HORTSCIENCE 60(1):23–27. 2025. https://doi.org/10.21273/HORTSCI18223-24

Fruit Bagging Enhances Peel Color and Affects Fruit Quality of Citrus under Protected Screen-grown Grapefruit-like Hybrid '914'

Shalini Pareek, Joseph H. Volpe, Emily S. Worbington, and Arnold W. Schumann
Citrus Research and Education Center, University of Florida, Institute of Food and Agricultural Sciences, Lake Alfred, FL 33850, USA

Yuan Yu
Center for Metabolomics, Haixia Institute of Science and Technology, Fujian Agriculture and Forestry University, Fuzhou, Fujian 350002, China

Alma D. Hurtado, Jude W. Grosser, Fred G. Gmitter Jr, and John M. Chater
Citrus Research and Education Center, University of Florida, Institute of Food and Agricultural Sciences, Lake Alfred, FL 33850, USA

Keywords. breeding, citrus, fruit manipulation, grapefruit-like, scions

Abstract. **Fruit external color is one of the primary factors associated with consumer choice at the market level. Grapefruit, pomelos, and grapefruit-like hybrids are fruits that can develop different external colors based on horticultural practices. The fruit of '914', which is a grapefruit-like hybrid, is similar to grapefruit in flavor and appearance; however, it has a higher total soluble solids content. The fruit rind tends to be green-yellow to yellow with a pink blush, depending on the harvest date and site conditions. Fruit bagging is a horticultural practice that has been used for more than a century to improve the product quality and appearance of various fruit crop species. During our experiments, fruits of '914' were bagged at two locations in Central Florida to determine the effects of bagging on external fruit color and internal fruit quality. Both locations had fruit-bearing trees in citrus under protected screen structures to exclude Asian citrus psyllid from the cropping system. Fruits were bagged in Jul 2023 and followed until harvest. At the Alturas, FL, USA site, there was one harvest date; however, at the Citrus Research and Education Center site, there were two harvest dates. Data trees were strip-harvested on each harvest date. Fruit weight, diameter, length, and peel color as well as total soluble solids, titratable acidity, and maturity index (soluble solids:acid) were measured. The results indicated that bagging '914' positively influences external peel color and can affect internal fruit quality. More research is needed to determine the optimal windows of fruit bagging of '914' grapefruit-like hybrid and the effects of bagging on consumer sensory perception and postharvest quality.**

Fruit bagging is a common method used by growers to protect fruits from mechanical damage, such as that caused by insect or bird attacks, and physiological damage (sunscald, sunburn, splitting), caused by harsh climatic conditions of sunlight, high and low temperature extremes, and winds that can result in heavy crop loss. Bagging changes the microenvironment around the fruit and mainly affects light, humidity, temperature, and air movement (Ali et al. 2021). Preharvest bagging is an ecofriendly practice that protects fruit from external damage and can improve the external and internal quality of the fruit (Rajan et al. 2020). Increased and decreased fruit size, weight, and changes in color as well as variable influences on fruit appearance and maturity have been reported as effects of preharvest bagging (Sharma et al. 2014). For citrus, various bags are used for bagging purposes; these include paper bags, and plastic bags (transparent or lightproof), depending on the requirement (Hiratsuka et al. 2012; Jiang et al. 2022; Lado et al. 2015, 2019; Magwaza et al. 2013; Promkaew et al. 2020).

Bagging of citrus increases the brightness of the rind (peel) color, accelerates degreening, and increases total flavonoids, lycopene, β-carotene, total carotenoids, and total anthocyanin; additionally, it decreases the total soluble solids (TSS), total phenolics, titratable acidity (TA), and ascorbic acid. The effects of fruit bagging also depend on the stage of fruit, cultivar type, duration and timing of bagging, and the harvest date (Jiang et al. 2022; Lado et al. 2019; Promkaew et al. 2020).

