Long-term Yield and Harvest Time Fruit Quality Attributes in Various Fuji Apple Strains

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Abstract. ‘Fuji’ apple (*Malus × domestica* Borkh) has gained popularity in the past decades, but poor color of this apple mandates introduction of new strains. To pursue this objective, long-term effects of five ‘Fuji’ apple strains, consisting of ‘Autumn Rose’, ‘Desert Rose’, ‘Myra’, ‘September Wonder’, and ‘Top Export’ on RN 29 rootstock on fruit yield (in 7 years) and harvest time quality attributes (in 6 years) under climate conditions of southwest Idaho were studied during 2004–10. Fruit of ‘September Wonder Fuji’ trees were larger than those of other strains in 5 of 6 years. The type or pattern of peel color among the “low-coloring” and “high-coloring” strains varied widely. Fruits of ‘Autumn Rose Fuji’, ‘Myra Fuji’, and ‘Top Export Fuji’ always had less but ‘September Wonder Fuji’ and ‘Desert Rose Fuji’ had more red color. Fruit of ‘September Wonder Fuji’ had lower firmness but higher starch degradation pattern (SDP) than those of other strains every year as a result of the earlier maturity of this strain. Fruit of ‘Top Export Fuji’ had the lowest SDP among all strains. Fruit of ‘Autumn Rose Fuji’ tended to have lower soluble solids concentration in 3 of 6 years of this study. Considering all yield and quality attributes at harvest, ‘September Wonder’ was a great choice for an early-maturing and ‘Desert Rose’ was suitable for a late-maturing ‘Fuji’ strain. ‘Myra Fuji’ was particularly desirable for its attractive pink color that resembles bagged ‘Fuji’ without the expensive cost of labor associated with bagging.

Merging new orchard designs with an efficient rootstock and high-coloring strain of an apple cultivar can result in production of higher yield with better fruit quality (Fallahi et al., 2011; Marini et al., 2008; Veberic et al., 2007). Consumer acceptance is determined by fruit color, size, eating quality, and texture (Crassweller and Hollender, 1989; Donati et al., 2003; Fisher and Ketchie, 1989; MacFie, 1995; Salveit, 1983). Nevertheless, poor color can drastically reduce the value of red-peeled apples even if they have acceptable fruit size (Baughner et al., 1990; Crassweller and Hollender, 1989; Iglesias and Alegre,

2006). Apple fruit color best in climates with clear bright days and cool nights during the preharvest period (Blankenship, 1987; Faragher, 1993; Westwood, 1993). Formation of red color in apple is also influenced by light (Arakawa, 1991; Saure, 1990), cultivar (Curry, 1997; Dickinson and White, 1986; Iglesias et al., 1999), strain (Fallahi et al., 2011; Greene and Autio, 1993), fruit bagging (Fallahi et al., 2001), evaporative cooling (Williams, 1993), and the use of reflective film to increase the intensity of light into the tree canopy (Ju et al., 1999). However, the high cost of many of these practices mandates planting high-coloring strains. Delaying harvest time can also improve color but this practice, in addition to the increased risk of freeze injury, can lead to higher respiration and endogenous ethylene production, lower firmness, and shorter storage life, particularly when trees are supplied with excess nitrogen (Fallahi et al., 1985).

Most of today’s red-peeled cultivars are developed by apple breeding programs (Sansavini et al., 2005), but the majority of highly colored strains are identified based on visual and/or physiological changes that occur on a limb of the original cultivar tree (limb mutations) such as ‘Gala’, ‘Delicious’, or ‘Fuji’. These mutants could show some reversions as a result of a lack of stability (Lacey and Campbell, 1987).

