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A Long-Time Assessment of Yield and Harvest Quality Attributes Among Five Strains of 'Fuji' Apples

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Summary

'Fuji' apple (*Malus* × *domestica* Borkh) is a popular cultivar due to its superior flavour, texture, and storability; however, poor fruit colour of this cultivar is a major problem worldwide. The objective of this study was to investigate effects of five 'Fuji' strains on yield (in 7 years) and fruit harvest-time quality attributes (in 6 years) under climate conditions of Intermountain West region of the United States. The strains were: 'Beni Shogun Fuji', 'Naga Fu 12 Fuji', 'Sun Fuji', 'T.A.C. 114 Fuji', and 'Torres Fuji' on M.9 T337 rootstock. 'Sun Fuji' often had lower fruit weight than other strains. Strains differed widely with respect to their fruit peel colour. In general, fruits of 'Sun Fuji' and 'T.A.C. 114 Fuji' always had less but 'Beni Shogun Fuji' had more red colour than other strains. 'Torres Fuji' also tended to have slightly higher colour than some strains. Fruit of 'Beni Shogun Fuji' had higher starch degradation pattern than other strains because this strain matured earlier. 'Beni Shogun' also had higher sunburn and surface cracks but lower watercore than all other strains. Considering all yield and quality attributes at harvest, 'Beni Shogun Fuji' was a great choice for an early strain.

Key words. *Malus domestica* – strain – fruit colour – fruit size – fruit quality – starch index – yield

Introduction

The highly competitive nature of global fruit market mandates production of high quality fruit with minimum cost. Establishment of high-density orchards with the use of an efficient rootstock and a high-colouring 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 colour, size, eating quality and texture (Crassweller and Hollender 1989; Donati et al. 2003; Fisher and Ketchie 1989; MacFie 1995; Salveit 1983). Nevertheless, poor colour 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). Apple fruits colour best in climates with clear bright days and cool nights during the preharvest period (Blankenship 1987; Faragher 1993; Westwood 1993). Formation of red colour in apple is also influenced by light (Arakawa 1991; Saure 1990), cultivar (Curry 1997; Dickinson and White 1986; Iglesias et al. 1999; Sansavini et al. 2005), strain (Fallahi et al 2011; Greene and Autio 1993; Iglesias and Echeverría 2009; Iglesias et al. 2012; Lacey and Campbell 1987), fruit bagging (Schupp et al. 2002), evaporative cooling (Williams 1993), and the use of the reflective film to increase the intensity of light into the tree canopy (Iglesias and Alegre 2009; Ju et al. 1999). However, the high cost of many of these practices mandates planting high-colouring strains. Delaying harvest time can also improve colour 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).

'Fuji' has gained high popularity because of its outstanding flavor, high soluble solids concentration (SSC), low starch degradation pattern (SDP), and long storage life. However, poor fruit colour of this cultivar is a major problem worldwide, and researchers and apple growers have been focusing on finding high-colouring strains with high quality in the past decades (Blanchet and Ramat 1995; Marquina et al. 2004). 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 colour 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 colour

(stripe or blush) was not always stable as trees matured. The striped-type sports showed more tendencies to develop red colour 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 stripe-type clones were comparable with standard 'Fuji' (Komatsu 1998). Iglesias et al. (2012), in a recent comprehensive study on 'Fuji' strains, reported that the most coloured 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 (SSC, titratable acidity, SDP, firmness) 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 colour 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 SSC when compared with the other strains while the 'Aki Fu 1 Fuji' fruit had a smaller 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 colour 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.

The Intermountain West region of the United States, particularly Idaho, is a major area for production of 'Fuji' apples. However, 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 to those of the Intermountain West 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 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. Cultural practices other than strains were similar to those recommended for commercial orchards in the Pacific Northwest (Washington State University 2014).

