PAB = Biglerville, Pa.; PAR = Rock Springs, Pa. Data for graph from Hampson et al. (2004). 1 g = 0.0353 oz.

WV planting sites for ‘Braeburn’ and ‘Golden Delicious’.

The shape of an apple can be an important factor in marketing. Fruit length:diameter (L:D) ratio characterizes fruit shape and provides a measure of fruit typiness. There was a significant cultivar $\times$ planting site interaction for fruit L:D ratio when 19 cultivars were compared over 14 planting sites (Table 4). When averaged across sites, ‘Creston’, ‘Golden Supreme’, ‘Orin’, and ‘Shizuka’ were the most typey fruit among those evaluated and ‘Gala Supreme’ and NY75414-1 the least typey based on L:D ratio (Table 4). The largest difference in L:D ratio among sites occurred with ‘Golden Delicious’ grown at the ME or NYI sites and the WVP site. ‘Orin’ was fairly consistent in fruit shape across all sites and produced the smallest difference in L:D ratio among sites (Table 4). ‘GoldRush’, ‘Pristine’, and ‘Shizuka’ also exhibited considerable consistency in fruit L:D ratio across planting sites. ‘Arlet’ produced highly typey fruit at the BC site, but noticeably less typey fruit at the more northern VT and NYG sites and the two most southern

sites in West Virginia (WV and WVP) (Table 4). In contrast, the NYI site produced a more typey ‘Fortune’ when compared to the BC site. While the BC site recorded the highest mean L:D ratio for the 19 cultivars, only six of 19 cultivars tested produced fruit, with the largest L:D ratio when grown at the BC site. The NYI site had the second largest mean L:D ratio behind the BC site and had 10 of the 19 cultivars with the largest L:D ratio. The lowest mean L:D ratio for all 19 cultivars occurred at the two WV sites. High temperatures during the post-bloom period generally result in a fruit that is less conical and more oblate in shape (Shaw, 1914). Climatic influences on fruit shape have also been shown to extend beyond the brief period after bloom (Westwood, 1962).

Soluble solids content and acidity play significant roles in the taste and flavor perceived in eating an apple and as such help characterize an apple’s quality. Not unexpectedly, in the NE-183 Regional Project, SSC and TA were affected by the cultivar main effect (Table 3). ‘Golden Delicious’, ‘Gala Supreme’, and ‘GoldRush’ had sig-

Table 4. Generalized least-squares means for cultivar × planting site for length : diameter (L:D) ratio for 19 apple cultivars in the NE-183 Regional Project.

Cultivar	L:D ratio for planting site													
	BC ^a	MA	ME	NJ	NYG	NYH	NYI	ON	PAB	PAR	VT	WI	WV	WVP
Arlet	1.02	0.92	0.95	---	0.88	0.92	0.92	---	0.89	0.90	0.88	0.93	0.88	0.87
Braeburn	0.94	0.90	0.92	---	0.88	0.90	0.97	0.86	0.88	0.90	0.87	0.91	0.88	0.89
Creston	1.02	0.94	0.97	---	0.91	0.91	0.97	0.92	0.90	0.90	---	---	---	0.90
Cameo	0.96	0.90	0.92	---	0.86	0.91	0.94	0.91	0.86	0.89	0.87	0.88	0.88	0.88
Enterprise	0.92	0.89	0.93	0.84	0.86	0.91	0.94	---	0.87	0.93	0.86	0.86	0.87	0.86
Fortune	0.88	0.84	---	0.84	0.85	---	0.93	0.91	0.83	0.84	0.84	0.86	0.80	0.79
Fuji Red														
Sport #2	0.91	0.87	0.92	---	0.87	---	0.94	---	0.81	0.86	---	0.87	0.83	0.84
Gala Supreme	---	0.82	---	0.82	0.82	0.82	0.89	---	0.79	0.80	0.79	---	0.78	0.83
Ginger Gold	0.97	0.89	---	0.90	0.91	---	---	0.95	0.87	0.89	0.86	0.97	0.92	0.85
Golden														
Delicious	0.97	0.93	0.98	0.94	0.92	---	0.98	0.95	0.89	0.92	0.93	0.94	0.90	0.80
Golden														
Supreme	0.99	0.92	0.93	0.94	0.89	0.94	0.95	0.94	0.91	0.91	0.92	0.95	0.94	0.92
GoldRush	0.94	0.93	---	0.92	0.92	0.93	0.97	0.95	0.92	0.91	0.89	0.93	0.91	0.91
Honeycrisp	0.90	0.86	0.88	---	0.84	0.84	0.92	0.87	0.86	0.85	0.89	0.99	0.83	0.82
NY 75414-1	0.88	0.80	---	0.78	0.80	0.86	0.89	0.83	0.77	0.82	0.82	0.84	0.77	0.78
Orin	0.97	0.92	0.97	---	0.91	---	0.98	---	0.91	0.93	0.92	0.93	0.91	0.91
Pristine	0.86	0.83	0.84	0.81	0.81	0.81	0.87	0.84	0.83	0.83	0.87	0.86	0.78	0.80
Shizuka	0.99	0.95	0.95	---	0.91	0.92	0.98	0.93	0.91	0.93	0.93	0.95	---	0.90
Suncrisp	0.94	0.92	0.97	0.98	0.90	0.93	0.96	---	0.88	0.90	0.92	0.90	0.88	0.89
Sunrise	0.96	0.89	0.95	0.89	0.89	---	0.95	0.91	0.86	0.88	0.97	0.90	0.86	0.88
Mean	0.95	0.89	0.93	0.88	0.88	0.89	0.94	0.91	0.86	0.88	0.88	0.91	0.86	0.86