Differences in ‘Fuji’ strain quality attributes have been reported in Japan (Komatsu,

1998), Tasmania (Brown et al., 1998), and Spain (Iglesias et al., 2012). In each of these reports, a different set of strains has been compared for their quality attributes. Komatsu (1998) reported that color of different sports of ‘Fuji’ varied, depending on the location where they were grown and the year when they were observed. Some clones did well in cold but not hot climate areas and vice versa. Based on that report, the pattern of peel color (stripe or blush) was not always stable. Also, some striped strains reverted back to produce poor-colored apples like standard ‘Fuji’. The striped-type sports showed more tendencies to develop red color in sectors than did the solid-type sports. Poor eating quality was detected in some red sports, more often in solid type than in stripe type. However, some striped-type clones were comparable with standard ‘Fuji’ (Komatsu, 1998). Iglesias et al. (2012) measured fruit anthocyanin content and visual color of different strains and reported that the most colored strain was ‘Zhen Aztec Fuji’ (blushed) followed by ‘6629 Fuji’ (also blushed), ‘Kiku 8 Fuji’, and ‘Rubin Fuji’ (both striped). Differences in various quality attributes among ‘Fuji’ strains remained proportionally the same across different harvest times (Iglesias et al., 2012). Comparing four strains of ‘Fuji’ apples in Tasmania, ‘Naga Fu 2 Fuji’ produced the largest fruit with best red color but least firmness (Brown et al., 1998). In that study, Akafu strains maintained higher fruit firmness than Naga Fu strains. ‘Naga Fu 1 Fuji’ had lower soluble solids concentration (SSC) when compared with the other strains, whereas the ‘Aki Fu 1 Fuji’ fruit had a lower area of red peel. Veberic et al. (2007) compared fruit quality attributes of ‘Kiku 7 Fuji’, ‘Kiku 8 Fuji’, ‘Naga-fu 6 Fuji’, and ‘Standard Fuji’ over two seasons. In their study, ‘Kiku 8 Fuji’ fruit had the best red color and accumulated the largest amount of reducing sugars with the lowest quantity of phenols in both years and recommended this strain for planting in the areas with high variations in daily and nightly temperatures.

Although the Pacific Northwest, particularly Idaho, is a major area for production of ‘Fuji’, there have not been any comparative studies among different strains of ‘Fuji’ in the region. Thus, the objective of this long-term experiment was to study the yield and harvest time fruit quality differences among ‘Fuji’ strains in southwest Idaho, which has similar climate conditions as those of the Intermountain West region of the United States and many other regions worldwide.

Materials and Methods

Orchard establishment. The experimental orchard was established at the University of Idaho Parma Research and Extension Center in spring and early summer of 2002. The experimental site was located at latitude 43.8° north, longitude 116.9° west, and 673 m elevation above sea level with an annual precipitation of ≈297 mm and a sandy loam soil of pH ≈7.3. Crested wheatgrass

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[*Agropyron cristatum* (L.) Gaertn.], which is a drought-tolerant grass, was planted between the herbicide strips as the orchard floor cover in all treatments. Cultural practices other than the use of this set of strains were similar to those recommended for commercial orchards in the Pacific Northwest (Washington State University Tree Fruit Research and Extension Center, 2014).

'Autumn Rose Fuji', 'Desert Rose Fuji', 'Myra Fuji', 'September Wonder Fuji' (formerly named 'Jubilee Fuji'), and 'Top Export' strains, all on RN 29 rootstock, were planted at 1.52 m × 4.27-m spacing with an east-west row orientation. These strains are among the most commonly available 'Fuji' trees in the fruit industry in the United States and were thus used for comparison in this study. The trees were obtained from Columbia Basin Nursery, Quincy, WA; Van Wells Nursery, Wenatchee, WA; and C & O Nursery, Wenatchee, WA. 'Snow Drift' crab apple (*Malus* × 'Snowdrift') on Bud 9 rootstock (C & O Nursery) was planted in each row as a pollinizer between every 10 'Fuji' trees, because this arrangement ensures sufficient pollination to the actual trees (Westwood, 1993).

