Optimum Harvest of Low-chill Melting and Non-melting Flesh Peach Cultivars for Direct Ripening and Ripening following Low Temperature Storage

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Abstract. The physical and chemical characteristics of two melting flesh (MF) cultivars, TropicBeauty and Flordaprince, and two non-melting flesh (NMF) cultivars, UFSun and Gulfking, with advancing maturities, were determined at harvest, after ripening at 20 °C for 7 days (i.e., direct ripening) and after storage at 0 °C for 14 days then ripening at 20 °C for 7 days (i.e., ripening following low temperature storage). The NMF cultivars were able to retain flesh firmness better than the MF cultivars as fruit matured and ripened on the tree and after the two storage treatments. The NMF fruit of the least mature to the most advanced maturity groups (MGs) were ≈ 2 to 7 times firmer than the MF fruit in the same MGs after ripening in both storage conditions. For both MF and NMF fruit, a significant reduction of titratable acidity (TA) occurred with no significant changes in soluble solids content (SSC) and total soluble sugar (TSS) as maturity and ripening progressed on the tree and after ripening in both storage conditions. Minimum quality standards of “ready for consumption” peaches were used as general guidelines to determine the optimum harvest maturity of all four cultivars. The NMF fruit ripened directly had wider optimum harvest maturity ranges and could be harvested at more advanced stages than the MF fruit. The MF fruit that ripened following low temperature storage needed to be picked at earlier maturity stages than those that were directly ripened. The optimum harvest maturity of NMF UFSun for the low temperature storage treatment was more advanced than that of the other three cultivars due to abnormal softening found in the lower MGs after ripening. Linear correlation analyses showed that the skin ground color (GC) a^* values of both MF cultivars and NMF ‘UFSun’ were highly correlated with the flesh color (FC) a^* values, suggesting that GC a^* values can be an informative harvest indicator for this NMF cultivar instead of the traditionally used FC. The GC a^* values also had high linear correlation with TA for all four cultivars, suggesting that TA can be a potential maturity index for both MF and NMF peaches. Significant correlations of GC a^* values and flesh firmness (GC-FF) were found in all four cultivars in one year but only in MF peaches in both years, showing that flesh firmness was the most consistent maturity indicator for the MF cultivars in this study.

The bulk of peach production in the United States occurs in temperate, high-chill regions, with fruit available from late May through October. Developing low-chill peach cultivars in the subtropical regions that produce fruit in the early season is economically important. Not only a fresh supply of peaches would be available for local markets, but there is also a potential to transport fruit for higher values to more distant markets that have no peach production at the time (Rouse and Sherman, 2002).

There are two major types of peaches. The traditional MF cultivars are primarily grown

for fresh market. The NMF cultivars have historically been grown for canning (i.e., canning peaches) because the fruit is able to maintain its integrity during the high-temperature retort treatment (Robertson et al., 1992). The main distinction between NMF and MF peaches is that the former lack the rapid loss of flesh firmness or “melting of the fruit” toward the end of ripening. No clear differences in flavor, phenolics, TA, and SSC were found between the two flesh types (Sandefur et al., 2014).

Early season peaches tend to exhibit inconsistent fruit textural quality and lack of flavor (Beckman and Krewer, 1999). The MF peaches are usually harvested at the “firm-mature” stage to minimize mechanical injuries, but consequently they may have suboptimal eating quality if they have not reached physiological maturity at harvest (Cascales et al., 2005; Williamson and Sargent, 1999). The firm flesh characteristic of NMF peaches allows growers to harvest fruit when tree ripe, resulting in fruit with better flavor (Byrne, 2005; Sherman et al.,

1990; Topp et al., 2008). It was reported that consumers preferred “tree-ripened” NMF peaches over traditional MF peaches that were harvested at ground color break (Williamson and Sargent, 1999).

Harvesting timing is known to be one of the most important factors that influences fruit quality (Diehl et al., 2013; Zerbini, 2008). Although information on harvest dates can help growers to achieve high yield with desirable fruit quality (Fallahi et al., 2009a, 2009b), picking the fruit at the optimum harvest maturity requires the identification of optimal postharvest conditions (Kader, 2008). Little is known about the optimum harvest maturity of low-chill NMF peaches developed for fresh consumption and other low-chill MF cultivars that would lead to fruit of satisfactory condition after storage and shipping. Because NMF peaches can retain firm texture longer than MF peaches, standard harvest maturity of MF cultivars may not be suitable for NMF cultivars.

Many of the physical and chemical characteristics of maturing MF peaches have been studied to obtain suitable indices of harvest maturity. The flesh firmness and ground color (GC) have been suggested as reliable maturity indices for MF cultivars (Delwiche and Baumgardner, 1983, 1985; Rood, 1957; Salunkhe et al., 1968), while flesh color (FC) was recommended for canning peach cultivars (Fuleki and Cook, 1976; Josan and Chohan, 1982; Kader et al., 1982). There have been great advances in the development of nondestructive methods for peach maturity assessment (Infante, 2012). Index of absorbance difference (IAD), a potential maturity index that is based on the difference of fruit skin absorbance spectra (A) at two wavelengths ($IAD = A_{670} - A_{720}$), was reported to have high correlation with flesh firmness of MF cultivars but not with that of NMF ‘Kakamas’ (Shinya et al., 2013; Ziosi et al., 2008). Information on the maturity indices of fresh market NMF cultivars is currently limited.

The purpose of this study was to examine the fruit quality of the newer, low-chill MF and NMF cultivars developed for fresh consumption. Evaluations were made at harvest, after ripening at 20 °C for 7 d (i.e., direct ripening), or after storage at 0 °C for 14 d, then ripening at 20 °C for 7 d (i.e., ripening following low temperature storage). From the physical and chemical characteristics evaluated, the optimum harvest maturity for the two storage conditions and potential maturity indices specific for the MF and NMF cultivars were identified.

Materials and Methods

Plant materials

During the spring seasons of 2007 and 2008, MF ‘Flordaprince’, MF ‘TropicBeauty’, and NMF ‘UFSun’ fruit were harvested three times from the University of Florida Plant Science Research & Education Unit at Citra, FL. MF ‘Gulfking’ fruit were harvested two times in 2007 and three times in 2008.

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Table 1. Physical and chemical characteristics of the least mature to most advanced MF and NMF peaches at harvest in 2007.

Maturity groups (GCa*)	N	GC (a*)	FW (g)	Diam (mm)	PB (%)	FC (a*)	FF (N)	SSC (%)	TSS (%)	TA (%)	SSC/TA	pH
MF 'Flordaprince'												
–5>	5	–8.81 g ^z	87.23	50.76 b	23.00 c	–7.85 c	68.45 a	10.00 ab	4.58	1.07 a	9.40	3.60
–5 to 0	8	–3.20 f	92.30	52.71 ab	40.00 bc	–3.97 bc	60.14 a	9.64 ab	5.17	1.04 a	9.33	3.72
0 to 5	3	2.26 e	106.26	55.60 ab	70.00 ab	–2.35 bc	59.07 a	0.77 a	5.61	1.01 a	10.83	3.80
5 to 10	3	7.22 d	101.12	53.83 ab	67.50 ab	–2.02 bc	65.57 a	10.23 ab	5.47	0.92 ab	11.19	3.72
10 to 15	2	13.00 c	124.62	61.10 a	87.50 a	4.62 ab	31.56 b	10.65 a	5.91	0.74 b	11.92	4.02
15 to 20	3	17.95 b	111.78	57.13 ab	66.67 ab	4.96 ab	4.91 c	7.83 b	4.26	0.74 b	10.59	3.88
20+	6	24.81 a	129.69	61.27 a	80.00 ab	9.12 a	4.18 c	8.40 ab	5.6	0.78 bc	10.76	3.82
Significance		*	NS	*	*	*	*	*	NS	*	NS	NS
MF 'TropicBeauty'												
–5>	10	–6.37 d	105.51 b	56.23 b	31.67 c	–3.70 c	80.18 a	12.51	7.32	1.13 a	11.13 b	4.07 ab
–5 to 0	6	–2.16 cd	120.83 b	58.13 b	69.00 ab	1.26 bc	62.23 b	12.02	8.02	1.12 a	11.09 b	4.02 ab
0 to 5	2	0.86 c	132.08 b	60.65 ab	50.00 bc	4.83 b	57.29 b	12.65	10.03	0.99 a	12.82 b	3.71 c
5 to 10	1	8.05	142.93	63.20	30.00	3.39	58.01	12.80	9.07	1.04	12.35	4.07
10 to 15	3	12.53 b	137.30 ab	59.60 ab	65.00 b	14.50 a	3.89 d	11.20	7.63	0.56 b	12.49 b	3.94 ab
15 to 20	2	15.73 b	120.19 b	61.15 ab	75.00 ab	5.40 b	47.81 c	12.40	10.03	1.02 a	12.12 b	3.91 ab
20+	6	28.35 a	166.52 a	67.88 a	93.00 a	13.48 a	3.88 d	13.02	9.76	0.51 b	25.45 a	4.24 a
Significance		*	*	*	*	*	*	NS	NS	*	*	*
NMF 'UFSun'												
–5>	10	–7.53 e	98.32	55.05	35.5 b	–0.82 b	53.67 a	9.93	4.69	1.03	9.64	3.83
–5 to 0	4	–3.25 d	124.60	60.80	39.5 b	3.59 b	49.00 a	10.30	5.70	0.98	10.55	3.79
0 to 5	3	1.96 c	127.99	60.90	60.0 ab	3.76 b	42.65 ab	10.25	5.15	0.94	10.92	3.82
5 to 10	1	5.76	120.67	60.00	50.0	14.26	22.89	8.20	6.08	0.74	11.12	4.22
10 to 15	3	13.76 b	152.46	65.03	50.0 ab	7.00 ab	17.60 c	11.55	6.49	0.78	16.01	4.04
15 to 20	7	17.44 b	142.67	63.34	74.0 ab	9.52 ab	25.46 bc	9.63	5.20	0.73	13.13	3.99
20+	2	29.07 a	137.61	63.55	93.5 a	17.65 a	18.74 c	10.85	6.00	0.71	15.29	4.02
Significance		*	NS	NS	*	*	*	NS	NS	NS	NS	NS
NMF 'Gulfking'												
–5>	6	–7.78 f	95.72	54.40	40.83	–0.07 c	47.02	11.13	6.49	0.87 a	12.89 ab	3.86 cd
–5 to 0	3	–2.55 ef	102.16	55.93	69.00	3.88 bc	42.37	11.75	8.68	0.99 a	11.99 b	3.82 d
0 to 5	2	2.84 de	91.68	53.35	54.00	8.45 b	23.43	10.30	6.00	0.58 ab	17.77 ab	4.19 ab
5 to 10	3	9.02 cd	116.92	58.77	67.33	6.92 b	21.54	–	–	–	–	–
10 to 15	2	13.17 bc	123.42	58.30	85.00	24.89 a	32.74	10.1	6.08	0.70 ab	14.48 ab	3.99 bcd
15 to 20	2	18.65 b	159.18	65.10	75.00	7.80 b	17.95	9.00	5.46	0.59 ab	15.63 ab	4.08 bc
20+	2	30.27 a	156.25	65.90	90.00	9.77 b	13.77	9.10	11.89	0.35 b	25.95 a	4.41 a
Significance		*	NS	NS	NS	*	NS	NS	NS	*	*	*

