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Yield, Biennial Bearing, and Fruit Quality of Ten Commonly Available Strain/Rootstock Combinations of 'Fuji' Apples at a Single Harvest Date over Seven Years

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Abstract

'Fuji' apple (*Malus* × *domestica* Borkh) has gained popularity and the objective of this study was to investigate effects of ten most commonly available 'Fuji' strain/rootstock combinations on tree trunk cross sectional area (TCA; in 2010), yield and biennial bearing index (in 7 years; 2004-2010), and harvest-time fruit quality attributes (in 6 years) under climate conditions of southwest Idaho, USA. The strains and rootstocks were: 'Autumn Rose Fuji', 'Desert Rose Fuji', 'Myra Fuji', 'September Fuji', and 'Top Export Fuji', each on RN 29 rootstock, and 'Beni Shogun Fuji', 'Naga Fu 12 Fuji', 'Sun Fuji', 'T.A.C. 114 Fuji', and 'Torres Fuji', each on M.9 T337 rootstock. Tree TCA was relatively the largest in T.A.C. 114/ M.9 T337 but smallest in Naga Fu 12/M.9 T337. Myra/RN 29 trees appeared to be more precocious and had more yield per tree in 2004 than Beni Shogun/M.9 T337, Naga Fu 12/M.9 T337, T.A.C. 114/ M.9 T337, and Torres/M.9 T337. Myra/RN 29 trees also had relatively higher cumulative yield efficiency and a lower biennial bearing index than many other strain/rootstock combinations. The 6-year average fruit weights of Desert Rose/RN 29 and Sun/M.9 T337 were lower than those of Beni Shogun/RN 29, Naga Fu 12/M.9 T337, September Wonder/RN 29, and T.A.C. 114/ M.9 337. Desert Rose/RN 29, Beni Shogun/M.9 T337, and September Wonder/RN 29 had evenly distributed red blush and Myra/RN 29 had a uniform pink and attractive color. Myra/RN 29 had significantly higher 6-year average soluble solids concentration than Autumn Rose/RN 29, Sun/M.9 T337, and T.A.C. 114/M.9 T337. Beni Shogun/RN 29, September Wonder/RN 29, and Myra/RN 29 had higher but Top Export/RN 29 had lower starch degradation pattern (SDP) than other strain/rootstock combinations. Among all treatments, fruit of Beni Shogun/M.9 T337 and September Wonder/RN 29 matured earlier than other strain/rootstock combinations as indicated by their higher SDP and lower firmness. Considering all yield and quality attributes at harvest, Beni Shogun/M.9 T337 and September Wonder/RN 29 were the most suitable choices for early 'Fuji' and Desert Rose/RN 29 and Myra/RN 29 were the best choices for late-maturing strain/rootstock combinations. Myra/RN 29 was particularly desirable for its relatively high yield efficiency, low biennial bearing, and attractive pink fruit color that resembled bagged 'Fuji' without the expensive cost of labor associated with bagging.

The competitive nature of the global fruit market mandates production of high quality apples, and 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 apples even if they have acceptable fruit size (Baugher et al., 1990; Crassweller and Hollender 1989; Iglesias and Alegre, 2006). Current red-peel cultivars are mostly 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 can show some reversions as a result of a lack of stability (Lacey and Campbell, 1987).

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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). Apple fruits 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 the reflective film to increase the intensity of light into the tree canopy (Ju et al., 1999). However, the high cost of some of these practices mandates planting high-coloring strains. Delaying harvest time can also improve color but this practice, in addition to the increasing the chance of freezing 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).

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. Some strains had blush color during early years of evaluation but had stripe color pattern as trees matured and visa versa. Also, some stripped 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-types than in stripe-types. 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 while 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 day and night 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 the most commonly available 'Fuji' strain/rootstock combinations under the southwest Idaho conditions, which has similar climate conditions to those of the Intermountain West and many other regions worldwide. The main objective in this project was to study the impact of these ten strain/rootstock combinations (rather than either strain or rootstock effects) on yield, biennial bearing, and fruit quality. Consequently, a complete randomized design was used and each strain/rootstock combination was treated as a separate treatment.

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 43.8° N latitude, 116.9° W longitude, and 673 m elevation above sea level, with an annual precipitation of about 297 mm and a sandy loam soil of pH ~ 7.3. Crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.], which is a drought-tolerant grass, was planted between the herbicide strips as the orchard floor cover in all treatments. Trees were irrigated using a drip system (Fallahi et al., 2011). Cultural practices other than strains were similar to those recommended for commercial orchards in the Pacific Northwest (Washington State University, 2014).