Grapefruit is a popular edible citrus fruit known for its fresh and unique fragrance and flavor. Grapefruit is typically rich in flavonoids, coumarins, and carotenoids. Some secondary metabolites, such as naringin, may give it a bitter taste. Grapefruit bagging with black plastic bags and paper bags has resulted in enhanced accumulation of carotenoids and, hence, fruit rind color, thus improving its overall appearance and marketability (Jiang et al. 2022; Lado et al. 2015). Other than the juice and fruit quality, the data from National Health and Nutrition Examination Survey 2003–08 showed the dietary health benefits of grapefruit. Grapefruit is rich in vitamin C, magnesium, potassium, and dietary fibers, and it is effective for controlling body weight and blood pressure (Dow et al. 2012; Murphy et al. 2014). Contrary to its health benefits, grapefruit contains furanocoumarins, which interact with heart medications (Bailey et al. 1998). Furanocoumarins are potent irreversible inhibitors of P450-3A (CYP3A) enzymes in the human gastrointestinal tract that are involved in the metabolism of some drugs (Paine et al. 2005). Ingesting grapefruit or its juice with such medications can alter drug kinetics, thus increasing their levels in plasma, which may be harmful. Continuous efforts are being pursued by researchers to lower the concentration of furanocoumarins in grapefruit by using breeding and genetics approaches to rescue the grapefruit from potential market risks (Chen et al. 2011, 2014).

Using this approach, a unique grapefruit-like hybrid '914' (hybrid of grapefruit and pummelo) with a low furanocoumarin content was developed and patented (US PP26,177 P3) (Cancalon and Gmitter 2013; Gasic and Preece 2014; Gmitter 2015). The fruit rind tends to be green-yellow to yellow with a pink blush, depending on the harvest date and site conditions. A previously unknown artificial sweetener, Oxime V, is also found naturally in grapefruit-like hybrid '914' (Wang et al. 2022). To improve the potential economic value of this medically important '914' grapefruit-like hybrid, the present study was performed to determine whether fruit bagging can enhance fruit quality in terms of peel color by increasing the pink or red color, thereby increasing consumer appeal. During this experiment, comparisons of external and internal fruit quality between bagged and unbagged fruit (replicated at two sites) were performed. These experiments were conducted using two separate citrus under protected screen (CUPS) systems. This horticultural technique, if successful, would allow growers to bag fruit so that the fruit quality could be enhanced and the harvest window for this unique cultivar could be expanded; therefore, multiple harvests were performed.

Received for publication 16 Sep 2024. Accepted for publication 21 Oct 2024.
Published online 3 Dec 2024.
J.M.C. is the corresponding author. E-mail: jchater@ufl.edu.