^zValues accompanied by the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$).

*Significant; NS = nonsignificant.

MF = melting flesh; NMF = non-melting flesh; GC = skin ground color; FW = fresh weight; PB = peel blush; FC = flesh color; FF = flesh firmness; SSC = soluble solids content; TSS = total soluble sugar; TA = titratable acidity.

The harvest time was determined by monitoring changes in GC of 100 marker fruit from four trees, beginning as they approached full size. The 100 marker fruit were selected at random and considered to be representative of the population of each cultivar. The 100 marker fruit remained on the tree until the end of the harvest season and were not included in any sample collection. Random samples of 50 other fruit of each cultivar were harvested when 50%, 70%, and 90% of the 100 marker fruit had reached commercial harvest stage (GC changed from green to yellow) to obtain a range of maturities. In 2007, NMF 'Gulfking' fruit were harvested when 50% and 90% of the 100 marker fruit reached commercial harvest stage due to a rapid change in GC from green to yellow.

For each harvest, the maturities of the 50-fruit samples were visually assessed based on the GC and fruit diameter, then they were sorted into three categories of fruit with similar ranges of maturities before any treatments. The first category contained ten fruit that were used for both nondestructive and destructive quality analyses immediately after harvest. The nondestructive measurements included GC a* value, percent peel blush, fruit diameter, and fresh weight. The destructive measurements included flesh

firmness, FC a* value, SSC, TSS, TA, and pH. The second and third categories each contained 20 fruit and were stored at 20 °C for 7 d, or 0 °C for 14 d, then ripened at 20 °C for 7 d. After storage and ripening, both nondestructive analyses and destructive analyses were performed. Relative humidity (RH) for both storage conditions ranged from 83% to 97%.

Nondestructive analyses

Skin ground color and flesh color determination. The GC and FC a* values were measured using a reflectance colorimeter (Minolta CR-400; Konica Minolta, Tokyo, Japan). The a* value was used because it increases with increasing maturation and ripening both in the peel (Delwiche and Baumgardner, 1985) and in the flesh of peaches (Kader et al., 1982; Robertson et al., 1991). The GC a* value was obtained from the least advanced portion of the skin, avoiding areas with red blush. The FC a* value was obtained after removing a small (≈ 2 cm diameter) patch of skin from the fullest part of the fruit on opposite sides near the equator.

Fruit diameter, peel blush, and fresh weight determination. The diameter was determined by measuring the diameter midway

between the stem and blossom end with a Vernier caliper. The peel blush was subjectively measured by estimating the total percentage of red coloration on each fruit. The fresh weight of individual fruit was measured using a weighing balance.

Destructive analyses

Soluble solids content, titratable acidity, pH, and total soluble sugar determination. About 100 g of frozen tissues were partly thawed, then pureed in a Waring blender for 1 min. The resulting slurry was centrifuged at 15,000 g_n for 20 min at 4 °C, and the clear supernatant (juice) was used to measure SSC, TA, and pH. The SSC was determined with a temperature compensated digital refractometer (Model ABBE Mark II; Cambridge Instruments Inc, Buffalo, NY) and expressed as percent fresh weight (FW) of juice. For TA analysis, a 0.1 N sodium hydroxide solution was used to titrate 6 g of peach juice in 50 mL of water until pH 8.2 was reached. The TA was expressed as percent malic acid. Both TA and juice pH were measured with a Titrimo (Model 719; Metrohm, Herisau, Switzerland) automatic titrator.

Juice TSS was measured using the phenol-sulfuric assay of Dubois et al. (1956), with the juice sample diluted as needed using 80%

Table 2. Physical and chemical characteristics of the least mature to most advanced MF and NMF peaches at harvest in 2008.

Maturity groups (GCa*)	N	GC (a*)	FW (g)	Diam (mm)	PB (%)	FC (a*)	FF (N)	SSC (%)	TSS (%)	TA (%)	SSC/TA	pH
MF 'Flordaprince'												
0>	2	-2.48 e ^z	73.10 b	52.50 b	72.0050	1.77 ab	45.48 ab	10.30	6.21	0.89 a	11.57 c	3.83
0 to 5	3	3.18 d	73.50 b	53.67 b	55.00	-1.25 b	50.42 a	10.03	4.93	0.79 ab	12.72 bc	3.88
5 to 10		—	—	—	—	—	—	—	—	—	—	—
10 to 15	3	14.08 c	70.49 b	51.33 b	63.33	0.62 ab	43.53 ab	10.73	5.41	0.71 abc	15.42 bc	3.95
15 to 20	6	17.47 c	81.12 b	55.55 ab	65.00	3.66 ab	42.49 abc	11.05	8.14	0.64 abc	17.79 ab	3.96
20 to 25	3	23.42 b	86.42 ab	56.63 ab	66.67	3.27 ab	19.27 bcd	9.77	5.10	0.60 bc	14.69 bc	3.95
25 to 30	7	27.19 b	116.28 a	61.39 a	75.00	5.99 a	14.03 cd	10.44	5.56	0.66 abc	16.10 abc	3.89
30+	6	32.37 a	81.48 b	54.52 ab	85.00	6.09 a	7.03 d	10.5	5.77	0.47 c	21.36 a	4.12
Significance		*	*	*	NS	*	*	NS	NS	*	*	NS
MF 'TropicBeauty'												
0>	4	-4.61 g	79.10	54.95	58.75	-3.00 b	63.02 a	12.53	4.52	0.89 a	14.25	3.90
0 to 5	8	2.00 f	100.41	58.81	68.13	1.74 ab	45.88 ab	12.69	5.67	0.84 a	15.70	3.98
5 to 10	4	7.11 e	97.36	58.10	73.75	2.63 ab	53.56 a	12.88	5.93	0.78 a	15.68	3.93
10 to 15	4	12.93 d	92.20	57.80	83.75	4.33 ab	49.66 a	12.90	6.14	0.78 a	15.42	3.79
15 to 20	6	17.82 c	110.62	61.77	78.33	6.14 ab	38.63 abc	12.62	5.80	0.71 a	18.51	4.03
20 to 25	2	24.95 b	128.02	64.40	80.00	11.33 a	9.23 bc	13.35	6.73	0.70 ab	19.38	3.78
25+	2	29.91 a	103.32	57.10	70.00	8.81a	4.27 c	12.30	6.58	0.57 b	25.38	4.27
Significance		*	NS	NS	NS	*	*	NS	NS	*	NS	NS
NMF 'UFSun'												
0>	3	-2.82 g	80.88	54.97	58.33	0.21 b	38.15 a	11.53	5.81	0.95 a	12.12	3.82
0 to 5	1	1.89	83.73	57.00	85.00	7.15	17.78	13.00	7.07	0.76	17.15	4.11
5 to 10	3	6.37 f	95.46	57.93	55.00	5.46 ab	35.94 a	10.07	4.90	0.77 ab	13.44	4.02
10 to 15	2	12.07 e	74.47	52.65	75.00	4.88 ab	35.92 a	12.45	5.58	0.90 ab	13.91	3.98
15 to 20	3	17.48 d	87.83	56.53	60.00	8.69 bc	22.14 ab	11.60	5.19	0.59 ab	17.60	4.07
20 to 25	6	22.02 c	94.42	57.13	67.50	10.48 c	18.52 b	12.02	6.00	0.55 ab	18.56	4.13
25 to 30	5	28.46 b	90.38	56.40	83.00	17.34 c	18.37 b	10.52	5.81	0.48 b	19.41	4.30
30 to 35	2	31.48 b	91.58	56.10	85.00	10.41 abc	26.83 ab	11.60	3.81	0.58 ab	16.86	4.04
35+	5	36.02 a	95.63	57.40	89.00	9.70 bc	22.84 ab	11.20	4.85	0.59 ab	19.47	4.12
Significance		*	NS	NS	NS	*	*	NS	NS	*	NS	NS
NMF 'Gulfking'												
0>		—	—	—	—	—	—	—	—	—	—	—
0 to 5		—	—	—	—	—	—	—	—	—	—	—
5 to 10	5	8.16 e	83.71 a	53.36 ab	90.80	12.04	29.38 a	12.54 a	6.98	0.70 a	17.99	4.00 b
10 to 15	5	13.40 d	105.00 a	58.42 a	95.00	13.40	20.85 ab	11.88 ab	6.40	0.60 b	19.93	4.11 b
15 to 20	10	16.79 c	89.65 a	55.65 ab	92.70	14.90	19.80 ab	11.59 ab	6.26	0.54 c	21.68	4.19 b
20 to 25	6	22.82 b	85.08 a	53.43 ab	86.17	18.48	13.75 b	9.62 bc	5.81	0.42 d	22.68	4.49 a
25+	4	26.98 a	57.28 b	50.20 b	85.75	16.03	18.17 b	7.30 c	3.79	0.35 e	21.36	4.58 a
Significance		*	*	*	NS	NS	*	*	NS	*	NS	*