The strains evaluated, their colour pattern and origin were: 'Beni Shogun Fuji' (blushed, mutated from 'Yataka'), 'Naga Fu 12 Fuji' (diffused red), 'Sun Fuji' (blushed), 'T.A.C. 114 Fuji' (stripped, mutated from 'Red Spur 2'), and 'Torres Fuji' (mostly blushed, mutated from 'BC.2 Fuji'), all on M.9 T337 rootstock, were planted at 1.52 × 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 USA, and were thus used for comparison in this study. 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* × 'Snow Drift') on Bud 9 rootstock (C & O Nursery, Wenatchee, Washington, USA) 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 irrigated with a drip system, using evapotraspirayion information, adjusted for the size of the tree canopy. Each tree received about 40 g of actual nitrogen in form of Urea (46 % N) through drip irrigation in late May every year. 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. Trees in 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 a rate of 56.8 kg ha^{-1} in early July, followed by three one-week interval applications, each at 28.4 kg ha^{-1} every year.

Fruit, yield and quality attributes

Yield (kg $tree^{-1}$) was recorded for each strain over the 7 year period 2004–2010 and quality attributes over the 6 year period (2008 data not taken). For quality evaluation, we harvested all strains together only at the traditional commercial harvest date, which was between October 17 and October 27 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. Twenty fruits were randomly sampled from each tree for quality analysis at harvest and the total yield per tree was recorded. For fruit quality assessment at harvest, peel colour was visually rated on a scale of 1 to 5, with 1 = 20 % of peel surface had red colour in either strip or blush pattern, progressively to 5 = 100%% of peel surface covered with red colour. Thus, a colour ranking of 3.5 corresponds with about 70 % of red colour. We did not measure the intensity of fruit red colour, although, we took a note of the colour 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 (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). 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). SDP rating pattern represents starch hydrolysis from 1 = least to 6 = highest.

Experimental design and statistics

The experiment was arranged based on a completely randomized design with eight individual trees per strain. Year and strain interactions were also tested. 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

Fruit yield and quality attributes

Yield varied from year to year, resulting in a similar 7-year cumulative yield among all strains (Table 1). Precocity did not necessarily have a relationship with maturity date. For example, 'Beni Sogun Fuji', which was an early-maturing combination (as described later), was not more precocious than other strains (Table 1).

'Sun Fuji' often had lower fruit weight than other strains. The 6-year average fruit weight of this strain was significantly lower than those of other strains (Table 2). However, the fruit weight of 'Sun Fuji' was always greater than 255 g (Table 2), which is considered a medium sized and preferred by many consumers.

Apple yield is negatively correlated with fruit size (Westwood 1993). However, such a correlation did not always exist in our study. For example, trees in 'Beni Shogun' had smaller fruits despite their low yield in 2007 (Tables 1 and 2). This observation indicates that fruit thinning was conducted properly, and numbers of remaining fruit on the trees after thinning were not excessive to create negative crop-fruit size relationships. General fruit weight and yield relations in this study were in agreement with a comprehensive study on crop load adjustment reported from Japan by Koike and Ono (2014).

Strains differed widely in respect to their fruit peel colour but relative differences among strain stayed the same from year to year (Table 2). In general, fruits of 'Sun Fuji' and 'T.A.C. 114 Fuji' always had less but 'Beni Shogun Fuji' had more red colour than other strains during most years, leading to a higher 6-year average colour in 'Beni Shogun Fuji' (Table 2). Other than 'Beni Shogun Fuji', 'Torres Fuji' also tended to have slightly higher colour than most other strains, although differences were not always significant.

Fruit of 'Beni Shogun Fuji' had lower firmness than all other strains in 5 of 6 years (Table 2). There were no significant differences in SSC among strains in 3 of 6

Table 1. Effect of 'Fuji' apple strains on yield in 7 years during 2004–2010.