The strains and rootstocks were: 'Autumn Rose Fuji', 'Myra Fuji', 'September Fuji' (formerly named as 'Jubilee Fuji'), and 'Top Export Fuji' on RN 29 rootstock and 'Beni Shogun Fuji', 'Naga Fu 12 Fuji', 'Sun Fuji', 'T.A.C. 114 Fuji', and 'Torres Fuji' on M.9 T337 rootstock. 'September Wonder' and 'Beni Shogun' were known to mature earlier than other strains. These strain/rootstock combinations were among the most commonly available 'Fuji' trees in the fruit industry in the USA and thus, were used for comparison in this study. The name of each strain/rootstock combination rather than the strain name alone is used throughout this report. This is to signify that each of these strain/rootstock combinations was treated as a treatment and the effect of each combination, rather than effect of either rootstock or strain alone, was the objective of this study. For example, 'Autumn Rose Fuji' was included on RN 29 but not on M.9 T337 rootstock and this particular combination is referred to as Autumn Rose/RN 29 throughout the study.

Trees were planted at 1.52 × 4.27 m spacing with an east-west row orientation. The trees were obtained from Columbia Basin Nursery, Quincy, Washington, Van Wells Nursery, Wenatchee, Washington, and C & O Nursery, Wenatchee, Washington. 'Snow Drift' crab apple (*Malus x* 'Snowdrift') on Bud 9 rootstock (C & O Nursery, Wenatchee, Washington) was planted in each row as a pollinizer between every 10 'Fuji' trees, as 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 about 3.7 m height. Crops in trees of all treatments were blossom-thinned at about 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 crop load) 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 and was applied at petal-fall. The second post-bloom thinner (when applied, depending on the crop load) was carbaryl at 0.125 to 0.156% formulation that was applied when fruitlet diameter was about 7 mm. Fruits were subsequently hand-thinned when they were about 12-18 mm in diameter (around 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 the rate of 56.8 $kg \cdot ha^{-1}$ in early July, followed by three one-week interval applications, each at 28.4 $kg \cdot ha^{-1}$ every year.

Trunk cross sectional area, yield, biennial bearing, and quality attributes. Trunk cross sectional area from 30 cm above the bud union was measured in late Fall, 2010 (last year of this study). Twenty fruits were randomly sampled from each tree for quality analysis in 2004, 2005, 2006, 2007, 2009, and 2010 (6 years) and the total yield per tree was recorded in every year during 2004-2010 (7 years). Cumulative yield efficiency was calculated as cumulative yield per tree over the 2004-2010 seasons in kg·TCA^{-1} in 2010 in cm^2. The degree of alternate bearing was quantified using a method developed by Hoblyn et al. (1926) and reviewed by Pearce and Dobersek-Urbanc (1967) as follows:

$$I = \frac{\sum \frac{|a_{i+1} - a_i|}{a_{i+1} + a_i}}{n - 1}$$

where: I = the biennial bearing index, n = number of years for which the alternate bearing index is calculated, and a_i = yield in the *ith* year with a_1 being the first year in which harvest occurred.

All strains were harvested together only at the traditional commercial harvest date for late-maturing 'Fuji' apples, which was between October 17 and October 27 in the region. This harvest date was determined by a field visual inspection of the fruit peel and flesh color, taste, and sweetness of the latest maturing strain/rootstock combination. Fruit of 'September Wonder/RN 29 and Beni Shogun/M9 were more mature than others at this traditional commercial harvest date, but this issue did not affect the objective of this study. The main purpose of this study was to evaluate relative differences among various strain/rootstock combinations at that one reference commercial harvest time.

For fruit quality assessment at harvest, average fruit weight was calculated and 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. The intensity of red color was not measured although note was taken of color intensity and pattern.

Each individual fruit was gently wiped with a damp cloth and the percentage of fruit with visible russet, cracks, bitter pit, and sunburn on the fruit peel was calculated as: (number of fruits with the disorder/total number of sampled fruit) × 100.