Materials and Methods

Plant material and field experiment. Bagging of grapefruit-like hybrid '914' (Fig. 1) was conducted at a CUPS facility at the University of Florida, Citrus Research and Education Center (CREC), Lake Alfred, FL, USA, and at a CUPS facility in Alturas, FL, USA. In Lake Alfred, which is approximately 17 miles north of Alturas, the mean high temperature is approximately 30 °C, and the mean low temperature is approximately 19 °C; this climate is similar to that of Alturas, FL, USA, with mean humidity ranging from 51% to 73%, depending on time of year. Both Lake Alfred and Alturas are located in the humid subtropical zone according to the Köppen climate classification system. Trees with similar vigor were selected randomly at each location. At Alturas, the rootstock was 'US 897' for each tree, and the spacing was 2.3 m × 4.6 m; the planting date was Apr 2019. At the CREC CUPS facility, there were two experimental and unreleased rootstocks from the CREC rootstock breeding program with tighter spacing of 1.5 m × 3 m and a planting date of Aug 2014. Data trees were selected at random in mature soil-planted and potting container-planted trees at the CREC and the Alturas site; all trees were planted in the soil, which is a Candler series soil that is quite sandy, with adequate drainage for citrus production. Fruits were bagged on 3 Jul 2023 at the CREC CUPS facility and on 6 Jul 2023 at the Alturas CUPS facility; bagging was performed using an orange-red paper bag with black coating inside to exclude natural light (Fig. 1). The phenological stage of the tree was after fruit set, months after petal fall. At the CREC CUPS facility, all fruits on eight trees were bagged, no fruits on eight control trees were bagged (control), and five fruits on eight trees were bagged (mixed treatment); however, except for the five bagged fruit, the remaining mixed treatment fruit were unbagged. At the Alturas CUPS facility, all fruits on three trees were bagged; on another three trees, no fruits were bagged (control). It was assumed that the trees were not infected with the *C*Las bacterium (putative causative agent of huanglongbing) and not infested with Asian citrus psyllid because they were protected by the CUPS system and displayed no symptoms of huanglongbing. There were no mixed treatment trees at the Alturas CUPS facility. The fruit were first harvested on 4 Dec 2023 at Alturas and on 5 Dec 2023 at the CREC CUPS facility. At the CREC, four trees each of the bagged control trees were strip-harvested. The second harvest from the CREC CUPS facility was completed on 2 Feb 2024. For the mixed treatment, all the remaining bagged fruits (some fruit lost their bags during the experiment) and the same number of unbagged fruits were harvested per tree. At the Alturas CUPS facility, all three trees from both treatment groups were strip-harvested. The fruits were stored in a cold room at 5 to 6 °C until processing and data collection. Data regarding weight and external color were collected immediately after each harvest. Internal quality data were collected approximately 3 to 4 weeks after each harvest.

Fruit weight and size measurement. The weight of each fruit was measured in grams using a digital balance (CR2200; OHAUS Corp., NJ, USA), whereas the equatorial diameter and longitudinal length were measured in millimeters using digital long jaw calipers.

Flavedo color analysis. The CIE LAB color space (L* a* b* values) of the blush (pink) and shade (yellow) color of the rind were measured using a color meter (data processor DP-301 for chroma meter CR 300 series; Minolta, Tokyo, Japan) at three evenly distributed equatorial sites on the fruit surface. Three readings for each coordinate of each fruit were performed. The citrus color index was calculated as $1000 \times a^*/(L^* \times b^*)$ (Cubero et al. 2018; Jiang et al. 2022).

Total soluble solids. Juice was expressed (five fruits from each tree were juiced individually) to determine the TSS contents and TA. The TSS contents were detected using a bench top refractometer HI96801 (HANNA Instruments Inc., Smithfield, RI, USA); three measurements per fruit were performed (20 fruit repetitions for each group). The refractometer was cleaned with deionized water between sample applications and dried with Kimwipe tissues (Kimberly-Clark Professional, Roswell, GA, USA). The device was calibrated using deionized water before beginning the juice data collection. For each sample, 0.5 mL of juice from the collected juice sample was transferred to the sample platform and the resulting measurement was recorded.

Titratable acidity. The TA in citric acid equivalents was measured using an automatic mini-titrator HI84532 (HANNA Instruments Inc.) and low-range titrant HI84532-50 (HANNA Instruments Inc.). Samples were prepared and autotitrated by mixing 5 mL of juice with 45 mL of deionized water to calculate the percent of citric acid equivalents in solution. One sample per fruit was used for titration.

Maturity index. The maturity index was determined by calculating the total soluble solids to acid ratio (TSS:TA).

Statistical analysis. The experimental data were analyzed using an analysis of variance fit general linear model with Minitab Statistic Software (version 19; Minitab LLC, State College, PA, USA). Tukey's and Bonferroni's pairwise comparisons were performed with an experiment-wise error rate of $\alpha = 0.05$ among means of different variables (fruit weight, diameter, length, Blush L*, Blush a*, Blush b*, Blush color index, Shade L*, Shade a*, Shade b*, Shade color index, TSS, %TA, and TSS:TA) of the control and bagged fruits of different sites. The relationships between TSS, TA, and TSS:TA were analyzed using linear regression ($\alpha = 0.05$). The two-sample t test was used to determine treatment effects at the site in Alturas, FL, USA.