^aBC = British Columbia; MA = Massachusetts; ME = Maine; NJ = New Jersey; NYG = Geneva, N.Y.; NYH = Highland, N.Y.; NYI = Ithaca, N.Y.; ON = Ontario; PAB = Biglerville, Pa.; PAR = Rock Springs, Pa.; VT = Vermont; WI = Wisconsin; WV = West Virginia; WVP = West Virginia pest planting to test for disease and insect susceptibility.

Table 5. Generalized least-squares means for 19 apple cultivars for average soluble solids concentration across 14 planting sites and titratable acidity at six planting sites in the NE-183 Regional Project.

Cultivar	Soluble solids (%)	Titratable acidity (%)
Arlet	14.1 c-e	0.73 c-e
Braeburn	13.4 gh ^a	0.75 cd
Creston	13.6 e-h	0.58 g-j
Cameo	14.2 c-e	0.61 g-j
Enterprise	14.6 b	0.73 c-e
Fortune	13.9 d-g	0.72 c-f
Fuji	14.5 bc	0.46 kl
Gala Supreme	15.6 a	0.67 d-g
Ginger Gold	13.0 hi	0.51 i-l
Golden Delicious	15.2 a	0.63 f-i
Golden Supreme	13.5 f-h	0.53 jk
GoldRush	15.5 a	0.99 a
Honeycrisp	13.3 h	0.78 c
NY 75414-1	14.0 c-f	0.80 c
Orin	14.4 b-d	0.41 l
Pristine	12.4 i	0.91 b
Shizuka	14.0 c-f	0.57 h-j
Suncrisp	14.7 b	0.79 c
Sunrise	12.6 i	0.65 e-h
Mean	14.0	0.67

^aMeans followed by the same letter are not significantly different by *t* test at the 5% level.

nificantly higher SSC than the 16 other cultivars tested across 14 planting sites (Table 5). ‘GoldRush’ is the latest maturing cultivar among the 19 cultivars evaluated (Miller et al., 2004). ‘Pristine’, ‘Sunrise’, and ‘Ginger Gold’, ironically the earliest maturing cultivars (Miller et al., 2004), produced the lowest SSC across all sites. In addition to exhibiting one of the highest SSC levels, ‘GoldRush’ also had the highest TA (Table 5) and was significantly higher in TA than all other cultivars evaluated. In contrast, ‘Pristine’, the earliest maturing cultivar, had the second highest TA among all cultivars evaluated and was significantly higher in TA than all other cultivars except ‘GoldRush’ (Table 5). Based on these results with 19 apple cultivars, TA level at harvest is not related to time of fruit maturity. ‘Orin’, a cultivar characterized as sweet and of low acid (Greene et al., 1997; Miller et al., 2004), had the lowest TA; however, it was not significantly lower than ‘Fuji’ or ‘Ginger Gold’ (Table 5).