Soluble solids concentration was measured using a temperature-compensated refractometer (Atago N1, Tokyo, Japan). Fruit firmness was measured with a Fruit Texture Analyzer (Guss, Strand, Western Cape, South Africa), equipped with an 11-mm probe. Fruit were then cut equatorially in halves and starch degradation pattern (SDP) of equatorial halves of each fruit was recorded by comparison with the SDP standard chart developed for 'Fuji' apples by Bartram et al. (1993).

Experimental design and statistics. The experiment was arranged based on a completely randomized design with eight individual trees per strain/rootstock combination. Year-treatment interactions were tested by using the data for each parameter in each year in a factorial arrangement. 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, USA, 2007), with PROC GLM and means were separated using Fisher's Protected Least Significant Difference (LSD) at $P \leq 0.05$.

Results and Discussion

Interactions. There were no significant interactions between years and strain/rootstock combinations for any of the attributes that were investigated in this study. Other researchers also found that interactions between strain and seasonal variations (i.e. seasonal temperature differences) were less among 'Fuji' strains than other apple strains such as 'Delicious' and 'Gala' (Blanchet and Ramat, 1995; Iglesias et al., 1999).

Tree trunk cross-sectional area, yield per tree, and yield efficiency. Although trees in all treatments had a similar size at planting, TCA in 2010 was larger in trees of T.A.C. 114/M.9 T337 and smaller in those of Nag12/M.9 T337 (Table 1). The 7-year

Table 1. Effects of various strain/rootstock combinations on trunk cross sectional area, yield per tree, and yield efficiency in 'Fuji' apples.

Strain/rootstock[z]	2010 TCA (cm^2)[z]	Yield (kg/tree) 2004	2005	2006	2007	2008	2009	2010	Cum. yield 2004-10	Yield efficiency (kg/TCA)
A. Rose/RN 29	67.7 ab[y]	8 ab[y]	19 a	17 bc	13.1 abc	10 e	26 abc	15 c	108 a	1.62 c
BeniSho /M.9	64.1 abcd	7 b	12 cd	24 a	7 c	28 abcd	16 c	33 a	126 a	1.95 abc
D.Rose /RN 29	65.6 abc	7 ab	13 bcd	19 ab	7 c	30 ab	22 abc	30 ab	129 a	2.01 abc
Myr/RN 29	57.6 bcd	11 a	16 abc	17 bc	15 abc	26 abcd	29 ab	27 abc	144 a	2.40 a
Nag12/M.9	54.9 d	6 b	15 abc	12 cd	20 a	17 bcde	30 ab	18 abc	118 a	2.16 ab
SepWo/RN 29	63.1 abcd	8 ab	5 e	11 d	11 abc	33 a	26 abc	27 abc	120 a	1.96 abc
Sun/M.9	58.9 bcd	8 ab	18 ab	18 b	15 abc	14 de	27 abc	17 bc	116 a	1.95 abc
TAC114/M.9	69.9 a	6 b	12 cd	14 bcd	19 ab	15 cde	33 a	24 abc	123 a	1.78 bc
Torres/M.9	56.4 cd	7 b	9 de	19 ab	9 c	29 abc	19 bc	27 abc	119 a	2.16 ab
T.Exp/RN 29	60.7 abcd	8 ab	13 bcd	17 bc	10 bc	21 abcde	21 abc	23 abc	113 a	1.90 abc

[z] Abbreviation for strain/rootstock combinations: A. Rose/RN 29= Autumn Rose/RN 29; BeniSho /M.9 = Beni Shogun/M.9 T337; D.Rose /RN 29 = Desert Rose/RN 29; Myr/RN 29 = Myra/RN 29; Nag12/M.9 = Naga Fu12/M.9 T337; SepWo/RN 29= September Wonder/RN 29; Sun/M.9 =Sun/M.9 T337; TAC114/M.9 = T.A.C. 114/M.9 T337; Torres/M.9 = Torres/M.9 T337; T.Exp = Top Export/RN 29; 2010 TCA = trunk cross sectional area in 2010; 2010 YldEf = yield efficiency, calculated as cumulative yield per tree over 2004-10/trunk cross sectional area.