*Values accompanied by the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$).

*Significant; NS = nonsignificant.

MF = melting flesh; NMF = non-melting flesh; GC = skin ground color; FW = fresh weight; PB = peel blush; FC = flesh color; FF = flesh firmness; SSC = soluble solids content; TSS = total soluble sugar; TA = titratable acidity.

ethanol. Sample absorbance was measured at 490 nm with glucose (Certified ACS grade; Fisher Scientific, Fair Lawn, NJ) as the standard, and the TSS was expressed as percent FW of juice.

Flesh firmness determination. The flesh firmness was measured at the fruit equator on opposite sides, on the cheeks, without skin. The analysis was performed with an Instron Universal Testing Instrument (Model 4411-C8009; Canton, MA) with which a compressive force from a 50-kg load cell was applied using a convex tip probe (Magness-Taylor type), 7.9 mm in diameter, attached to the load cell moving at a speed of 12 cm/min. The firmness was expressed as the maximum bioyield force (N).

Statistical analysis

Because at harvest differences in the physical and chemical characteristics were generally not significant for any of the four peach cultivars, the data collected from all harvests of each cultivar were pooled together for statistical analysis. Data in 2007 and 2008 were analyzed separately. The number of MGs and the increment of GC a* values of each MG

were assigned after considering several peach maturity studies, including Delwiche and Baumgardner (1985), Delwiche (1987), Fuleki and Cook (1976), and Robertson et al. (1991). In 2007, the samples were divided into seven MGs, ranging from GC a* value <-5 to a* value >20 , in 5-unit increments. More than seven MGs were assigned to MF 'Flordaprince' and NMF 'UFSun' in 2008 (GC a* values from <0 to >30 or >35 , respectively) because those cultivars had a broader range of GC a* values than in 2007.

The General Linear Model (GLM) program of the Statistical Analysis System (SAS; SAS Institute, Cary, NC) was used to analyze significant differences among the harvests and the MGs for any physical and chemical characteristics; and significance was determined at the 5% level. Tukey's test was used for mean separation. Correlation coefficients (r) between fruit qualities at harvest were obtained at the 5% level of significance.

Results and Discussion

Evaluations at harvest. In general, the GC and FC a* values of all four peach cultivars

increased significantly during maturation and ripening on the tree (Tables 1 and 2), meaning both the peel and flesh gained yellow and orange coloration and decreased in green coloration. All the cultivars achieved at least ≈ 90 g fresh weight and a 57-mm diameter minimum size in 2007, the most common size sold in the early season market (Beckman and Krewer, 1999; Beckman et al., 2008) (Table 1). Smaller fruit size was observed in all the cultivars in 2008 (Table 2), which could have been due to climate, crop load, and time of thinning (Drogoudi et al., 2009). All the cultivars reached 60% peel blush during early maturity (MGs ≥ 0) (Tables 1 and 2); thus, they would be considered to have sufficient red blush for market acceptance (Beckman et al., 2008). Similar size and percent peel blush for MF 'Flordaprince' and 'TropicBeauty' were reported by the Texas A&M University (TAMU) Stone Fruit Breeding Program (Department of Horticultural Sciences, TAMU, 2019). The NMF 'Gulfking' fruit were highly covered with red blush, having the highest percent peel blush in both years (Tables 1 and 2). The fruit softening patterns

Table 3. Physical and chemical characteristics of the least mature to most advanced MF and NMF peaches after ripening at 20 °C for 7 d in 2007.

Maturity groups (GC a*)	N	GC (a*)	FC (a*)	FF (N)	SSC (%)	TSS (%)	TA (%)	SSC/TA	pH
MF 'Flordaprince'									
–5>	13	5.23 d ^z	6.36 c	4.39 a	11.27	5.02	1.07 a	10.97 d	3.82 c
–5 to 0	10	13.23 c	8.96 abc	3.37 b	11.25	6.01	0.80 ab	14.82 cd	4.10 abc
0 to 5	6	15.49 c	7.83 bc	3.49 b	11.17	5.48	0.88 b	12.93 cd	3.96 bc
5 to 10	6	20.97 b	11.29 a	2.90 bc	10.80	5.91	0.68 bcd	17.02 bcd	4.25 ab
10 to 15	7	24.14 b	9.91 ab	2.64 bc	10.50	5.44	0.50 d	21.45 ab	4.42 a
15 to 20	9	28.52 a	10.11 ab	2.49 c	10.58	5.25	0.57 cd	19.26 abc	4.37 a
20+	9	30.67 a	11.08 a	2.18 c	12.14	7.01	0.52 d	24.31 a	4.37 a
Significance		*	*	*	NS	NS	*	*	*
MF 'TropicBeauty'									
–5>	15	5.32 d	9.56 b	4.04 a	13.39	7.42 b	1.19 a	11.47 d	4.08
–5 to 0	11	11.19 c	12.03 ab	3.44 ab	13.44	7.09 b	1.00 ab	13.42 cd	4.15
0 to 5	12	13.36 c	12.86 ab	3.54 ab	13.21	7.67 b	0.76 bc	16.86 bcd	4.15
5 to 10	7	19.81 b	11.74 ab	3.00 b	13.22	8.19 b	0.79 bc	17.74 bcd	4.25
10 to 15	4	20.48 b	14.80 a	2.97 b	13.75	12.10 a	0.58 cd	20.70 abc	4.36
15 to 20	3	29.07 a	13.37 a	2.76 b	14.23	7.02 b	0.62 cd	27.20 a	4.31
20+	8	26.98 a	11.86 ab	2.90 b	12.35	7.58 b	0.51 d	25.13 ab	4.21
Significance		*	*	*	NS	*	*	*	NS
NMF 'UFSun'									
–5>	13	11.61 d	10.53	20.76 a	10.65	7.81	0.83 a	13.46 c	4.21 b
–5 to 0	12	14.65 cd	12.31	18.25 ab	11.34	7.55	0.64 ab	17.44 bc	4.30 b
0 to 5	8	16.47 bc	11.18	16.05 abc	9.54	5.33	0.58 bc	17.04 bc	4.41 ab
5 to 10	4	20.87 ab	11.65	13.98 abc	9.88	7.91	0.46 bc	22.89 ab	4.64 a
10 to 15	14	22.33 a	12.96	9.18 c	10.13	6.74	0.40 c	26.43 a	4.67 a
15 to 20	6	21.23 a	14.34	10.12 bc	9.88	5.04	0.39 c	26.36 a	4.71 a
20+	3	19.96 ab	13.49	10.28 bc	9.30	5.65	0.40 c	23.43 ab	4.68 a
Significance		*	NS	*	NS	NS	*	*	*
NMF 'Gulfking'									
–5>	8	9.61 e	9.60	18.01	11.83	10.84	0.67 a	18.24 c	4.29 b
–5 to 0	10	11.25 de	12.23	20.51	10.46	7.43	0.50 b	20.94 c	4.45 ab
0 to 5	3	14.46 d	11.94	19.83	10.37	6.91	0.52 ab	19.97 c	4.46 ab
5 to 10	2	21.86 bc	11.70	16.49	9.95	4.89	0.35 b	28.54 ab	4.71 a
10 to 15	4	18.76 c	17.71	12.98	8.05	4.89	0.37 b	22.36 ab	4.79 a
15 to 20	5	23.45 b	12.91	14.09	10.84	6.48	0.39 b	28.95 ab	4.77 a
20+	8	27.33 a	13.03	8.70	11.54	9.31	0.35 b	33.74 a	4.74 a
Significance		*	NS	NS	NS	NS	*	*	*

^zValues accompanied by the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$).