Trees were trained into a vertical axis system (Westwood, 1993) during the dormant season in early March every year. Tree central leaders were maintained at ≈3.7 m height. Trees in all treatments were blossom-thinned at ≈80% bloom with 5% lime sulfur followed by one or two applications of post-bloom thinners. The first post-bloom thinner (when applied, depending on the cropload) was a mixture of carbaryl (44.1% by weight a.i.; Sevin XLR; 1-naphthyl N-methylcarbamate; Bayer Crop Science, Research Triangle Park, NC) at a rate of 0.156% to 0.187% of formulation and ethephon [21.7% a.i.; Ethrel [(2-chloroethyl) phosphonic acid]; Bayer Crop Science} at a rate of 0.125 to 0.156 of formulation was applied at petal fall. The second post-bloom thinner (when applied, depending on the cropload) was carbaryl at 0.125% to 0.156% formulation that was applied when fruitlet diameter was ≈7 mm. Fruits were subsequently hand-thinned when they were ≈12 to 18 mm in diameter (approximately mid-June) to maintain a space of at least 12.5 to 15 cm between fruits. Kaolin (95% a.i.; Surround; Englehard, Iselin, NJ) was sprayed for sunburn protection at a rate of 56.8 kg·ha⁻¹ in early July followed by three 1-week interval applications, each at 28.4 kg·ha⁻¹ every year.

Fruit yield and quality attributes. Thirty-five fruits were randomly sampled from each tree for quality analysis and the total yield per tree was recorded as the total weight of all fruits at harvest time every year. Average weight of these 35 fruit was calculated. Twenty of these fruit were used for evaluation of quality attributes at harvest and 15 were kept in perforated plastics bags and stored in a regular storage at 0 °C and 90% relative humidity for 5 months. For quality evaluation, we harvested all strains together only at the traditional commercial harvest

date, which was between 17 Oct. and 27 Oct. in the region. Although fruit in some strains were more mature at this harvest date, it was a harvest reference point to evaluate relative differences among strains in that "one point of time." The commercial maturity date was determined by a field visual inspection of the fruit peel and flesh color, taste, and sweetness. For fruit quality assessment at harvest, peel color was visually rated on a scale of 1 to 5 with 1 = 20% of peel surface covered with red color in either strip or blush pattern progressively to 5 = 100% of peel surface covered with red color. Thus, a color ranking of 3.5 corresponds with ≈70% of red color. We did not measure the intensity of fruit red color, although we took a note of the color intensity and pattern.

At harvest, each individual fruit was gently wiped with a damp cloth and the percentage of fruit with visible russet, minor cracks, bitter pit, and sunburn on the fruit peel was calculated as: (number of fruits with the disorder/total number of sampled fruit) × 100. Cracks in this study are referred to minor fissures on the peel. We did not have any case of fruit splitting.

SSC was measured using a temperature-compensated refractometer (Atago N1, Tokyo, Japan) and fruit firmness was measured, using an 11-mm probe, with a Fruit Texture Analyzer (Guss; Strand, Western Cape, South Africa) and firmness values were reported in Newtons (N). Fruit were then cut equatorially in halves and percentage of fruit with watercore was determined as: (number of fruits with the watercore/total number of sampled fruit) × 100. SDP of equatorial halves of each fruit at harvest was recorded by comparison with the SDP standard chart developed for 'Fuji' apples by Bartram et al. (1993). After storage, SSC, firmness, and percentages of disorders were measured. However, in this report, only results of quality attributes at harvest are reported.

Experimental design and statistics. The experiment was arranged based on a completely randomized design with eight individual trees per strain. The assumption of normal data distribution was checked by performing univariate analyses for all tree responses in this study. Analyses of variance were conducted using SAS (SAS Institute, Cary, NC) with PROC GLM and means were separated using Fisher's protected least significant difference at $P \leq 0.05$.

Results and Discussion

General comments. In addition to the results in each year, results of 7-year cumulative yield during 2004–10 and 6-year average for each quality attributes during 2004, 2005, 2006, 2007, 2009, and 2010 are reported. For the percentage of fruit surface cracks, only the average values over 6 years are reported.