[y] Mean separation within columns by Fisher's protected Least Significant Difference (LSD) at 0.05. For each strain, every value within a year represents an average of eight replications.

cumulative yields among all strain/rootstock combinations were statistically similar, although year-to-year variations existed among the different strain/rootstock combinations (Table 1). Myra/RN 29 trees had higher yield in 2004 (two years after planting) than Beni Shogun/M.9 T337, Naga Fu 12/M9 T337, T.A.C. 114/M.9 T337, and Torres/M.9 T337 (Table 1), which could be an indication of precocity in this scion/rootstock combination. Precocity did not necessarily have a relationship with maturity date. For example, Beni Sogun /RN 29 which was an early-maturing combination (as described later), was not more precocious than other strain/rootstock combinations (Table 1). Myra/RN 29 trees had significantly higher cumulative yield efficiency than those with T.A.C. 114/M.9 T337 and Autumn Rose/RN 29 combinations (Table 1).

Biennial bearing index. Calculating biennial bearing indexes revealed that Myra/RN 29 appeared to have less yield fluctuations from year to year as compared to other combinations (Table 2), making this strain/rootstock a more reliable combination for regular cropping. T.A.C. 114/M.9 T337 and Sun/M.9 T337 combinations also appeared to have lower biennial bearing indexes than some other combinations.

Fruit quality attributes at harvest. Sun/M.9 T337 and Desert Rose/RN 29 often had lower fruit weight than other strain/rootstock combinations (Table 3). The 6-year average fruit weights of these combinations were significantly lower than those of Beni Shogun/RN 29, Naga Fu 12/M.9 T337, September Wonder/RN 29, and T.A.C. 114/M.9 T337 (Table 3). Fruit weight of Desert Rose /RN 29 was always greater than 273 g (Table 3), which falls into the medium size (64 to 72 fruit per box) category (Packing Guide Chelan Fresh, 2014), and it is the preferred size in certain markets (E. Fallahi, personal knowledge).

Apple fruit size is negatively correlated with yield (Fallahi and Simons, 1993). However, such a correlation did not always exist in this study. For example, trees in Desert Rose/RN 29 and Beni Shogun/M.9 T337 had smaller fruits despite their low yield in 2007 (Tables 1 and 3). This observation indicates that fruit thinning was conducted appropriately and numbers of fruit left on the trees after thinning were not excessively high to create negative crop-fruit size relationships. General fruit weight and yield relations in this study were in agreement with a compre-

Table 2. Effects of various strain/rootstock combinations on biennial bearing index in 'Fuji' apples.

Strain/rootstock[z]	Biennial bearing index[x]						
	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	Mean (2004-10)
A. Rose/RN 29	0.47 a[Y]	0.27 abc	0.52 abc	0.60 a	0.42 a	0.41 a	0.44 ab
BeniSho /M.9	0.39 ab	0.37 ab	0.70 a	0.67 a	0.36 a	0.39 a	0.48 a
D.Rose /RN 29	0.24 b	0.34 ab	0.62 ab	0.64 a	0.24 a	0.34 a	0.40 ab
Myr/RN 29	0.22 b	0.11 c	0.33 bc	0.49 a	0.28 a	0.19 a	0.27 b
Nag12/M.9	0.38 ab	0.18 bc	0.32 bc	0.46 a	0.49 a	0.37 a	0.37 ab
SepWo/RN 29	0.25 ab	0.45 a	0.46 abc	0.57 a	0.40 a	0.43 a	0.43 ab
Sun/M.9	0.40 ab	0.17 bc	0.34 bc	0.47 a	0.28 a	0.33 a	0.33 b
TAC114/M.9	0.31 ab	0.11 c	0.29 c	0.53 a	0.45 a	0.21 a	0.32 b
Torres/M.9	0.28 ab	0.33 ab	0.42 abc	0.54 a	0.31 a	0.43 a	0.39 ab
T.Exp/RN 29	0.33 ab	0.21 bc	0.53 abc	0.69 a	0.36 a	0.37 a	0.42 ab

[z] Abbreviation for strain/rootstock combinations: see Table 1.

[y] Mean separation within columns by Fisher's protected Least Significant Difference (LSD) at 0.05. For each strain, every value within a year represents an average of eight replications.

[x] The degree of alternate bearing (biennial bearing index) was quantified using a method developed by Hoblyn et al. (1926) and reviewed by Pearce and Dobersek-Urbanc (1967) as follows:

$$I = \frac{\sum \frac{|a_{i+1} - a_i|}{a_{i+1} + a_i}}{n - 1}$$

where I = the alternate bearing index, n = number of years for which the alternate bearing index is calculated, and a_i = yield in the *ith* year with a_1 being the first year in which harvest occurred.

Table 3. Effects of various strain/rootstock combinations on fruit weight (g) at harvest in 'Fuji' apples in 6 years.