*Significant; NS = nonsignificant.

MF = melting flesh; NMF = non-melting flesh; GC = skin ground color; FC = flesh color; FF = flesh firmness; SSC = soluble solids content; TSS = total soluble sugar; TA = titratable acidity.

during ripening were significantly different for the MF and NMF cultivars. MF cultivars in MGs 5 to 10 and below in 2007 and MGs 15 to 20 and below in 2008 were very firm (Tables 1 and 2). The flesh firmness of the MF fruit dropped tremendously, while that of the NMF fruit decreased relatively slowly as ripening progressed.

Several peach maturity studies were considered when assigning the number of MGs and the increment of GC a* values of each MG in this study (Delwiche and Baumgardner, 1985; Delwiche, 1987; Fuleki and Cook, 1976; Robertson et al., 1991). Delwiche and Baumgardner (1985) developed six color references using uniform increments of GC a* value to cover the maturity range of the cultivars studied. Robertson et al. (1991) followed Delwiche and Baumgardner (1985) for the first three MGs, and they assigned MG four to six using non-uniform increments and added tree-ripe as the seventh MG. Overall, it was not clear how the increments of GC a* values were selected. The cultivars used in this study appeared to have markedly higher GC a* value ranges than that of Delwiche and Baumgardner (1985), which made it not suitable to use their color references. Combining the concepts from these maturity studies, we found that 6 to 7 MGs

with uniform increment of GC a* values were ideal for analyzing the effect of maturity on fruit qualities.

Fruit SSC was generally unaffected by maturity for these cultivars (Tables 1 and 2). It was possible that all the fruit had largely attained physiological maturity at the time of the first harvest. Most of the cultivars had SSC between 8 and 11%, which is typical for early ripening cultivars (Bryne, 2005). There were no significant changes in TSS as fruit matured and ripened on the tree for all four cultivars (Tables 1 and 2), like the results reported by Brooks et al. (1993). Due to similar SSC among the MGs, the observed increase in SSC/TA was mainly due to a gradual decrease of TA as ripening progressed (Tables 1 and 2). The pH of NMF 'Gulfking' increased as the fruit ripened; however, the pH of MF 'Flordaprince' did not change in either year (Tables 1 and 2). The pH of MF 'Flordaprince' at more advanced maturity could have been maintained by a higher level of TA (Moing et al., 1998). The effect of maturity on pH was inconsistent in the other two cultivars over the two seasons.

Evaluations after direct ripening. Color changes associated with ripening strongly influence visual and eating quality of fruits

(McGuire, 1992). All the peach cultivars in this study had higher GC a* values after direct ripening compared with the values measured at harvest, especially the fruit of the lowest MGs (Tables 1–4). This result agrees with that of Robertson et al. (1993), who reported that immature fruit (Maturity 1) exhibited the largest increase in GC a* value, and mature fruit (Maturity 3) exhibited the least increase during ripening. Ripening generally was accompanied by higher FC a* values in all the cultivars, which indicated that fruit flesh became more yellow and orange (Tables 1–4).

As expected, the NMF cultivars maintained flesh firmness better than the MF cultivars after direct ripening. The MF peaches of the least mature to the most advanced MGs lost $\approx 95\%$ to 25% of the initial flesh firmness, respectively; thus the ripened fruit were very soft (≤ 5 N) (Tables 1–4). The NMF peaches in the same MGs as the MF peaches lost $\approx 60\%$ to 20% of the initial flesh firmness; consequently, the NMF peaches remained two to seven times firmer than the MF peaches after ripening (≈ 9 to 21 N) (Tables 1–4).

All the peach cultivars in this study generally had similar SSC and TSS, lower TA, and higher SSC/TA and pH after direct

Table 4. Physical and chemical characteristics of the least mature to most advanced MF and NMF peaches after ripening at 20 °C for 7 d in 2008.

Maturity groups (GC a*)	N	GC (a*)	FC (a*)	FF (N)	SSC (%)	TSS (%)	TA (%)	SSC/TA	pH
MF 'Flordaprince'									
0>	2	7.48 d ²	6.89 b	5.37 a	11.75	7.14	0.77 a	15.33	3.80
0 to 5	2	9.30 d	5.96 b	3.43 b	12.40	8.27	0.67 ab	18.72	3.90
5 to 10	7	15.58 dc	6.95 b	3.60 b	11.24	7.20	0.58 bc	19.21	3.89
10 to 15	8	20.83 c	6.72 b	3.74 b	10.91	7.00	0.54 bc	19.89	4.22
15 to 20	10	23.38 abc	6.79 b	2.96 ab	10.94	6.22	0.52 bc	21.64	4.21
20 to 25	11	26.22 ab	8.78 ab	2.92 b	11.33	6.76	0.52 bc	22.67	4.25
25 to 30	8	31.65 a	9.33 ab	2.85 b	11.10	5.64	0.47 bc	24.21	4.28
30+	12	31.87 a	11.52 a	2.39 b	11.81	7.34	0.50 bc	23.48	4.31
Significance		*	*	*	NS	NS	*	NS	NS
MF 'TropicBeauty'									
0>	15	5.29 e	6.70 b	4.80 a	13.37	6.66	0.94 a	14.54 b	3.93 c
0 to 5	5	12.46 d	7.92 ab	3.53 ab	12.48	6.60	0.80 ab	15.62 b	4.04 ab
5 to 10	11	15.77 c	8.79 ab	3.61 ab	13.31	6.51	0.75 ab	18.82 b	4.12 ab
10 to 15	7	18.51 c	9.54 ab	3.07 b	13.61	8.52	0.62 bc	22.59 ab	4.25 ab
15 to 20	5	23.96 b	9.50 ab	3.47 ab	12.92	6.82	0.63 bc	21.17 ab	4.24 ab
20 to 25	7	24.08 b	9.56 ab	3.08 b	13.63	7.13	0.51 c	29.16 a	4.34 a
25+	10	29.51 a	10.95 a	2.46 b	12.77	8.05	0.49 c	27.93 a	4.34 a
Significance		*	*	*	NS	NS	*	*	*
NMF 'UFSun'									
0>	2	8.44 e	8.65	16.67	9.70 b	5.07	0.75 a	12.91	4.25 ab
0 to 5	2	17.58 d	10.85	20.75	11.15 ab	6.43	0.73 a	15.92	3.70 b
5 to 10	2	21.44 cd	10.11	10.80	11.20 ab	4.29	0.77 a	14.70	4.22 ab
10 to 15	7	17.82 d	11.70	16.71	13.60 a	8.57	0.61 ab	23.61	4.36 a
15 to 20	13	23.05 cd	11.84	16.45	11.36 ab	5.38	0.46 ab	24.18	4.55 a
20 to 25	8	25.48 bc	12.00	13.98	12.33 ab	6.37	0.49 ab	25.68	4.55 a
25 to 30	6	29.84 ab	14.21	18.05	12.32 ab	6.59	0.50 ab	20.20	4.46 a
30 to 35	10	32.12 a	14.36	17.45	10.87 ab	6.45	0.46 ab	26.34	4.45 a
35+	10	32.78 a	12.31	18.08	12.00 ab	6.93	0.39 b	31.87	4.67 a
Significance		*	NS	NS	*	NS	*	NS	*
NMF 'Gulfking'									
0>	2	4.81 f	7.29 b	11.32	11.00	5.45	0.73 a	15.14 b	4.18 c
0 to 5	4	14.94 e	10.94 ab	15.24	11.88	6.92	0.52 b	23.06 ab	4.39 bc
5 to 10	7	18.42 d	12.03 ab	14.46	11.01	6.41	0.44 c	24.93 ab	4.46 ab
10 to 15	11	20.98 c	19.19 a	12.75	12.20	7.35	0.39 d	31.23 a	4.48 abc
15 to 20	17	24.09 b	17.51 ab	12.74	10.35	5.78	0.33 e	31.79 a	4.65 ab
20 to 25	18	26.83 a	17.62 ab	13.50	8.81	4.46	0.27 f	32.95 a	4.90 a
25+	1	28.52	19.03	8.93	6.20	2.90	0.23	26.50	5.04
Significance		*	*	NS	NS	NS	*	*	*

²Values accompanied by the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$).

*Significant; NS = nonsignificant.

MF = melting flesh; NMF = non-melting flesh; GC = skin ground color; FC = flesh color; FF = flesh firmness; SSC = soluble solids content; TSS = total soluble sugar; TA = titratable acidity.

ripening compared with the values measured at harvest (Tables 1–4). Using PCA analysis, Delgado et al. (2013) demonstrated that the sensory attributes “sourness” and “sweetness” were highly correlated with ripe TA and ripe SSC, respectively. Sweetness has been reported to correlate positively with overall liking and consumer acceptance of peaches (Cirilli et al., 2016; Crisosto et al., 2006; Delgado et al., 2013). MF ‘TropicBeauty’ consistently had the highest ripe SSC among the cultivars, which might lead to higher consumer acceptance. For certain peach, nectarine, and plum cultivars, consumer acceptance of ripe fruit was associated with the SSC/TA rather than SSC (Crisosto et al., 2004). This finding could be due to the sweetness perceived, because sweetness was reported to correlate with SSC/TA better than individual sugars such as sucrose, fructose, and glucose in some peach and nectarine cultivars (Colaric et al., 2005). Higher SSC/TA values were found in the more advanced MGs of all four cultivars (Tables 3 and 4), indicating that fruit harvested at more advanced stages might be more desirable to the consumers than those in the lower MGs after

ripening. Robertson et al. (1993) reported that threshold mature (Maturity 2) fruit, ripened at 20 °C for 7 d, received significantly higher scores for fruity, peachy, sweet, and juicy attributes and possessed greater overall acceptability than less mature peaches.