Soluble solids was not affected by planting site ($P = 0.788$), suggesting that for the apple cultivars in this study a grower could expect a characteristic SSC level regardless of the environment

in which they are grown. In contrast, TA was affected by the planting site main effect ($P < 0.10$; Table 3). Among the six planting sites that measured TA, BC had the highest mean TA, although it was not significantly higher than the mean TA for the same cultivars grown at the NYI site (Fig. 3). The two WV sites reported the lowest TA, but not significantly lower than the NYG, NYI, or PAB sites (Fig. 3). The results might suggest that apples grown in arid environments coupled with high light levels (such as in British Columbia) may tend to have higher acidity levels than when grown in more temperate environments. The cultivar × planting site interaction for SSC and TA was nonsignificant.

While flavor and other internal quality attributes have gained importance as factors in consumer selection of apples, appearance still ranks high in consumers’ buying habits (Great Lakes Fruit Growers News, 1995). Red overcolor is a subjective measure of fruit quality. Surface red color was affected by the main treatment effects and the cultivar × planting site interaction (Table 3). Among the 11 planting sites (BC, MA, ME, NJ, ON, PAB, PAR, VT, WI, WV, and WVP) that

Fig. 3. Effect of planting site on mean titratable acidity for 19 apple cultivars in the NE-183 Regional Apple Evaluation Project. Vertical bars with the same letter are not significantly different at the 5% level by *t* test. BC = British Columbia; NYG = Geneva, N.Y.; NYI = Ithaca, N.Y.; PAB = Biglerville, Pa.; WV = West Virginia; WVP = West Virginia pest planting to test for disease and insect susceptibility.

Fig. 4. Interaction of cultivar and planting site for surface red overcolor among nine cultivars at seven planting sites in the NE-183 Regional Project. For clarity, only a portion of the complete data set representing 19 cultivars at 11 planting sites is presented. BC = British Columbia; ON = Ontario; PAR = Rock Springs, Pa.; WI = Wisconsin; WVP = West Virginia pest planting to test for disease and insect susceptibility; NJ = New Jersey; and VT = Vermont.

measured red overcolor, the VT site reported the highest mean percentage of surface red color (55%) and the PAB site showed the lowest mean surface red color (19%) among the 19 cultivars evaluated (data not shown). Averaged over all sites 'Enterprise' had the most surface red color (86%) followed closely by NY 75414-1 (85%). Among the normally red-skinned cultivars, 'Creston' produced the least

amount of surface red color (33%). The interaction of cultivar $\times$ planting site for red overcolor is illustrated in Fig. 4 using nine selected cultivars at eight of the 11 planting sites. 'Orin', a green-skinned cultivar, produced a prominent reddish blush when grown at the WI site, but no red blush when grown at the BC, ON, WVP, or NJ planting sites (Fig. 4). The largest difference in red color between planting

sites occurred with 'Fortune', which had 91% surface red color at the WI site compared to just 38% red color at the WV and WVP sites (Fig. 4). In contrast, 'Enterprise' produced 80% or better red overcolor at all planting sites and showed the smallest difference between planting sites among the red-skinned cultivars.

The interaction of cultivar and planting site was nonsignificant for russet, but the main treatment effects were significant (Table 3). Among 19 cultivars evaluated, 'Arlet' had the most surface covered with russet, about 10% when averaged across nine planting sites (data not shown). 'Gala Supreme' had the next highest percentage of surface russet, about 5%. 'Enterprise' had the least amount of surface russet, less than 1.0%. Among the nine planting sites that measured surface russet, the NJ site had more russet than all other sites except the NYH site (data not shown). The BC site reported the lowest level of surface russeting (data not shown).

The two-way interaction was significant for all sensory attribute response variables except crispness and sweetness (Table 3). Crispness is one of the major traits consumers desire in apples (Stebbins, 1994) and to be labeled as a high quality apple it must have crispness (Barritt, 2001). Crispness of the apple cultivars in the NE-183 Regional Project, as rated by project cooperators, was affected by planting site and cultivar (Fig. 5). Among the seven planting sites rating crispness, apples grown at the MA, PAR, and VT sites were rated higher for crispness than the same cultivars grown at the NYG, PAB, and the two WV sites (Fig. 5A). 'GoldRush' and 'Creston' were rated crisper than all other cultivars evaluated except 'Braeburn', 'Ginger Gold', and 'Honeycrisp' (Fig. 5B). 'Enterprise' along with NY 75414-1 and 'Pristine' were rated significantly less crisp than all other cultivars.