Fig. 1. '914' grapefruit-like hybrid from the unbagged treatment harvested in Sep 2023 (**A**). An image of the paper bags used in the study can be seen along with the markings indicating the manufacturer of the material (**B**, lower left). The bags had a wire to tie the bags to the branch holding the fruit (Photo credit: T. Weeks, University of Florida Institute of Food and Agricultural Sciences).

Results

Fruit weight and size measurement. There were significant differences among treatments and between sites for several of the variables measured during the two experiments. Treatment effects were assessed for each site separately. For fruit weight, there were significant differences between sites and among treatments (Table 1). The heaviest fruit, on average, were harvested from the bagged fruit from the Alturas CUPS facility, where the mean fruit weight was 931 g. These fruit were significantly different from the fruit of the unbagged treatment and were on younger trees grown on 'US-897' rootstock. The lightest

Table 1. Comparison of bagging effects on the external quality of grapefruit-like hybrid '914'. External quality traits included weight (g), diameter (mm), length (mm), peel color on the blushed and shaded sides of the fruit in the CIE LAB color space (L* a* b* values), and the color index of the shaded side of the fruit. Fruit were strip-harvested at the Alturas site in Dec 2023, and they were strip-harvested at the Citrus Research and Education Center (CREC) during two harvests, with the first harvest in Dec 2023 and the second harvest in Feb 2024. The variable n indicates sample number. The sites were statistically analyzed separately.

					Peel color							
Site and treatment (harvest time)	n	Weight (g)	Diam (mm)	Length (mm)	Blush L	Blush a	Blush b	Blush color index	Shade L	Shade a	Shade b	Shade color index
Alturas unbagged (Dec 2023)	175	783 b[1]	134.6 b	115.9 b	58.03 a	16.64 b	34.21 a	9.0 b	63.4 b	−3.0 b	44.4 a	−1.2 b
Alturas bagged (Dec 2023)	137	931 a	150.5 a	126.6 a	56.45 b	24.89 a	31.77 b	14.3 a	64.8 a	12.1 a	40.6 b	4.8 a
P value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	<0.001	<0.001	<0.001
CREC unbagged First harvest (Dec 2023)	170	467 c	104.9 b	90.7 b	61.65 b	7.09 c	37.33 b	3.63 d	65.21 b	−2.88 d	44.40 b	−1.02 d
CREC bagged First harvest (Dec 2023)	119	682 b	124.0 a	106.9 a	57.87 c	24.74 a	31.47 c	13.76 a	67.36 a	10.49 b	40.61 c	3.96 b
CREC unbagged Second harvest (Feb 2024)	113	752 a	127.5 a	107.0 a	63.03 a	12.84 b	40.45 a	5.37 c	68.41 a	3.24 c	48.69 a	1.00 c
CREC bagged Second harvest (Feb 2024)	79	659 b	107.0 b	91.3 b	58.57 c	25.84 a	37.50 b	11.95 b	63.55 c	15.76 a	42.32 c	6.04 a
P value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[1] Means that do not share a letter are significantly different according to Tukey's honestly significant difference test for the CREC site or the two-sample t test for the Alturas site ($P < 0.05$).

fruit were from the CREC CUPS facility unbagged treatment on the first harvest date, with a mean weight of 467 g; these fruit were significantly different from the fruit of the other treatments at that site. The largest fruit were from the bagged fruit treatment harvested at the Alturas CUPS facility and were significantly different from the unbagged fruit. The fruit with the smallest diameter were unbagged fruit harvested from the CREC CUPS facility at the first harvest and the bagged fruit from the CREC site at the second harvest; both of these were significantly different from the bagged fruit at the first harvest and the unbagged fruit at the second harvest. Regarding the longitudinal fruit length, the longest fruit were the bagged fruit at the Alturas location and the unbagged fruit of the second harvest at the CREC. The shortest fruit were from the unbagged treatment at the first harvest and from the bagged treatment at the second harvest at the CREC CUPS site; their lengths were significantly different from those of the bagged first harvest fruit and unbagged second harvest fruit.