Evaluations after ripening following low temperature storage. The GC a* values of all the peach cultivars were slightly higher after fruit ripening following low temperature storage compared with the values collected after direct ripening (Tables 3–6). Low temperature had a major impact on the FC a* values of both NMF cultivars. The FC a* values were markedly higher after the low temperature treatment compared with the values measured after direct ripening (Tables 3–6). Karakurt et al. (2000) observed that total carotenes and xanthophylls increased in three NMF cultivars and decreased in MF ‘Flordaprince’ and MF ‘TropicBeauty’ during 2 to 5 d of storage at 8 °C. Because no browning was observed, this development was not considered to be related to chilling injury (CI).

Low temperature storage only affected softening of NMF ‘UFSun’. Both MF and

NMF ‘Gulfking’ fruit that ripened following low temperature storage generally had similar flesh firmness as those that were directly ripened (Tables 3–6). In 2007, NMF ‘UFSun’ fruit in MG 5 to 10 and less, and in 2008, fruit in MG 0 to 5 and MG 5 to 10, did not soften as much following low temperature storage as those that were directly ripened (Tables 3–6). This abnormal softening pattern suggests that the less mature fruit may have exhibited greater susceptibility to CI (Fernandez-Trujillo and Artes, 1997). Fruit with abnormal softening appeared to be similar in color and composition to fruit in nearby MGs (Tables 5 and 6), like the results reported by Robertson et al. (1992). Because only one NMF cultivar was affected in this way by the low temperature storage condition used in this study, it is not clear how this relates to the suggestion by Brovelli et al. (1998b) that CI affects the quality of MF more than NMF genotypes.

Both MF and NMF fruit had similar or slightly higher SSC and TSS after ripening following low temperature storage compared with those that were directly ripened (Tables 3–6). Fruit in the lower MGs (such

Table 5. Physical and chemical characteristics of the least mature to most advanced MF and NMF peaches after storage at 0 °C for 14 d then ripening at 20 °C for 7 d in 2007.

Maturity groups (GCa*)	N	GC (a*)	FC (a*)	FF (N)	SSC (%)	TSS (%)	TA (%)	SSC/TA	pH
MF 'Flordaprince'									
–5>	15	11.82 d ^a	9.80	4.38 a	12.94	7.19	0.98 a	13.58 c	3.95 c
–5 to 0	7	16.12 c	11.45	3.33 ab	11.90	7.65	0.79 ab	16.54 bc	4.21 bc
0 to 5	5	19.81 bc	10.85	3.41ab	11.48	9.05	0.65 bc	17.77 bc	4.29 ab
5 to 10	8	22.84 b	11.04	2.43 b	12.08	7.48	0.60 bcd	20.79 b	4.30 ab
10 to 15	7	21.99 b	11.07	2.94 ab	12.01	8.98	0.56 cd	22.26 b	4.40 ab
15 to 20	7	27.37 a	11.97	2.34 b	10.93	6.30	0.53 cd	20.42 b	4.40 ab
20+	11	30.49 a	10.22	2.36 b	11.94	7.74	0.42 d	28.35 a	4.57 a
Significance		*	NS	*	NS	NS	*	*	*
MF 'TropicBeauty'									
–5>	6	7.64 e	13.47	3.74	14.45 a	6.91	1.05 a	14.15 b	4.32 a
–5 to 0	15	13.16 d	12.99	3.20	13.85 ab	7.72	0.83 b	16.86 b	4.28 b
0 to 5	7	15.92 cd	12.27	3.58	14.10 ab	8.37	0.76 b	17.81 b	4.40 ab
5 to 10	10	19.52 bc	13.33	3.16	12.55 ab	7.35	0.55 c	22.63 ab	4.40 ab
10 to 15	7	20.63 b	13.81	3.25	13.63 ab	9.33	0.52 c	27.54 a	4.29 b
15 to 20	6	22.43 b	11.71	3.57	13.35 ab	10.91	0.46 c	31.63 a	4.63 a
20+	9	27.04 a	12.36	3.36	12.11 b	7.79	0.40 c	30.08 a	4.54 ab
Significance		*	NS	NS	*	NS	*	*	*
NMF 'UFSun'									
–5>	17	14.22 c	12.07 c	26.26 a	11.72 ab	7.24	0.76 a	15.75 b	4.31 c
–5 to 0	8	18.81 ab	18.51 abc	23.31 a	12.50 a	6.95	0.62 ab	21.20 a	4.46 bc
0 to 5	12	17.53 bc	15.35 bc	19.96 ab	11.24 ab	7.13	0.65 ab	18.22 b	4.44 bc
5 to 10	6	20.44 ab	17.79 abc	20.94 ab	10.78 ab	7.09	0.52 bc	21.17 ab	4.51 abc
10 to 15	5	19.48 ab	23.26 ab	11.97 c	7.80 c	4.51	0.37 c	21.07 ab	4.80 a
15 to 20	6	20.49 ab	25.07 a	12.31 c	11.35 ab	8.18	0.46 bc	25.50 a	4.64 ab
20+	6	22.64 a	23.43 ab	9.11 c	9.53 bc	5.66	0.36 c	27.36 a	4.82 a
Significance		*	*	*	*	NS	*	*	*
NMF 'Gulfking'									
–5>	8	11.01 e	13.99 b	18.71	12.18	7.70	0.71 a	18.04 bc	4.28 b
–5 to 0	5	16.77 cd	20.87 ab	23.83	11.88	6.56	0.57 ab	21.54 ab	4.50 ab
0 to 5	6	21.74 bc	23.51 ab	18.76	11.37	9.25	0.49 b	23.72 ab	4.54 ab
5 to 10	4	15.85 de	20.60 ab	17.61	9.75	6.51	0.48 b	19.97 ac	4.56 ab
10 to 15	5	21.55 bc	26.54 ab	12.74	9.68	6.86	0.36 c	27.32 a	4.77 a
15 to 20	6	25.95 ab	22.99 ab	17.70	11.70	8.53	0.40 c	28.94 a	4.59 ab
20+	6	30.24 a	26.83 a	12.31	11.47	8.25	0.41 c	28.40 a	4.55 ab
Significance		*	*	NS	NS	NS	*	*	*

^aValues accompanied by the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$).

*Significant; ns = nonsignificant.

MF = melting flesh; NMF = non-melting flesh; GC = skin ground color; FC = flesh color; FF = flesh firmness; SSC = soluble solids content; TSS = total soluble sugar; TA = titratable acidity.

as those in MG –5 to 0 of both MF cultivars and MG <0 of NMF 'UFSun' in 2007 and MG <0 of MF 'TropicBeauty' and NMF 'UFSun' in 2008) were able to attain an SSC/TA of 15 (Tables 3–6) after ripening following low temperature storage, a value suggested to be indicative of high-quality peaches (Robertson et al., 1990). This was mainly due to an even lower TA that developed during the prolonged storage period. Shinya et al. (2014) reported that peaches stored at 0 °C for 35 d and ripened for 2 d at 21 °C contained less TA than fruit that were ripened without cold storage.

Optimum harvest maturity determination. Peaches of the MF type are considered "ready for consumption" when they reach minimum quality standards such as 8.8 to 13.2 N flesh firmness and 10% to 12% SSC (Crisosto et al., 2006; Kader and Mitchell, 1989; Testoni, 1995; Ventura et al., 2000). Moreover, it was found that high-quality MF peaches possess SSC/TA ≥ 15 and a TA of 0.5% to 0.8% (Robertson et al., 1990). Similarly, Rouse et al. (2004) suggested that an average of at least 11% SSC and 0.6% TA would ensure desirable eating quality of NMF 'UFSun' peaches. Sensory analyses had indicated that there were no clear dis-

tinctions in flavor aspects of MF and NMF fruit (Brovelli et al., 1999); hence, those proposed minimum quality standards and the quality attributes for high-quality peaches in terms of SSC, TA, and SSC/TA were used as general guidelines for analyzing the optimum harvest maturity of all four peach cultivars in this study, while a minimum flesh firmness of 8.8 N was used for the MF cultivars only.