Strain/rootstock[z]	Fruit weight (g)					
	2004	2005	2006	2007	2009	2010	6-year mean
A. Rose/RN 29	299.1 b[y]	297.3 ab	311.6 bc	322.7 ab	296.2 cd	275.9 bcd	299.8 ab
BeniSho /M.9	295.7 b	288.7 abcd	325.4 abc	313.1 b	323.3 ab	319.4 a	310.9 a
D.Rose /RN 29	289.0 b	286.4 abcd	318.4 abc	273.2 c	308.8 abcd	283.5 bc	291.1 b
Myr/RN 29	304.1 ab	279.4 bcd	314.5 bc	335.3 ab	299.0 bcd	271.8 bcd	302.0 ab
Nag12/M.9	302.0 ab	295.0 ab	345.5 a	353.8 a	297.5 bcd	277.5 bcd	313.9 a
SepWo/RN 29	331.7 a	268.9 d	334.2 abc	338.8 ab	326.7 a	290.4 ab	314.1 a
Sun/M.9	276.6 b	273.5 cd	309.2 c	327.7 ab	283.4 d	255.2 cd	287.6 b
TAC114/M.9	279.1 b	303.3 a	338.7 ab	327.6 ab	311.9 abc	279.7 bcd	307.1 a
Torres/M.9	301.6 b	276.5 bcd	332.4 abc	333.7 ab	304.0 abcd	260.3 bcd	301.4 ab
T.Exp/RN 29	283.5 b	291.8 abc	329.8 abc	336.2 ab	317.4 abc	250.7 d	301.6 ab

[z] Abbreviation for strain/rootstock combinations: see Table 1.

[y] Mean separation within columns by Fisher's protected Least Significant Difference (LSD) at 0.05. For each strain, every value within a year represents an average of eight replications.

hensive study on crop load adjustment reported from Japan by Koike and Ono (2014). Thus, differences among treatments for yield and fruit size are indicative of true strain/rootstock combination rather than a crop load effect.

Strains differed widely in respect to their fruit peel color and differences among strain/rootstock combinations were consistent from year to year (Table 4). In general, fruits of Autumn Rose/RN 29, Myra/RN 29, Sun/M.9 T337, T.A.C. 114/M.9 T337, Torres/M.9 T337, and Top Export/RN 29 always had less red color but Beni Shogun/M.9 T337, September Wonder/RN 29 in particular and Desert Rose Fuji/RN 29 had more red color than other strains during most years and over all six seasons (Table 4). Naga Fu 12 Fuji/M.9 T337 also had relatively high color in two of six years (in 2007 and 2009; Table 4). The type or pattern of peel color among the "low-coloring" and "high coloring" strains varied widely. For example, September Fuji/RN 29 and Beni Shogun/M.9 T337 seemed, from the regular observations that were made, to mature about three weeks before other strain/

rootstock combinations and had a high reddish blush and very attractive color. Fruit of Desert Rose/RN 29 had evenly distributed red blush coloration on the peel, even in the shaded areas of the tree. Among the strains tested, 'Desert Rose Fuji' had the best color among late-season 'Fuji' strains. Myra/RN 29 fruit peel had 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/RN 29 had deep red stripes with wider strips of green-beige color in between. Autumn Rose/RN 29 had poor red stripe and blush (mixed) color, and under high nitrogen conditions, the color was less acceptable for the market (data not shown).

Fruit of Beni Shogun/M.9 T337 and September Wonder/RN 29 had lower firmness than all other strains in five of six years and six of six years studied, respectively (Table 5) due to their earlier maturity. These fruits had shorter storage life (data not shown). These two strains should be harvested earlier and should not be kept in a long-term storage. Iglesias et al. (2012) reported that fruit firmness in all strains of 'Fuji' remained high and were completely acceptable even at the

Table 4. Effects of various strain/rootstock combinations on fruit peel color at harvest in 'Fuji' apples in 6 years.