Fruit yield and quality attributes. Trees of 'September Wonder Fuji' had lower yield per tree than those of the other strains when trees were young during 2004 through 2006, but differences were mostly insignificant after 2007 (Table 1). There were no significant differences in the 7-year cumulative yield among 'Fuji' strains (Table 1). Fruit of 'September Wonder Fuji' trees were numerically or significantly larger than those of other strains in 5 of 6 years in this study (Table 2). Over the period of 6 years, average fruit weight of 'September Wonder Fuji' was significantly greater than that of 'Desert Rose Fuji'.

Apple yield is negatively correlated with fruit size (Westwood, 1993). However, such a correlation did not always exist in this study. For example, trees in 'Desert Rose Fuji' had small fruit despite their low yield in 2007 (Tables 1 and 2). This observation shows that fruit thinning was conducted properly and numbers of fruit left on the trees after thinning

Table 1. Effect of 'Fuji' apple strains on yield per tree in 7 years.

Strain	Yield (kg/tree)							Cumulative 7 years
	2004	2005	2006	2007	2008	2009	2010	
Autumn Rose	8.0 a ²	18.9 a	17.3 a	13.1 a	9.8 b	26.1 a	15.1 a	97.4 a
Desert Rose	7.4 a	13.3 ab	19.2 a	6.8 a	29.8 a	21.7 a	30.0 a	114.6 a
Myra	11.0 a	17.6 ab	16.0 a	17.0 a	26.1 ab	29.4 a	26.7 a	133.4 a
S. Wonder	7.5 a	4.6 c	11.2 b	10.7 a	32.7 a	25.8 a	27.1 a	119.7 a
Top Export	8.4 a	12.0 b	16.3 ab	11.4 a	21.1 ab	20.7 a	20.9 a	109.2 a

²Mean separation within columns by Fisher's protected least significant difference at $P \leq 0.05$. For each strain, every value within a year represents an average of eight replications. S. Wonder = September Wonder.

Table 2. Effect of 'Fuji' apple strains on fruit weight in 6 years.

Strain	Fruit wt (g)						Avg 6 years
	2004	2005	2006	2007	2009	2010	
Autumn Rose	299.1 ab ²	297.3 a	311.6 a	322.7 a	296.2 b	275.9 a	299.8 ab
Desert Rose	289.0 b	286.4 ab	318.4 a	273.0 b	308.8 ab	283.5 a	291.1 b
Myra	304.1 ab	279.4 ab	314.5 a	335.3 a	299.0 ab	271.8 ab	302.0 ab
S. Wonder	331.7 a	268.9 b	334.2 a	338.8 a	326.7 a	290.4 a	314.1 a
Top Export	283.5 b	291.8 ab	329.8 a	336.2 a	317.4 ab	250.7 b	301.6 ab

²Mean separation within columns by Fisher's protected least significant difference at $P \leq 0.05$. For each strain, every value within a year represents an average eight replications. S. Wonder = September Wonder.

were not excessive to create a negative relationship between yield and fruit size. General fruit weight and yield relations in this study were in agreement with a comprehensive study on cropland adjustment reported from Japan by Koike and Ono (2014). Thus, differences among treatments for yield and fruit size are true strain rather than cropland effect.

Significant differences in fruit color were found among different strains of 'Fuji' (Table 3). In general, fruits of 'Autumn Rose Fuji', 'Myra Fuji', and 'Top Export Fuji' always had less but 'September Wonder Fuji' and 'Desert Rose Fuji' had more red color than other strains during each year and over 6 years of this study (Table 3). The type or pattern of peel color among the "low-coloring" and "high-coloring" strains varied widely. For example, 'September Wonder Fuji' seemed to mature ≈ 2 weeks before other strains and had reddish blush and very attractive color. Fruit in 'Desert Rose Fuji' had evenly distributed red blush coloration on the peel, even in the shaded areas of the tree. Among strains tested here, 'Desert Rose Fuji' had the best color among late-season 'Fuji' strains. 'Myra Fuji' fruit peel had a uniform light red (almost pink) color covering the entire peel, resembling bagged 'Fuji', and the pink color was overlaid with slightly darker pinkish red stripes, giving an attractive and marketable appearance to the fruit. 'Top Export' had deep red stripes with wider strips of green-beige color in between. In this study, any peel color ranking less than 3.5 (70% red), when the background color was greenish or "muddy red," was considered less acceptable for the market (E. Fallahi, personal experience). The peel of 'Autumn Rose Fuji' fruit had a 6-year average color ranking of 3.2 ($\approx 64\%$ red) (Table 3) with poor red stripes and blush (mixed), and under high nitrogen conditions, the color was even less acceptable for the market (data not shown).