In 2007, MG 5 to 10 was determined as the optimum harvest maturity of MF 'Flordaprince' for direct ripening because softening had not been initiated and the fruit attained an SSC/TA of 17 after ripening (Tables 1 and 3). MG –5 to 0, to MG 5–10 of MF 'Flordaprince' was determined as the optimum harvest maturity range for ripening following low temperature storage (Table 5). MG <–5 of MF 'Flordaprince' was not included in this range because the ripened fruit still possessed high TA, resulting in an SSC/TA <15 (Table 5). MG 10–15, to MG 20+ of MF 'Flordaprince' was not suitable for either storage condition because the "melting" process had already begun in fruit of MG 10 to 15 and MG 15 to 20; and fruit of MG 20+ were already too soft (<8.8 N) at harvest (Table 1). In 2008, MG <0 to MG 15–20 of

MF 'Flordaprince' were still firm at harvest (flesh firmness >40 N) (Table 2), and the fruit were generally able to achieve the minimum SSC and TA after ripening in both storage conditions (Tables 4 and 6). Hence, the optimum harvest maturity ranges of MF 'Flordaprince' in 2008 were determined as MG <0 to MG 15–20 for direct ripening, and MG 0–5 to MG 15–20 for ripening following low temperature storage. MG <0 of MF 'Flordaprince' was not included in the optimum harvest maturity range for the low temperature treatment due to the persistence of higher TA after ripening (Table 6).

In 2007, MG 0–5 to MG 5–10 of MF 'TropicBeauty' was considered as the optimum harvest maturity range for both storage conditions. Fruit of MG –5 to 0 and less might be too immature, still having a TA >0.8% after ripening in both storage conditions (Tables 3 and 5). For MF 'TropicBeauty' in 2008, MG 5–10 to MG 15–20 was the optimum harvest maturity range for direct ripening, and MG <0 to MG 15–20 was optimum for ripening following low temperature storage (Tables 4 and 6). MG 20–25 and above of MF 'TropicBeauty' were not included for either storage condition because the fruit were already too soft at harvest

Table 6. Physical and chemical characteristics of the least mature to most advanced MF and NMF peaches after storage at 0 °C for 14 d then ripening at 20 °C for 7 d in 2008.

Maturity groups (GCa*)	N	GC (a*)	FC (a*)	FF (N)	SSC (%)	TSS (%)	TA (%)	SSC/TA	pH
MF 'Flordaprince'									
0>	1	9.03	8.76	3.11	14.30	8.48	0.97	14.80	4.00
0 to 5	2	14.92 e ^z	7.32 b	5.58 a	12.40	6.96	0.63 ab	19.80 b	4.28 ab
5 to 10	8	17.01 de	9.51 ab	4.87 a	13.38	7.89	0.70 a	19.27 b	4.18 b
10 to 15	7	23.13 cd	11.07ab	2.72 b	12.20	5.85	0.58 abc	21.34 b	4.30 ab
15 to 20	9	25.47 bc	10.37 ab	2.87 b	12.46	6.57	0.55 abc	23.29 ab	4.26 ab
20 to 25	10	28.31 abc	10.12 ab	2.58 b	11.91	6.44	0.48 bc	25.23 ab	4.38 ab
25 to 30	6	31.56 ab	11.69 ab	2.54 b	11.82	6.41	0.50 bc	24.03 ab	4.34 ab
30+	17	32.84 a	13.28 a	2.14 b	12.89	7.39	0.44 c	30.69 a	4.49 a
Significance		*	*	*	NS	NS	*	*	*
MF 'TropicBeauty'									
0>	17	9.12 e	9.80	3.60 a	13.14	5.96	0.69 a	20.43 b	4.26 b
0 to 5	9	13.64 de	11.07	3.21 ab	13.76	7.22	0.65 a	22.81 b	4.25 b
5 to 10	9	17.50 cd	10.65	3.34 a	13.27	5.98	0.53 ab	26.14 b	4.33 b
10 to 15	4	22.09 bc	11.72	3.57 a	13.13	7.24	0.48 ab	27.45 b	4.47 ab
15 to 20	11	21.65 bc	11.75	3.20 ab	12.64	5.99	0.47 ab	28.56 b	4.50 ab
20 to 25	3	26.07 ab	10.20	2.67 ab	11.80	5.99	0.46 ab	27.25 b	4.52 ab
25+	7	4.12 a	13.62	2.34 b	12.91	6.34	0.33 b	45.11 a	4.72 a
Significance		*	NS	*	NS	NS	*	*	*
NMF 'UFSun'									
0>	4	14.33 d	10.91 b	13.07 b	11.73 ab	5.04 b	0.81 a	15.55 b	4.25 b
0 to 5	3	18.71 c	14.87 ab	26.26 a	10.33 b	4.11 b	0.58 ab	17.91 ab	4.31 ab
5 to 10	4	22.70 bc	16.82 ab	21.10 ab	11.95 ab	5.13 b	0.60 ab	20.00 ab	4.37 ab
10 to 15	7	22.21 bc	14.00 ab	17.47 b	12.66 ab	6.01 ab	0.63 ab	20.71 ab	4.41 ab
15 to 20	10	23.92 b	19.40 a	14.86 b	13.66 ab	7.15 ab	0.51 b	26.67 ab	4.58 ab
20 to 25	9	31.00 a	21.20 a	16.60 b	11.12 ab	5.68 ab	0.43 b	27.74 a	4.74 a
25 to 30	10	29.95 a	18.45 ab	16.90 b	11.99 ab	6.51 ab	0.44 b	27.86 a	4.70 ab
30 to 35	7	30.50 a	17.73 ab	16.11 b	15.40 ab	9.66 a	0.56 ab	27.43 a	4.45 ab
35+	6	31.23 a	21.62 a	14.97 b	13.05 ab	6.97 ab	0.48 b	27.64 a	4.49 ab
Significance		*	*	*	*	*	*	*	*
NMF 'Gulfking'									
0>	4	13.36 g	16.23 c	19.73	12.18 ab	5.71	0.65 a	18.94 c	4.24 d
0 to 5	11	17.32 f	19.69 bc	16.46	12.49 ab	6.62	0.56 b	22.32 bc	4.29 d
5 to 10	7	19.61 e	16.84 c	16.08	12.89 a	6.73	0.51 c	25.36 bc	4.42 cd
10 to 15	11	22.68 d	27.38 a	15.63	12.85 a	7.02	0.44 d	29.38 abc	4.58 c
15 to 20	7	24.67 c	26.21 ab	14.73	12.43 ab	7.05	0.39 e	31.69 ab	4.61 c
20 to 25	14	27.28 b	28.61 a	13.60	10.16 b	4.96	0.33 f	30.57 abc	4.85 b
25+	6	30.09 a	26.88 a	13.15	10.18 b	4.75	0.27 g	39.45 a	5.08 a
Significance		*	*	NS	*	NS	*	*	*

^zValues accompanied by the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$).

*Significant; NS = nonsignificant.

MF = melting flesh; NMF = non-melting flesh; GC = skin ground color; FC = flesh color; FF = flesh firmness; SSC = soluble solids content; TSS = total soluble sugar; TA = titratable acidity.

Table 7. Summary of optimum harvest maturities and the common maturity ranges for the MF and NMF peach cultivars between years 2007 and 2008.

Cultivar	20 °C for 7days		Common maturity range	0 °C for 14 d + 20 °C for 7 d		Common maturity range
	Yr 2007 (MG)	Yr 2008 (MG)		Yr 2007 (MG)	Yr 2008 (MG)	
MF 'Flordaprince'	5 to 10	<0 to 20	5 to 10	-5 to 10	0 to 20	0 to 10
MF 'TropicBeauty'	0 to 10	5 to 20	5 to 10	0 to 10	<0 to 20	0 to 10
NMF 'UFSun'	0 to 20+	0 to 35+	0 to 20	10 to 20+	10 to 15	10 to 15
NMF 'Gulfking'	<-5 to 20+	<0 to 25	0 to 20	<-5 to 20+	<0 to 10	0 to 10

MF = melting flesh; NMF = non-melting flesh; MG = maturity group.

(Table 2). Fruit of MG 0–5 and less still possessed a TA $\geq 0.8\%$ after direct ripening, and thus, they were not included in the optimum harvest maturity range (Table 4).

Due to the slow softening characteristic of NMF peaches after ripening initiation, the flesh firmness at harvest does not need to be as high as that of the MF peaches. NMF 'UFSun' was reported to have 14 N flesh firmness at commercial harvest maturity (bright yellow ground color) with desirable eating quality (Rouse et al., 2004). Hence, flesh firmness equal to or greater than 14 N at harvest was considered when analyzing the optimum harvest maturity for direct ripening of NMF peaches. Because more handling is generally required for low temperature stored

peaches, the flesh firmness of NMF fruit at harvest needs to be higher than 14 N to minimize loss of peaches. Metheny et al. (2002) proposed that 27 N flesh firmness could be considered as the critical bruising threshold for mechanical harvest of NMF peaches. Therefore, flesh firmness values of around 27 N were considered when analyzing the optimum harvest maturity ranges of the ripening following a low temperature storage condition. In 2007, MG 0–5 to MG 20 + of NMF 'UFSun' was selected as the optimum harvest maturity range for direct ripening because all the fruit at harvest had flesh firmness >14 N, and the ripe fruit had SSC/TA >17 due to lower TA and flesh firmness ≤ 14 N (Tables 1 and 3). Fruit in MG -5 to 0

appeared to be more like those in MG <-5 than MG 0–5 in terms of GC a* value, flesh firmness, and TA after ripening (Tables 1 and 3), and hence, MG -5 to 0 was not included in the optimum harvest maturity range because more mature fruit were preferred. MG 5 to 10 and less of NMF 'UFSun' were determined to be susceptible to CI because the fruit ripened following low temperature storage were unable to soften to the same extent as those that were directly ripened (Tables 3 and 5). Thus, only the fruit at more advanced stages (i.e., MG 10–15 to MG 20+), which ripened normally following low temperature storage, were suitable for low temperature storage (Table 5). In 2008, all the NMF 'UFSun' fruit had flesh firmness >14 N at harvest, ranging

Table 8. Potential maturity indices for all four peach cultivars, MF specific, or NMF specific, based on the correlation coefficient (*r*) significant at $P \leq 0.05$ among fruit qualities at harvest.