When surveyed, consumers rank firmness just behind taste and crispness in importance toward their buying decision (Moxham, 2003). Planting site and cultivar interacted to affect flesh firmness in the NE-183 project (Table 3). The average mean difference in fruit firmness between sites with the firmest and least firm apples for 19 cultivars was 5.0 lbf. The largest difference in firmness was 6.6 lbf for

Fig. 5. Effect of planting site (A) and cultivar (B) on apple flesh crispness rating for 19 cultivars and seven planting sites in the NE-183 Regional Project. Sensory rating on a five-point unipolar intensity scale where 1 = not crisp, 3 = crisp, and 5 = extremely crisp. Horizontal or vertical bars with the same associated letters are not significantly different by *t* test at the 5% level. WVP = West Virginia pest planting to test for disease and insect susceptibility; WV = West Virginia; VT = Vermont; PAR = Rock Springs, Pa.; PAB = Biglerville, Pa.; NYG = Geneva, N.Y.; and MA = Massachusetts.

‘Suncrisp’ and occurred between the PAB and ON sites (Fig. 6). The least difference in firmness was 3.0 lbf for ‘Orin’ and occurred between the PAB site and the WVP site (Fig. 6). When the 19 cultivars were compared at 13 planting sites, the PAB site produced the firmest apples (19.8 lbf) and the ON site the least firm (15.0 lbf) apples at the time of harvest (data not shown). Firmness at the PAB planting site may, however, have been influenced

by the smaller fruit size at this site (Fig. 2; Miller et al., 2004). In addition to fruit size, maturity may have also played a role in the level of flesh firmness recorded. For example, ‘Orin’ and ‘Suncrisp’ matured late in ME, which was thought to contribute to their higher firmness readings at this site (R. Moran, personal communication). Eight of the 13 planting sites were recognized as having produced at least one cultivar identified as the

firmest, which further demonstrates the interaction between cultivar and planting site in this study.

Firmness as measured by a standard fruit penetrometer and crispness determined by sensory rating were affected differently by cultivar, planting site, and the cultivar $\times$ planting site interaction (Table 3). Instrumental firmness readings for the 19 apple cultivars across six planting sites were weakly correlated with crispness sensory ratings in this project ($r = 0.42$; $r^2 = 0.13$). Fruit firmness measurements indicate the resistance to force. Crispness, as defined in this project, was considered to be the condition of the flesh when chewed, specifically a firm flesh, but brittle enough to produce a distinct crunching sound (Miller et al., 2005). Our data suggest that a firm apple may not necessarily be a crisp apple. As an example in our study, ‘Creston’ received the highest crispness rating (3.9) among the 19 cultivars, but was only moderate in flesh firmness (16.9 lbf). Similarly, ‘Honeycrisp’, an apple characterized as “explosively crisp” (Bedford, 2001), had a mean flesh firmness of 16.8 lbf and a mean crispness rating of 3.8. In contrast, ‘GoldRush’ was the firmest (20.8 lbf) apple tested in this project and also received a relatively high rating for crispness (3.8).

Flavor, a quality attribute of great importance for apples (Barritt, 2001; Ricks et al., 1995; Stebbins, 1994), was affected by the cultivar $\times$ planting site interaction (Table 3). Only two cultivars, ‘Golden Delicious’ and ‘Golden Supreme’, received a rating of 3 (like) or above at all seven planting sites (Table 6). ‘Golden Supreme’ received the highest mean rating among the 19 cultivars evaluated. ‘GoldRush’ was rated above 3 at only one planting site and was rated lowest for flavor, on average, among all cultivars. ‘GoldRush’ is high in acid at harvest (Table 5) and probably would improve in flavor rating after a period of storage, as suggested by Greene (1998) and Brown et al. (1999). ‘Shizuka’ was rated near 5 (like extremely) at the MA site, but was rated below 3 at the VT and PAB planting sites (Table 6). The greatest difference in flavor rating occurred with the cultivar selection NY 75414-1, which received a mean rating of 4.1 (rating of 4.0 = like very much) at the VT site but a rating of 1.2 (rating of 1.0 = dislike) at the PAB