'September Wonder Fuji' had significantly lower fruit firmness than all other strains every year during 6 years of this study (Table 4) as a result of the earlier maturity of this strain.

'Autumn Rose Fuji' tended to have lower SSC in 3 of 6 years in this study (Table 5). However, averaging values over 6 years did not show any difference in SSC among strains. 'September Wonder Fuji' and 'Myra Fuji' had higher, whereas 'Autumn Rose Fuji' and 'Top Export Fuji' had lower SDP (Table 6), which could have contributed to the longer storage life of 'Top Export Fuji' (data not shown).

Fruit of 'Top Export' often had lower russet than those of other strains, although differences were not always significant (data not shown). Strains did not differ in the percentage of fruit sunburn or bitter pit in any year (data not shown). Percentages of fruit with watercore varied greatly from year to year and from strain to strain. However, 'Myra Fuji' tended to have (numerically or significantly) higher watercore in 4 of 6 years

in this study (Table 7). 'Fuji' fruit with watercore is preferred in some apple markets, although watercore incidence is considered as a negative fruit quality attribute in other apple cultivars (E. Fallahi, personal knowledge). The incidence of fruit cracks was low in all strains; however, fruit of 'September Wonder' had a higher 6-year average surface crack (Table 7). These cracks perhaps were

not noticeable if fruit were harvested earlier than other strains.

Considering all yield and quality attributes at harvest, 'September Wonder' was a good choice for an early strain. Fruit yield, weight, and color in this strain were satisfactory. Lower firmness and higher SDP, watercore, and surface cracking of fruit in this strain could be improved by harvesting fruit at an

Table 3. Effect of 'Fuji' apple strains on fruit peel color at harvest in 6 years.

Strain	Fruit peel color (1–5) ^a						Avg 6 years
	2004	2005	2006	2007	2009	2010	
Autumn Rose	2.8 c ^b	3.5 b	3.0 bc	3.8 ab	3.6 b	3.1 b	3.2 c
Desert Rose	3.7 b	4.4 a	3.7 ab	3.8 ab	4.5 a	4.2 a	4.0 b
Myra	3.1 c	3.7 b	2.8 c	3.4 b	3.8 b	3.0 b	3.3 c
September Wonder	4.6 a	4.5 a	4.5 a	4.6 a	4.7 a	4.5 a	4.6 a
Top Export	2.6 c	3.4 b	2.5 c	2.8 b	3.6 b	2.9 b	3.0 c

^aFruit peel color rating: 1 = green, progressively to 5 = red.

^bMean separation within columns by Fisher's protected least significant difference at $P \leq 0.05$. For each strain, every value within a year represents an average of eight replications.

Table 4. Effect of 'Fuji' apple strains on fruit firmness at harvest in 6 years.

Strain	Fruit firmness (N)						Avg 6 years
	2004	2005	2006	2007	2009	2010	
Autumn Rose	84.4 a ^z	85.3 ab	79.5 b	74.6 a	77.5 a	80.4 ab	80.3 ab
Desert Rose	82.4 a	83.4 ab	79.5 b	81.4 a	80.4 a	75.5 b	80.4 ab
Myra	84.4 a	87.3 a	83.4 a	75.5 a	80.4 a	82.5 a	82.3 a
September Wonder	66.7 b	70.7 c	67.7 c	62.8 b	65.7 b	68.7 c	67.1 c
Top Export	82.4 a	82.4 b	78.5 b	74.6 a	77.5 a	78.5 ab	79.0 b

^zMean separation within columns by Fisher's protected least significant difference at $P \leq 0.05$. For each strain, every value within a year represents an average of eight replications.