Yr	All cultivar	<i>r</i>		MF specific	<i>r</i>		NMF specific	<i>r</i>	
		Min	Max		Min	Max		Min	Max
2007	GC-TA	-0.86	-0.92	GC-FC	0.92	0.98	FF-pH	-0.83	-0.90
	GC-FF	-0.85	-0.90	FC-FF	-0.93	-0.97	TA-pH	-0.84	-0.97
	GC-Dia	0.78	0.90	FC-Dia	0.94	-0.97			
	FF-TA	0.87	0.98	FC-FW	0.89	0.95			
	FW-Dia	0.93	0.99	FC-TA	-0.92	-0.94			
2008	GC-TA	-0.82	-0.99	GC-FC	0.82	0.85	FF-SSC/TA	-0.92	-0.96
	FW-Dia	0.88	0.97	GC-FF	-0.89	-0.90	TA-pH	-0.84	-0.99
				GC-SSC/TA	0.79	0.84	FC-FF	-0.76	-0.93
				TA-SSC/TA	-0.91	-0.95	FC-SSC/TA	0.86	0.93

MF = melting flesh; NMF = non-melting flesh; GC = skin ground color; FC = flesh color; FF = flesh firmness; TA = titratable acidity; Dia = diameter; FW = fresh weight; SSC = soluble solids content.

from 18 to 38 N, and similar flesh firmness (average 16.5 N) after direct ripening (Tables 2 and 4). MG 0–5 to MG 35+ of NMF ‘UFSun’ was determined as the optimum harvest maturity range for direct ripening due to having SSC $\geq 11\%$ and 0.4% to 0.7% TA. Abnormal softening in NMF ‘UFSun’ fruit of MG 0 to 5 and MG 5 to 10 were found after ripening following low temperature storage when compared with fruit that were directly ripened (Tables 4 and 6). MG 10 to 15 of NMF ‘UFSun’ was determined to be the optimum harvest maturity range for ripening following low temperatures storage because the flesh firmness at harvest was greater than 27 N and the fruit were able to attain SSC/TA of 20 after ripening (Tables 2 and 6).

In 2007, NMF ‘Gulking’ fruit did not have any significant difference in flesh firmness among the MGs at harvest (average 28 N), after direct ripening (average 16 N), and after ripening following low temperature storage (average 17 N) (Tables 1, 3, and 5). Thus, the optimum harvest maturity range of NMF ‘Gulking’ for both storage conditions was determined to be MG <–5 to MG 20+ mainly because of a TA <0.8% and higher SSC/TA values (>18) (Tables 3 and 5). Similar trends were found in the second season for NMF ‘Gulking’. The flesh firmness among the MGs after fruit ripening was similar, and SSC and TA were comparable to that of high-quality MF peaches (Tables 4 and 6). The optimum harvest maturity ranges of NMF ‘Gulking’ for direct ripening and ripening following low temperature storage were determined to be MG <0 to MG 25+ due to fruit having flesh firmness ≥ 14 N at harvest and MG <0 to MG 5–10 due to fruit having flesh firmness >27 N, respectively (Tables 4 and 6).

In this 2-year study, we demonstrated that the NMF cultivars have a wider harvest window than the MF cultivars when ripened immediately after harvest without intervening cold storage (Table 7). Furthermore, the NMF fruit can be picked at more advanced stages than the MF fruit, resulting in better quality. For peaches placed in cold storage before ripening, it was found that the MF cultivars should be picked at earlier maturity stages than those destined for direct ripening (Table 7). One advantage of the low temper-

ature storage condition used in this study was that, compared with MF fruit that were directly ripened, cold storage allowed the MF fruit in the lower MGs to have enough time to develop acceptable flavor (i.e., cold storage promoted loss of TA, resulting in higher SSC/TA). Although cold-stored NMF fruit can be picked at maturity stages like fruit that are directly ripened (Table 7), for a cultivar that is more susceptible to CI, such as NMF UFSun, the fruit should be harvested at more advanced stages to avoid development of chilling symptoms like the abnormal softening observed here.

Potential maturity indices determination. The GC a* value was highly correlated with the FC a* value (GC-FC) for both MF cultivars (Table 8) and for NMF ‘UFSun’ in both 2007 and 2008 ($r = 0.83$ and 0.77 , $P \leq 0.05$). This result suggests that although the FC a* value has been selected as a maturity index primarily for the canning NMF cultivars (Fuleki and Cook, 1976; Kader et al., 1982), it can also be used for the MF cultivars. It also shows that GC a* value may be an informative harvest index for certain NMF cultivars. Consistent correlation of diameter and peel blush was only observed for NMF ‘Gulking’ ($r = 0.76$ and 0.90 , $P \leq 0.05$). This positive correlation of diameter and peel blush in NMF ‘Gulking’ may lead to better consumer acceptance because consumer perception depends primarily on external qualities such as fruit size and appearance (Iglesias and Echeverria, 2009).

Negative correlations between the GC a* value and the TA (GC-TA) were consistently found in all four cultivars in both years, indicating that fruit maturity affects acidity (Table 8). It was reported that growing conditions have less impact on TA than SSC, and TA remained relatively consistent season-to-season if fruit maturity was similar (Belisle et al., 2018; Delgado et al., 2013). Because the GC a* value did not have a high correlation with the FC a* value for NMF ‘Gulking’, which suggests that GC a* value may not be a reliable maturity index for this NMF cultivar, TA may be used as a maturity index only for the MF cultivars and NMF ‘UFSun’. The TA of both NMF cultivars was highly correlated with the pH (TA-pH) (Table 8). This correlation has also been observed with other NMF peaches (Kader et al., 1982).

High correlations were found between the GC a* value and the flesh firmness (GC-FF) of all four cultivars in 2007 (Table 8). This result is consistent with that of Brovelli et al. (1998a), who demonstrated the importance of flesh firmness as a potential maturity index, even in NMF cultivars. However, the correlations of GC-FF were only observed for the MF peaches in 2008 (Table 8), confirming that flesh firmness is the most consistent maturity indicator for the MF cultivars (Byrne et al., 1991; Sims and Comin, 1963).

Literature Cited

- Beckman, T.G. and G.W. Krewer. 1999. Postharvest characteristics of moderate-chill peach varieties. Proc. Annu. Meet. Fla. State Hort. Soc. 112:236–241.
- Beckman, T.G., G.W. Krewer, J.X. Chaparro, and W.B. Sherman. 2008. Potential of nonmelting flesh peaches for the early season fresh market. J. Amer. Pomol. Soc. 62:52–57.
- Belisle, C., U.T.X. Phan, K. Adhikari, and D.J. Chavez. 2018. A fruit quality survey of peach cultivars grown in the southeastern United States. HortTechnology 28:189–201.
- Brooks, S.J., J.N. Moore, and J.B. Murphy. 1993. Quantitative and qualitative changes in sugar content of peach genotypes [*Prunus persica* (L.) Batsch]. J. Amer. Soc. Hort. Sci. 118:97–100.
- Brovelli, E.A., J.K. Brecht, W.B. Sherman, and C.A. Sims. 1998a. Potential maturity indices and developmental aspects of melting-flesh and nonmelting-flesh peach genotypes for the fresh market. J. Amer. Soc. Hort. Sci. 123:438–444.
- Brovelli, E.A., J.K. Brecht, W.B. Sherman, and C.A. Sims. 1998b. Quality of fresh-market melting- and nonmelting-flesh peach genotypes as affected by postharvest chilling. J. Food Sci. 63:730–733.
- Brovelli, E.A., J.K. Brecht, W.B. Sherman, C.A. Sims, and J.M. Harrison. 1999. Sensory and compositional attributes of melting- and nonmelting-flesh peaches for the fresh market. J. Sci. Food Agr. 79:707–712.
- Byrne, D.H., A.N. Nikolic, and E.E. Burns. 1991. Variability in sugars, acids, firmness, and color characteristics of 12 peach genotypes. J. Amer. Soc. Hort. Sci. 116:1004–1006.
- Byrne, D.H. 2005. Trends in stone fruit cultivar development. HortTechnology 15:494–500.
- Cascales, A., E. Costell, and F. Romojaro. 2005. Effects of the degree of maturity on the chemical composition, physical characteristics and sensory attributes of peach (*Prunus persica*) cv. Caterin. Food Sci. Technol. Intl. 11:345–352.