Flavedo color analysis. Fruit bagging had significant effects on fruit flavedo color. Lightness (L*) was higher on the blushed side of the unbagged fruit treatments compared with that of the bagged fruit treatments at each site (Table 1). For the red–green axis (a*), the bagged fruit had the reddest color when compared with that of the unbagged fruit. For the yellow-blue axis (b*), unbagged fruit appeared to be yellower than bagged treatment fruit, with the exception of the bagged treatment from the second harvest at the CREC, which had a yellower color than the unbagged fruit at the Alturas site and a yellow color similar to the unbagged fruit at the first harvest at the CREC. The first harvest of the bagged treatment fruit at the CREC and the bagged treatment fruit at Alturas showed the highest color index, and the unbagged fruit from the first harvest at the CREC had the lowest color index for the blushed side of the fruit. There was less variability and less consistency in outcomes among treatments for lightness (L*) on the shaded side (facing inside of canopy) of the fruit, but there were significant differences among treatments and sites. There was also an inconsistency in treatment outcomes for the red–green measure for the shaded side of the fruit. However, for the yellow-blue axis and color index, there was a significant effect of treatment; the unbagged fruit were yellower than the bagged fruit, and the bagged fruit had a higher color index at both sites.

Total soluble solids. There were significant differences in the TSS among treatments and sites ($P < 0.001$) (Table 2). The mean TSS at the CREC was 12.6%, and the mean TSS at Alturas was 8.7%. All treatments and harvest dates at the CREC had higher TSS than that of fruit at the Alturas site. The highest TSS was measured in the unbagged fruit from the first harvest at the CREC, and the second highest TSS was measured in the second harvest bagged and unbagged treatments at the CREC CUPS site. A major site effect was revealed by significant differences in TSS between the Alturas and CREC sites. There was a 61% difference in the TSS between the fruit with the highest TSS (unbagged, first harvest at CREC) and the unbagged fruit at the Alturas site. The first harvest at the CREC site indicated differences between the bagged and unbagged treatments; the bagged treatment had a TSS of 11.6% and the unbagged treatment had a TSS of 13.7%. This was the only instance when bagging had a significant effect on TSS between treatments for a particular site–harvest date combination.

Titratable acidity. Similar to TSS, the TA was higher at the CREC compared with that at the Alturas site, regardless of the bagging treatment ($P < 0.001$). The fruit at the CREC had a mean TA of 0.82%, and the fruit at Alturas had a mean TA of 0.66%. The highest mean TA (0.95%) of the unbagged fruit was measured from the first harvest at the CREC. The lowest mean TA (0.63%) was observed in the bagged fruit at the Alturas site; this value was not significantly different than that of the unbagged fruit at that site. Bagging appeared to affect the fruit juice TA at the first harvest at CREC, with the bagging treatment having significantly less TA (0.73%) than

Table 2. Comparison of bagging effects on the internal quality of grapefruit-like '914'. Data of the total soluble solids (TSS) (%) and titratable acidity (TA) (%) were collected. Fruit were strip-harvested at the Alturas, FL, USA, site in Dec 2023, and they were strip-harvested at the Citrus Research and Education Center (CREC) during two harvests, with the first harvest in Dec 2023 and the second harvest in Feb 2024. The variable n indicates the sample number. The sites were statistically analyzed separately.