Strain/rootstock[y]	Fruit peel color rating[z]						
	2004	2005	2006	2007	2009	2010	6-year mean
A. Rose/RN 29	2.8 d[x]	3.5 d	3.0 cd	3.8 abc	3.6 de	3.1 de	3.2 d
BeniSho /M.9	4.0 ab	4.3 a	4.5 a	3.8 abc	4.3 ab	4.4 ab	4.2 ab
D.Rose /RN 29	3.7 bc	4.4 a	3.7 b	3.8 abc	4.5 a	4.2 abc	4.0 bc
Myr/RN 29	3.1 cd	3.7 cd	2.8 cde	3.4 bcde	3.8 bcd	3.0 e	3.3 d
Nag12/M.9	3.0 cd	3.9 bc	3.2 bcd	4.3 ab	4.2 abc	3.7 cd	3.7 c
SepWo/RN 29	4.6 a	4.5 a	4.5 a	4.6 a	4.7 a	4.5 a	4.6 a
Sun/M.9	2.6 d	3.6 cd	2.5 de	3.3 cde	3.2 e	3.1 de	3.0 d
TAC114/M.9	2.7 d	3.6 cd	2.1 e	2.7 e	3.5 de	3.0 e	3.0 d
Torres/M.9	3.2 cd	4.2 ab	3.4 bc	3.7 bcd	4.4 a	4.0 bc	3.8 c
T.Exp/RN 29	2.6 d	3.4 d	2.5 de	2.8 de	3.6 cde	2.9 e	3.0 d

[z] Fruit peel color rating: 1 = green, progressively to 5 = red.
[y] Abbreviation for strain/rootstock combinations: see Table 1.
[x] Mean separation within columns by Fisher's protected Least Significant Difference (LSD) at 0.05. For each strain, every value within a year represents an average of eight replications.

Table 5. Effects of various strain/rootstock combinations on fruit firmness at harvest in 'Fuji' apples in 6 years.

Strain/rootstock[z]	Firmness (N)						
	2004	2005	2006	2007	2009	2010	6-year mean
A. Rose/RN 29	84.4 a[y]	85.3 abc	79.5 bc	74.6 ab	77.5 ab	79.5 ab	80.1 a
BeniSho /M.9	72.6 c	73.6 e	66.7 c	73.4 bc	68.7 c	66.7 c	70.3 b
D.Rose /RN 29	82.4 ab	83.4 bcd	79.5 bc	81.4 a	80.4 a	75.5 b	80.4 a
Myr/RN 29	84.4 a	87.3 ab	83.4 ab	75.5 ab	80.4 a	82.4 a	82.2 a
Nag12/M.9	78.5 b	81.4 d	95.2 a	67.7 cd	75.5 b	81.4 a	80.0 a
SepWo/RN 29	66.7 d	70.6 e	67.7 c	62.8 d	65.7 c	68.7 c	67.0 b
Sun/M.9	84.4 a	83.4 bcd	80.4 bc	73.6 bc	78.5 ab	79.5 ab	80.0 a
TAC114/M.9	84.4 ab	83.3 cd	82.4 abc	75.5 ab	77.5 ab	80.4 a	80.6 a
Torres/M.9	80.4 b	88.3 a	78.5 bc	75.5 ab	80.4 a	78.5 ab	80.3 a
T.Exp/RN 29	82.4 ab	82.4 cd	78.5 bc	73.6 bc	77.5 ab	78.5 ab	78.8 a

[z] Abbreviation for strain/rootstock combinations: see Table 1.
[y] Mean separation within columns by Fisher's protected Least Significant Difference (LSD) at 0.05. For each strain, every value within a year represents an average of eight replications.

Table 6. Effects of various strain/rootstock combinations on fruit soluble solids concentration (SSC) at harvest in 'Fuji' apples in 6 years.

Strain/rootstock[y]	Soluble solids concentration (°Brix)						
	2004	2005	2006	2007	2009	2010	6-year mean
A. Rose/RN 29	14.1 b[y]	16.8 abc	15.9 a	16.0 ab	14.9 d	16.2 ab	15.8 bc
BeniSho /M.9	15.0 ab	17.3 ab	16.4 a	14.1 c	16.4 a	16.3 ab	15.9 abc
D.Rose /RN 29	15.7 a	17.1 abc	16.6 a	16.4 a	15.6 bcd	15.9 ab	16.3 ab
Myr/RN 29	16.2 a	17.5 a	16.7 a	15.7 ab	15.8 abc	16.7 a	16.5 a
Nag12/M.9	15.6 ab	16.6 abc	16.4 a	15.9 ab	15.2 cd	16.4 ab	16.0 abc
SepWo/RN 29	15.4 ab	17.4 a	16.1 a	15.2 bc	16.0 ab	16.4 ab	16.1 abc
Sun/M.9	14.8 ab	16.5 bc	16.3 a	15.2 bc	15.3 bcd	16.1 ab	15.7 c
TAC114/M.9	15.2 ab	16.3 c	16.5 a	15.4 ab	15.2 cd	16.0 ab	15.7 c
Torres/M.9	15.5 ab	17.4 a	16.4 a	15.9 ab	15.9 abc	16.0 ab	16.2 abc
T.Exp/RN 29	16.2 a	16.8 abc	16.1 a	15.5 ab	15.5 bcd	15.7 b	16.0 abc