- Cirilli, M., D. Bassi, and A. Ciacciulli. 2016. Sugars in peach fruit: A breeding perspective. *Hort. Res.* 3:15067.
- Colaric, M., R. Veberic, F. Stampar, and M. Hudina. 2005. Evaluation of peach and nectarine fruit quality and correlations between sensory and chemical attributes. *J. Sci. Food Agr.* 85:2611–2616.
- Crisosto, C.H., G.M. Crisosto, G. Echeverria, and J. Puy. 2006. Segregation of peach and nectarine [*Prunus persica* (L.) Batsch] cultivars according to their organoleptic characteristics. *Postharvest Biol. Technol.* 39:10–18.
- Crisosto, C.H., D. Garner, G.M. Crisosto, and E. Bowerman. 2004. Increasing 'Blackamber' plum (*Prunus salicina* Lindell) consumer acceptance. *Postharvest Biol. Technol.* 34:237–244.
- Delgado, C., G.M. Crisosto, H. Heymann, and C.H. Crisosto. 2013. Determining the primary drivers of liking to predict consumers' acceptance of fresh nectarines and peaches. *J. Food Sci.* 78:S605–S614.
- Delwiche, M.J. 1987. Grader performance using a peach ground color maturity chart. *HortScience* 22:87–89.
- Delwiche, M.J. and R.A. Baumgardner. 1983. Ground color measurements of peach. *J. Amer. Soc. Hort. Sci.* 108:1012–1016.
- Delwiche, M.J. and R.A. Baumgardner. 1985. Ground color as a peach maturity index. *J. Amer. Soc. Hort. Sci.* 110:53–57.
- Department of Horticultural Sciences. Texas A&M University. 2019. TAMU Stone Fruit Breeding Program. Low chill cultivar performance at Weslaco, TX. 14 Dec. 2019. <<https://aggie-horticulture.tamu.edu/stonefruit/allowchill.html>>.
- Diehl, D.C., N.L. Sloan, C.M. Bruhn, A.H. Simonne, J.K. Brecht, and E.J. Mitcham. 2013. Exploring produce industry attitudes: Relationships between postharvest handling, fruit flavor, and consumer purchasing. *HortTechnology* 23:642–650.
- Drogoudi, P.D., C.G. Tsipouridis, and G. Pantelidis. 2009. Effects of crop load and time of thinning on the incidence of split pits, fruit yield, fruit quality, and leaf mineral contents in 'Andross' peach. *J. Hort. Sci. Biotechnol.* 84:505–509.
- Dubois, M., K.A. Gilles, J.K. Hamilton, P.A. Rebers, and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. *Anal. Chem.* 28:350–356.
- Fallahi, E., B. Fallahi, B. Shafii, and M.E. Amiri. 2009a. Bloom and harvest dates, fruit quality attributes, and yield of modern peach cultivars in the intermountain western United States. *HortTechnology* 19:823–830.
- Fallahi, E., B. Fallahi, B. Shafii, M.E. Amiri, and M. Mirjalili. 2009b. Growing degree days, bloom and harvest dates, fruit quality and yield of new yellow and white nectarines. *J. Amer. Pomol. Soc.* 63:150–159.
- Fernandez-Trujillo, J.P. and F. Artes. 1997. Keeping quality of cold stored peaches using intermittent warming. *Food Res. Intl.* 30:441–450.
- Fuleki, T. and F.I. Cook. 1976. Relationship of maturity as indicated by flesh color to quality of canned clingstone peaches. *J. Inst. Can. Sci. Technol.* 9:43–46.
- Iglesias, I. and G. Echeverria. 2009. Differential effect of cultivar and harvest date on nectarine colour, quality and consumer acceptance. *Scientia Hort.* 120:41–50.
- Infante, R. 2012. Harvest maturity indicators in the stone fruit industry. *Stewart Postharvest Rev.* 8:1–6.
- Josan, J.S. and G.S. Chohan. 1982. Studies on maturity standards of peach (*Prunus persica* batsch) cv. Flordasun. *Haryana J. Hort. Sci.* 11:1–4.
- Kader, A., C. Heintz, and A. Chordas. 1982. Post-harvest quality of fresh and canned clingstone peaches as influenced by genotypes and maturity at harvest. *J. Amer. Soc. Hort. Sci.* 107:947–951.
- Kader, A.A. and E.G. Mitchell. 1989. Postharvest physiology, p. 158–164. In: J.H. La Rue and R.S. Johnson (eds.). *Peaches, plums, and nectarines: Growing and handling for fresh market*. Publ. 3331. University of California, Dept. Agr. Natural Resources.
- Kader, A.A. 2008. Flavor quality of fruits and vegetables. *J. Sci. Food Agr.* 88:1863–1868.
- Karakurt, Y., D.J. Huber, and W.B. Sherman. 2000. Quality characteristics of melting and non-melting flesh peach genotypes. *J. Sci. Food Agr.* 80:1848–1853.
- McGuire, R.G. 1992. Reporting of objective color measurements. *HortScience* 27:1254–1255.
- Metheney, P.D., C.H. Crisosto, and D. Garner. 2002. Developing canning peach critical bruising thresholds. *J. Amer. Pomol. Soc.* 56:75–78.
- Moing, A., L. Svanella, D. Rolin, M. Gaudillere, J.P. Gaudillere, and R. Monet. 1998. Compositional changes during the fruit development of two peach cultivars differing in juice acidity. *J. Amer. Soc. Hort. Sci.* 123:770–775.
- Robertson, J.A., R.J. Horvat, B.G. Lyon, F.I. Meredith, S.D. Senter, and W.R. Okie. 1990. Comparison of quality characteristics of selected yellow-and white-fleshed peach cultivars. *J. Food Sci.* 55:1308–1311.
- Robertson, J.A., F.I. Meredith, and W.R. Forbus. 1991. Changes in quality characteristics during peach (cv. Majestic) maturation. *J. Food Qual.* 14:197–207.
- Robertson, J.A., F.I. Meredith, B.G. Lyon, G.W. Chapman, and W.B. Sherman. 1992. Ripening and cold-storage changes in the quality characteristics of nonmelting clingstone peaches (fla 9-20c). *J. Food Sci.* 57:462–465.
- Robertson, J.A., F.I. Meredith, B.G. Lyon, and G.W. Chapman. 1993. Comparison of quality characteristics of 3 nonmelting clingstone peach selections. *J. Food Qual.* 16:197–207.
- Rood, P. 1957. Development and evaluation of objective maturity indices for California freestone peaches. *Proc. Amer. Soc. Hort. Sci.* 70:104–112.
- Rouse, R.E. and W.B. Sherman. 2002. Peaches for subtropical south Florida. *J. Amer. Pomol. Soc.* 56:179–184.
- Rouse, R.E., W.B. Sherman, and P.M. Lyrene. 2004. 'UFSun' peach. *J. Amer. Pomol. Soc.* 58:108–110.
- Sandefur, P., J.R. Clark, and C. Peace. 2014. Peach texture. *Hort. Rev.* 41:241–302.
- Salunkhe, D.K., P.B. Deshpande, and J.Y. Do. 1968. Effects of maturity and storage on physical and biochemical changes in peach and apricot fruits. *J. Hort. Sci. Biotechnol.* 43:235–242.
- Sherman, W.B., B.L. Topp, and P.M. Lyrene. 1990. Non-melting flesh for fresh market peaches. *Proc. Annu. Meet. Fla. State Hort. Soc.* 103:293–294.
- Shinya, P., L. Contador, S. Predieri, P. Rubio, and R. Infante. 2013. Peach ripening: Segregation at harvest and postharvest flesh softening. *Postharvest Biol. Technol.* 86:472–478.
- Shinya, P., L. Contador, T. Frett, and R. Infante. 2014. Effect of prolonged cold storage on the sensory quality of peach and nectarine. *Postharvest Biol. Technol.* 95:7–12.
- Sims, E.T.J. and D. Comin. 1963. Evaluation of objective maturity indices for Halehaven peaches. *Proc. Amer. Soc. Hort. Sci.* 82:125–130.
- Testoni, A. 1995. Momento di raccolta, qualità, condizionamento e confezionamento delle pesche. *Proc. Symposium "La peschicoltura Veronese alle soglie del 2000."* Verona, 25 February, p. 327–354.
- Topp, B.L., W.B. Sherman, and M.C.B. Raseira. 2008. Low-chill cultivar development, p. 106–138. In: D.R. Layne and D. Bassi (eds.). *The peach: Botany, production, and uses*. CAB International, Oxfordshire, UK.
- Ventura, M., A. Sama, A. Minguzzi, S. Lazoni, and S. Sansavini. 2000. Ottimizzazione del carico di frutti per migliorare la produzione e la qualità delle nettarine 'Supercrimson' e 'Venus'. In: S. Sansavini (ed.), *Per una nuova peschicoltura: Produzione, organizzazione, mercato*. XXIV Convengo Peschicolo, Cesena, 24–25 February, p. 173–176.
- Williamson, J.G. and S.A. Sargent. 1999. Postharvest characteristics and consumer acceptance of non-melting peaches. *Proc. Annu. Meet. Fla. State Hort. Soc.* 112:241–242.
- Zerbini, P.E. 2008. Managing maturity and ripening in the fruit production chain for improved flavour. *Acta Hort.* 804:63–70.
- Ziosi, V., M. Noferini, G. Fiori, A. Tadiello, L. Trainotti, G. Casadoro, and G. Costa. 2008. A new index based on vis spectroscopy to characterize the progression of ripening in peach fruit. *Postharvest Biol. Technol.* 49:319–329.