Table 5. Effect of 'Fuji' apple strains on fruit soluble solids at harvest in 6 years.

Strain	Soluble solids concn (% Brix)						Avg 6 years
	2004	2005	2006	2007	2009	2010	
Autumn Rose	14.1 b ^z	16.8 a	15.9 a	16.0 a	14.9 b	16.2 abc	15.9 a
Desert Rose	15.7 ab	17.1 a	16.6 a	16.4 a	15.6 ab	15.9 bc	16.3 a
Myra	16.2 a	17.5 a	16.7 a	15.7 a	15.8 a	16.7 a	16.5 a
September Wonder	15.4 ab	17.4 a	16.1 a	15.2 a	16.0 a	16.4 ab	16.1 a
Top Export	16.2 a	16.8 a	16.1 a	15.5 a	15.5 ab	15.7 c	16.0 a

^zMean separation within columns by Fisher's protected least significant difference at $P \leq 0.05$. For each strain, every value within a year represents an average eight replications.

Table 6. Effect of 'Fuji' apple strains on fruit starch degradation pattern at harvest in 6 years.

Strain	Starch degradation pattern ^z						Avg 6 years
	2004	2005	2006	2007	2009	2010	
Autumn Rose	3.7 b ^y	3.4 b	3.3 c	4.7 bc	3.5 bc	3.1 c	3.7 c
Desert Rose	4.1 b	3.8 b	3.4 c	4.1 c	2.9 d	2.8 c	3.6 cd
Myra	4.3 b	4.0 b	4.4 b	5.3 ab	3.8 b	3.6 b	4.3 b
September Wonder	5.8 a	5.3 a	5.8 a	5.8 a	5.5 a	5.6 a	5.6 a
Top Export	2.9 c	3.4 b	3.2 c	4.6 c	3.1 cd	2.8 c	3.3 d

^zStarch degradation pattern rating represents starch hydrolysis: 1 = least, progressively to 6 = highest.

^yMean separation within columns by Fisher's protected least significant difference at $P \leq 0.05$. For each strain, every value within a year represents an average of eight replications.

Table 7. Effect of 'Fuji' apple strains on fruit watercore and surface cracks at harvest in 6 years.

Strain	Watercore (%)						Cracks 6-year avg (%)
	2004	2005	2006	2007	2009	2010	
Autumn Rose	16.7 a ^z	75.0 ab	86.7 ab	53.3 ab	62.5 bc	75.0 a	53.5 b
Desert Rose	12.5 a	69.4 ab	88.9 a	69.4 ab	93.3 a	52.8 a	62.9 ab
Myra	41.7 a	97.6 a	85.7 ab	78.6 a	97.2 a	76.2 a	78.8 a
S. Wonder	50.0 a	66.7 ab	66.7 b	43.3 b	58.3 c	69.4 a	59.3 ab
Top Export	16.7 a	58.3 b	83.3 ab	58.3 ab	86.1 ab	52.8 a	59.3 ab

^zMean separation within columns by Fisher's protected least significant difference at $P \leq 0.05$. For each strain, every value within a year represents an average of eight replications.

S. Wonder = September Wonder.

earlier date than other strains. ‘Desert Rose’ was a good choice for a late-maturing strain. This strain had excellent color (Table 3), great storability, and shape (data not shown). ‘Myra Fuji’ was particularly desirable for its attractive pink color that resembles bagged ‘Fuji’ without the expensive cost of labor associated with bagging. Trees in this strain tended to be slightly more precocious than those of other strains (Table 1). Fruit of ‘Myra Fuji’ were slightly non-symmetrical (uneven shape) and thus, application of Promalin [benzyladenine, 8% (w/w) + gibberellins A4A7, 1.8% (w/w); Valent BioSciences Corporation, Libertyville, IL] could improve length/diameter ratio (typiness) of fruit in this ‘Fuji’ and this area deserves further study. If other strains such as ‘Desert Rose Fuji’ are available in the nurseries, we do not recommend planting ‘Autumn Rose Fuji’ because it produces fruit with a muddy color under conditions of the Intermountain West region of the United States.

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