Strain	Yield (kg tree^{-1})							
	2004	2005	2006	2007	2008	2009	2010	Cum. 2004–10
'Beni Shogun'	6.9 a[z]	11.8 bc	24.0 a	6.6 b	27.7 a	16.2 c	32.9 a	126.1 a
'Naga Fu 12'	5.9 a	15.2 ab	11.7 c	20.0 a	17.2 b	29.8 a	18.0 b	117.8 a
'Sun'	7.6 a	17.9 a	18.1 ab	14.5 ab	14.4 b	26.9 ab	16.6 b	116.1 a
'T.A.C. 114'	6.3 a	12.0 bc	14.1 bc	19.1 a	15.2 b	32.6 a	23.5 ab	122.8 a
'Torres'	6.9 a	9.4 c	19.2 ab	8.8 b	28.5 a	19.0 bc	27.3 ab	119.1 a

[z] 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 eight replications.

Table 2. Effect of 'Fuji' apple strains on fruit weight, fruit peel colour, fruit firmness, soluble solids concentration, and fruit starch degradation pattern at harvest in 6 years during 2004–2010.

Strain	2004	2005	2006	2007	2009	2010	Avg. 2004–10
				Fruit weight (g fruit^{-1})			
'Beni Shogun'	295.7 ab[z]	288.7 abc	325.4 ab	313.1 b	323.3 a	319.4 a	310.9 a
'Naga Fu 12'	302.0 a	295.0 ab	345.5 a	353.8 a	297.5 bc	277.5 b	313.9 a
'Sun'	276.6 b	273.5 c	309.2 b	327.6 ab	283.4 c	255.2 b	287.6 b
'T.A.C. 114'	279.1 b	303.3 a	338.7 a	327.6 ab	311.9 ab	279.7 ab	307.1 a
'Torres'	301.6 a	276.5 bc	332.4 a	333.7 ab	304.0 abc	260.3 b	301.4 a
				Fruit peel colour (1–5)[x]			
'Beni Shogun'	4.0 a[z]	4.3 a	4.5 a	3.8 ab	4.3 a	4.5 a	4.2 a
'Naga Fu 12'	3.0 b	3.9 ab	3.2 bc	4.3 a	4.2 a	3.7 b	3.7 b
'Sun'	2.6 b	3.6 b	2.5 cd	3.3 bc	3.2 b	3.1 c	3.0 c
'T.A.C. 114'	2.7 b	3.6 b	2.1 d	2.7 c	3.5 b	3.0 c	3.0 c
'Torres'	3.2 ab	4.2 a	3.4 b	3.7 ab	4.4 a	4.0 ab	3.8 b
				Fruit firmness (N)			
'Beni Shogun'	72.6 d[z]	73.6 c	66.7 b	73.6 ab	68.7 c	66.7 b	70.3 b
'Naga Fu 12'	78.5 c	81.4 b	95.2 a	67.7 b	75.5 b	81.4 a	80.0 a
'Sun'	84.4 a	83.4 b	80.4 ab	73.6 ab	78.5 ab	79.5 a	80.0 a
'T.A.C. 114'	82.4 ab	83.4 b	82.4 ab	75.5 a	77.5 ab	80.4 a	80.3 a
'Torres'	80.4 bc	88.3 a	78.5 ab	75.5 a	80.4 a	78.5 a	80.3 a
				Soluble solids concentration (% Brix)			
'Beni Shogun'	15.0 a[z]	17.3 ab	16.4 a	14.1 b	16.4 a	16.3 a	15.9 a
'Naga Fu 12'	15.6 a	16.6 ab	16.4 a	15.9 a	15.2 c	16.4 a	16.0 a
'Sun'	14.8 a	16.5 b	16.3 a	15.2 ab	15.3 bc	16.1 a	15.7 a
'T.A.C. 114'	15.2 a	16.3 b	16.5 a	15.4 a	15.2 c	16.0 a	15.7 a
'Torres'	15.5 a	17.4 a	16.4 a	15.9 a	15.9 ab	16.0 a	16.2 a
				Starch degradation pattern (SDP)[y]			
'Beni Shogun'	5.5 a[z]	5.5 a	5.6 a	6.0 a	5.5 a	5.7 a	5.6 a
'Naga Fu 12'	3.0 c	3.6 b	3.7 b	4.5 b	3.2 c	2.9 b	3.5 b
'Sun'	3.9 b	3.6 b	3.7 b	4.5 b	3.7 b	2.9 b	3.7 b
'T.A.C. 114'	3.1 bc	3.7 b	3.0 c	4.8 b	3.1 c	2.8 b	3.5 b
'Torres'	3.6 bc	3.6 b	3.0 c	4.5 b	3.3 bc	2.8 b	3.5 b