Fig. 6. Interaction of cultivar and planting site for flesh firmness among eight cultivars at eight planting sites in the NE-183 Regional Project. For clarity, only a portion of the complete data set representing 19 cultivars at 13 planting sites is presented. PAB = Biglerville, Pa.; NYH = Highland, N.Y.; MA = Massachusetts; VT = Vermont; BC = British Columbia; WVP = West Virginia pest planting to test for disease and insect susceptibility; ON = Ontario; ME = Maine. 1 lbf = 4.4482 N.

site. In contrast, ‘Golden Delicious’ showed the least difference in flavor rating with a high rating of 3.7 at the NYG site to a low rating of 3.0 at the WV planting site (Table 6). Averaged over all cultivars, the MA site had the highest mean flavor rating and the PAB site had the lowest mean rating among the seven sites reporting flavor sensory ratings (Table 6). It should also be noted that at most sites sensory evaluations, including flavor rating, were performed by a single individual and thus, individual preferences likely played a role in the final rating. To what extent this may have influenced the final results is difficult to ascertain.

Attractiveness and desirability were two other sensory attributes rated that were affected by the cultivar $\times$ planting site interaction. ‘Golden Supreme’ was rated the most attractive of the 19 cultivars across seven planting sites and also received the highest rating score [4.7 on a scale of 1 (dislike) to 5 (like extremely)] across all sites and

Table 6. Generalized least-squares means flavor sensory rating scores for the two-way interaction among 19 apple cultivars grown at seven planting sites in the 1995 NE-183 Apple Cultivar Evaluation Regional Project for the years 1998 through 2000.

Cultivar	Mean flavor rating score ^z							Cultivar mean
	VT ^y	MA	NYG	PAR	PAB	WV	WVP	
Arllet	3.3 bc ^x	3.4 de	3.5 a-c	3.3 ab	1.7 e-g	3.0 a-e	2.4 cd	2.9
Braeburn	4.0 a-c	3.3 de	3.3 a-c	2.9 a-c	2.9 a-d	3.8 a	3.3 a-c	3.4
Cameo	3.4 bc	4.0 a-e	2.9 a-d	2.7 a-c	2.4 c-f	2.7 b-e	2.9 a-d	3.0
Creston	n.d. ^w	4.5 a-c	3.4 a-c	2.8 a-c	3.5 ab	n.d.	2.0 d	3.2
Enterprise	3.4 a-d	3.2 de	2.3 cd	2.7 bc	2.0 d-g	3.2 a-d	2.9 a-d	2.8
Fortune	4.3 ab	3.8 a-e	4.2 ab	3.1 ab	2.9 a-d	3.2 a-d	3.5 a-c	3.6
Fuji Red Sport No. 2	n.d.	3.9 a-e	n.d.	2.8 a-c	3.5 a-c	3.4 ab	3.0 a-d	3.3
Gala Supreme	1.9 d	3.0 ef	2.6 b-d	2.9 a-c	3.1 a-c	2.3 c-e	2.0 d	2.5
Ginger Gold	4.1 a-c	4.4 a-d	2.0 cd	3.2 a-c	3.1 a-d	2.4 c-e	3.0 a-d	3.2
Golden Delicious	3.1 b-d	3.4 c-e	3.7 ab	3.6 ab	3.2 a-c	3.0 a-e	3.6 a-c	3.4
Golden Supreme	4.0 a-c	4.4 ab	4.2 ab	3.9 ab	3.5 ab	3.6 ab	3.4 a-c	3.9
GoldRush	2.9 cd	2.1 f	2.7 b-d	3.2 a-c	1.7 fg	2.2 de	2.0 d	2.4
Honeycrisp	4.5 a	3.9 a-e	4.0 a	3.0 a-c	3.5 ab	3.6 a-c	2.7 b-d	3.6
NY 75414-1	4.1 a-c	3.6 b-e	3.7 ab	3.7 a	1.2 g	2.3 c-e	2.5 cd	3.0
Orin	3.1 cd	3.8 a-e	3.0 abc	3.5 ab	2.8 b-d	2.6 b-e	3.9 a	3.2
Pristine	3.7 a-c	3.8 a-e	1.6 d	1.9 c	2.0 d-g	2.2 de	2.1 d	2.5
Shizuka	2.9 b-d	4.7 a	3.7 ab	3.6 ab	2.3 b-g	n.d.	3.7 ab	3.5
Suncrisp	4.0 a-c	3.2 de	4.0 a	2.7 a-c	2.8 a-e	3.4 a-e	3.4 a-c	3.4
Sunrise	3.5 a-c	3.7 a-e	2.3 cd	2.9 a-c	3.9 a	2.2 e	2.8 a-d	3.0
Planting site Avg.	3.5	3.7	3.2	3.1	2.7	2.9	2.9	