[z] Abbreviation for strain/rootstock combinations: see Table 1.
[y] Mean separation within columns by Fisher's protected Least Significant Difference (LSD) at 0.05. For each strain, every value within a year represents an average of eight replications.

Table 7. Effects of various strain/rootstock combinations on fruit starch degradation pattern (SDP) at harvest in 'Fuji' apples in 6 years.

Strain/rootstock[z]	Starch degradation pattern (SDP)[z]						
	2004	2005	2006	2007	2009	2010	6-year mean
A. Rose/RN 29	3.7 bc[x]	3.4 c	3.3 cd	4.7 cd	3.5 bc	3.1 c	3.7 c
BeniSho /M.9	5.5 a	5.5 a	5.6 a	6.0 a	5.5 a	5.7 a	5.6 a
D.Rose /RN 29	4.1 b	3.8 bc	3.4 cd	4.1 d	2.9 d	2.8 c	3.6 cd
Myr/RN 29	4.3 b	4.0 b	4.4 b	5.3 bc	3.8 b	3.6 b	4.3 b
Nag12/M.9	3.0 cd	3.6 bc	3.7 c	4.5 d	3.2 cd	2.9 c	3.5 cd
SepWo/RN 29	5.8 a	5.3 a	5.8 a	5.8 ab	5.5 a	5.6 a	5.6 a
Sun/M.9	3.9 b	3.6 bc	3.7 c	4.5 d	3.7 b	2.9 c	3.7 c
TAC114/M.9	3.1 cd	3.7 bc	3.0 d	4.8 cd	3.1 cd	2.8 c	3.5 cd
Torres/M.9	3.6 bcd	3.6 bc	3.0 d	4.5 d	3.3 bcd	2.8 c	3.5 cd
T.Exp/RN 29	2.9 d	3.4 c	3.2 cd	4.6 d	3.1 cd	2.8 c	3.3 d

[z] Starch degradation pattern represents starch hydrolysis: 1 = least, progressively to 6 = highest.
[y] Abbreviation for strain/rootstock combinations: see Table 1.
[x] Mean separation within columns by Fisher's protected Least Significant Difference (LSD) at 0.05. For each strain, every value within a year represents an average of eight replications.

last (latest) harvest date. Although we did not have multiple harvests in our study, similar to Iglesias et al. (2012), the fruit firmness in the early-maturing strain/rootstock combinations was sufficiently high (at least 66 N, Table 5) for a "crunchy" eating experience.

Autumn Rose/RN 29 tended to have lower and Myra/RN 29 had higher SSC in three of six years of this study (Table 6). Averaging values over six years revealed that Myra/RN 29 had significantly higher SSC than Autumn Rose/RN 29, Sun/M.9 T337, and T.A.C. 114/M.9 T337. Beni Shogun/M.9 T337, September Wonder/RN 29, and Myra/RN 29 had higher and Top Export/RN 29 lower SDP consistently for each of the six years of the study (Table 7).

Iglesias et al. (2012) compared fruit quality parameters of seven strains of 'Fuji' at different harvest dates and concluded that firmness, SSC, SDP, and titratable acidity of all strains were similar at each harvest date. In that report, fruit color intensity and pattern were not related to differences in fruit quality parameters or ripening time of different strains. In this study, quality and maturity differences occurred amongst the different strain/rootstock combinations. The differences may stem from the fact that Iglesias et al. (2012) was based on one-season of study (in 2008) as compared to the six to seven years reported here.

The proportion of fruit with watercore varied greatly from year to year and from strain to strain. Beni Shogun/M.9 T337 had lower watercore than many other combinations in four of six years (Table 8), in spite of its higher SDP ratings (Table 7). This observation suggests that starch hydrolysis and stage of maturity in this strain is not directly associated with watercore, which is the result of sorbitol accumulation in the core area. However, Myra/RN 29 tended to have (numerically or significantly) higher watercore in four of six years (Table 8).