[x] Fruit peel colour rating: 1 = green, progressively to 5 = red.

[y] Starch degradation pattern rating represents starch hydrolysis: 1 = least, progressively to 6 = highest.

[z] 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

years, leading to a statistically similar SSC in all strains (Table 2). 'Beni Shogun Fuji' had higher SDP than all other strains (Table 2). Lower firmness and higher SDP of 'Beni Shogun' was due to earlier maturity of this strain.

Percentages of fruit with watercore varied greatly from year to year. 'Beni Shogun Fuji' had lower watercore than other strains in 5 of 6 years (Table 3), in spite of its higher SDP ratings (Table 2). 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 (Yamada and Kobayashi 1999). However, 'Naga Fu 12 Fuji' tended to have (numerically or significantly) higher watercore than other strains in 5 of 6 years (Table 3).

Fruit of 'Torres Fuji' had higher russet than those of other strains although differences were not always significant. Fruit of 'Beni Shogun Fuji' had higher sunburn and surface cracks (Table 3). The higher sunburn in 'Beni

Table 3. Effect of 'Fuji' apple strains on fruit watervcore and peel disorders at harvest in 6 years during 2004–2010.

Strain	Watercore (%)							Disorders 6-year avg. (%)		
	2004	2005	2006	2007	2009	2010	6-yr avg.	Russet	Sunburn	Crack
'Beni Shogun'	21 a[z]	42 b	4.0 a	11 b	58 b	73 a	44.1 c	50.0 ab	41.5 a	3.9 a
'Naga Fu 12'	29 a	78 a	2.0 ab	77 a	97 a	73 a	73.0 a	46.1 bc	15.8 b	1.6 ab
'Sun'	17 a	72 ab	0.6 b	81 a	75 ab	67 a	65.3 ab	38.4 c	10.7 b	0.6 b
'T.A.C. 114'	8 a	69 ab	0.8 ab	53 a	80 ab	75 a	57.4 b	39.9 bc	12.9 b	0.8 ab
'Torres'	4 a	67 ab	3.3 ab	60 a	86 ab	77 a	63.2 ab	59.5 a	14.0 b	3.3 ab

[z] 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.

Shogun Fuji' 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 Fuji' 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 strains (data not shown).

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 colour intensity and pattern were not related to differences in the fruit quality parameters or ripening time of different strains. In our study, we had quality and maturity differences among different strains. The differences stem out from the fact that Iglesias et al. (2012) had a much shorter study as compared to ours, which was conducted over 6 to 7 years. In their study, 'Aztec Fuji' had high colour, but this strain received the lowest score for consumer acceptability (Iglesias et al 2012).

Interactions between years, fruit yield and quality attributes

There was no significant interaction between years and strains for any of the attributes in this study. Other researchers also found that interactions between strain and seasonal variations, such as temperatures, were less among 'Fuji' stains than other apple strains (Blanchet and Ramat 1995; Iglesias et al. 1999).

Conclusions

Considering all yield and quality attributes at harvest, 'Beni Shogun' was a great choice for an early strain. Fruit yield, weight, and colour in this strain were satisfactory. Lower firmness and higher SDP and surface cracking of fruit in this strain could be improved by harvesting fruit at an earlier date than other strains.

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