^zAttribute ratings based on a bipolar hedonic scale where 1 = dislike, 2 = dislike slightly, 3 = like, 4 = like very much, and 5 = like extremely

^yVT = Vermont; MA = Massachusetts; NYG = Geneva, N.Y.; PAR = Rock Springs, Pa.; PAB = Biglerville, Pa.; WV = West Virginia; WVP = West Virginia pest planting to test for disease and insect susceptibility.

^xMeans for the same location not sharing a common following letter are significantly ($P \leq 0.05$) different by pairwise t tests from the analysis of the mixed model for the attribute.

^wn.d. = no data.

cultivars when grown at the MA site (data not shown). However, 'Golden Supreme' only received a rating of 2.0 (dislike slightly) at the NYG planting site. The largest difference in attractiveness rating occurred with 'Pristine' between the MA and NYG sites. The smallest difference in attractiveness rating between sites was found with 'Enterprise' grown at the PAR and VT sites and 'Orin' produced at the PAR and PAB sites (data not shown). 'Ginger Gold', 'Golden Supreme', and 'Fuji' received equally high ratings (3.7) for desirability (data not shown). The greatest difference in desirability rating between sites occurred with NY 75414-1, which was given a 4.1 rating at the VT site but only a 1.2 rating at the PAB site. 'Gala Supreme' was rated least desirable among the 19 cultivars when averaged across seven planting sites.

The purpose of this paper was to demonstrate the effect of cultivar and site on apple quality using data from the NE-183 Regional Project. It was not our intent to demonstrate relationships between the objectively measured quality response variables (such as firmness, SSC, or TA) and the subjectively rated sensory variables (crispness, sweetness, acidity, or flavor). However, it is interesting to briefly examine some of these relationships and discuss the findings as they relate to this current project. Previous studies have shown both strong (Abbott et al., 1984; Saftner et al., 2002) and weak (Watada et al., 1981) relationships between objective instrumental measurements and subjective sensory ratings of apple quality characteristics. In the current project there was no relationship between SSC and sweetness rating ($r = 0.15$; $r^2 = 0.02$) among the 19 cultivars and seven planting sites. 'GoldRush' had the highest mean SSC (Table 5), but the lowest mean sensory rating for sweetness (rating score of 1.9). The relationship between the SSC:TA ratio and the rating for flavor was slightly better, but also weak ($r = 0.39$; $r^2 = 0.18$). This might be expected, however, since flavor was rated on a hedonic scale (relates to pleasure or acceptability) that would not be expected to correlate well with instrumental measurements. However, the relationship between the SSC:TA ratio and the sweetness rating was positive and strong ($r = 0.91$; $r^2 = 0.83$), while that for SSC:TA and acidity sensory

rating was strongly negative ($r = -0.90$; $r^2 = 0.81$). There was also a strong relationship between the analytically measured TA and the sensory rating for acidity ($r = 0.96$; $r^2 = 0.92$). These results suggest that for apple, sweetness or sugar content may be masked by acidity and the ratio of SSC to TA is a better indicator of perceived sweetness and acidity. The results also suggest that acidity is easier to distinguish by tasters than sugar. However, it should be pointed out that this study represents a very limited taste panel population. In addition, the tasters in this study received no universal training, but instead based their ratings on experience and a standard protocol developed by the project cooperators, a condition that may have impacted ratings.

Conclusions

The results in this study demonstrate the significant effect that cultivar and site can have on apple quality. For some quality attributes, such as SSC, and to some extent TA, there was uniformity in cultivar performance across the reporting sites and clear differences among cultivars. While differences did occur in surface russet and crispness across sites, these differences were minimal and may have little or no practical significance. However, many quality attributes were affected by the interaction between site and cultivar, as might be expected. No single cultivar developed superior qualities across all sites; likewise no one site consistently produced apple cultivars with the most superior quality. These results support the need for widespread systematic testing of new apple cultivars across many sites in order to ascertain performance under different soil and climatic conditions. Information gained from these replicated tests allows growers to select and plant cultivars adapted to their growing conditions and enhance the potential for producing apples of the highest quality.

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