Fruit of Top Export/RN 29 and Myra/RN 29 generally had lower but Torres/M.9 T337 had higher russet than those of other strain/rootstock combinations although differences were not always significant (Table 8). Fruit of Beni Shogun/M.9 T337 had highest sunburn and surface cracks, while Sun/M.9 T337 had low sunburn (Table 8). The higher sunburn in Beni Shogun/M.9 T337 cannot be related to its time of maturity. Most of the sunburn injury occurred during late June through July every year. It is possible that fruit growth in Beni Shogun was faster than other strains and as a result, fruit had a thinner cuticle at the peak of the hot season, exposing them to more sunburn, and this area deserves further study. Incidence of bitter pit was not affected by strain/rootstock combination (data not shown).

General Conclusions

Considering all yield and quality attributes at harvest, Beni Shogun/M.9 T337 and September Wonder/RN 29 were the preferred choices for early strain/rootstock combinations. Fruit yield, weight, and color in these strains were all satisfactory. Lower firmness and higher SDP, and surface cracking of fruit in these strain/rootstock combinations could be improved by harvesting fruit at an earlier date than other strain/rootstock combinations. Desert Rose/RN 29 was the preferred choice for a late-maturing ‘Fuji’. Fruit of this combination had excellent color (Table 4), great shape, flavor, and storability (data not shown). Myra/RN 29 was particularly desirable for its attractive pink color that resembles bagged ‘Fuji’ without the expensive cost of labor associated with bagging. Trees in Myra/RN 29 were also suitable for planting, as they tended to be slightly more precocious and had higher cumulative yield efficiency (Table 1) and lower biennial bearing index than those of other strain/rootstock combinations (Table 2). Fruit of Myra/RN

Table 8. Effects of various strain/rootstock combinations on fruit water core, russet, sunburn, and surface cracks at harvest in 'Fuji' apples in 6 years.

Strain/rootstock[z]	Watercore (%)							Disorders, 6-year average (%)		
	2004	2005	2006	2007	2009	2010	Avg. 2004-10	Russet	Sunburn	Cracking
A. Rose/RN 29	17 abc[y]	75 ab	87 a	53 ab	63 bc	75 a	54 cd	38 cd	16 bc	0.8 cd
BeniSho /M.9	21 abc	42 c	64 c	11 c	57 c	73 a	44 d	50 ab	42 a	3.9 a
D.Rose /RN 29	13 bc	69 abc	89 a	69 ab	93 a	53 a	63 bc	53 ab	21 bc	2.1 abcd
Myr/RN 29	42 ab	98 a	86 ab	79 a	97 a	76 a	79 a	35 d	18 bc	1.0 bcd
Nag12/M.9	29 abc	78 ab	89 a	77 a	97 a	73 a	73 ab	46 bc	16 bc	1.6 abcd
SepWo/RN 29	50 a	67 bc	67 bc	43 b	58 c	69 a	59 bcd	45 bc	26 b	3.5 ab
Sun/M.9	17 abc	72 abc	81 abc	81 a	75 abc	67 a	65 abc	38 cd	11 c	0.6 cd
TAC114/M.9	8 bc	69 abc	73 abc	53 ab	80 abc	75 a	57 cd	40 cd	13 c	0.8 cd
Torres/M.9	4 c	67 bc	83 abc	60 ab	86 ab	77 a	63 bc	60 a	14 c	3.3 abc
T.Exp/RN 29	17 abc	58 bc	83 abc	58 ab	86 ab	53 a	59 bcd	34 d	16 bc	0.0 d

[z] Abbreviation for strain/rootstock combinations: see Table 1.

[y] Mean separation within columns by Fisher’s protected Least Significant Difference (LSD) at 0.05. For each strain, every value within a year represents an average of eight replications.

29 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 the typiness of this 'Fuji' and this area deserves further study.

While other strain/rootstock combinations such as Desert Rose Fuji/RN 29 are available in nurseries, planting strain/rootstock combinations such as Autumn Rose/RN 29, Sun/M.9 T337, T.A.C. 114/M.9 T337, or Torres/M.9 T337 cannot be recommended because these produce fruit with poor color quality (a "muddy" appearance) under conditions of the Intermountain West.

Since new strains of 'Fuji' are frequently introduced to the apple industry, performance and quality attributes of each strain should regularly be evaluated, and this area deserves further study.

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