Site and treatment (harvest time)	n	TSS (%)	TA (%)	TSS:TA
Alturas unbagged (Dec 2023)	15	8.5 a[1]	0.68 a	12.8 a
Alturas bagged (Dec 2023)	15	8.9 a	0.63 a	14.0 a
P value		0.100	0.209	0.053
CREC unbagged first harvest (Dec 2023)	20	13.7 a	0.95 a	14.8 a
CREC bagged first harvest (Dec 2023)	18	11.6 c	0.73 b	15.9 a
CREC unbagged second harvest (Feb 2024)	20	12.2 bc	0.78 b	15.7 a
CREC bagged second harvest (Feb 2024)	20	12.7 b	0.81 b	15.7 a
P value		<0.001	<0.001	0.304

[1] Means that do not share a letter are significantly different according to Tukey's honestly significant difference test for the CREC site or the two-sample t test for the Alturas site ($P < 0.05$).

that of the unbagged treatment (0.95%). There was a significant positive but moderate correlation between TA and TSS (r = 0.6528; $P < 0.001$).

Maturity index. Differences in the maturity index between sites were observed ($P < 0.001$) (Table 2). The Alturas site had a significantly lower maturity index value (13.4) than that at the CREC site (15.5). However, for each site, there were no significant differences between treatments or harvest dates in terms of the maturity index values. For the Alturas site, the mean maturity index values ranged from 12.8 to 14.0; however, at the CREC site, the mean maturity index values ranged from 14.8 to 15.9. There were significant but moderate to weak correlations between TSS:TA and TSS (r = 0.4723; $P < 0.001$) and TSS:TA and TA (r = −0.3516; $P < 0.001$).

Discussion

Fruit bagging is an effective method of influencing color and other fruit quality traits of many fruit crop species (Ali et al. 2021). The results of these experiments demonstrated that fruit bagging can positively affect external fruit color (Fig. 2) and affect internal fruit quality as measured by the TSS and TA of the grapefruit-like hybrid ‘914’. Fruit bagging appears to affect the fruit weight and size as well. The fruit weight, size and length of the ‘914’ fruit were affected by long-term bagging; by the second harvest date, fruit from the bagged treatment changed from significantly heavier, larger, and longer to significantly lighter, smaller, and shorter than the unbagged fruit from the second harvest date at the CREC site. By the second harvest date, the bagged fruit had a rather orange external color (Fig. 2); additionally, on tasting, the texture of the fruit flesh seemed to be affected. Why the bagged fruit appeared to have lost size and weight compared with those of the unbagged fruit treatment from the second harvest date at the CREC CUPS site is unknown.

Studies of the effects on ‘Okitsu Wase’ Satsuma mandarin determined that bagging with paper bags influenced internal fruit quality by decreasing the TSS and TA compared with those of a control treatment; the bagged treatment reached TSS of 10.07% and TA of 1.61%, and the control treatments reached TSS of 10.33% and TA of 1.76% (Hiratsuka et al. 2012). Regarding color, Hiratsuka et al. (2012) concluded that bagging of the Okitsu-Wase mandarin resulted in a pale yellow fruit at harvest, suggesting that bagging this cultivar resulted in poorer external color of fruit compared with that of the control. A similar effect was found during a study performed by Magwaza et al. (2013), who found that fruit inside the canopy were lighter and had a higher L* value compared to the fruit outside of the canopy exposed to light. The results for ‘914’ were different from those of mandarin because the fruit appeared to become darker than the fruit from the control trees. Accumulation of lycopene (red) and an increased rate of chlorophyll degradation can occur in grapefruit in dark conditions, thus possibly explaining the better yellow peel color of bagged fruit in the early harvest and the redder color in the later-harvested fruit (Lado et al. 2019). The bagged fruit in the present experiment appeared to be orange with pink to reddish blush, and the unbagged fruit appeared to be more yellow with some pink blush, as evidenced by the color data.

Fig. 2. Images of fruit used in the ‘914’ bagging experiment performed during the 2023–24 season at two different citrus under protected screen (CUPS) facilities in Polk County, FL, USA. The external color differences between unbagged (upper greenish set) and bagged (lower orangish set) fruit during the second harvest in Feb 2024 at the Citrus Research and Education Center CUPS facility (**A**). Bagged fruit from the CUPS site in Alturas, FL, USA (**B**) and unbagged fruit from the CUPS site in Alturas, FL, USA (**C**). Cut bagged fruit (**D**) and cut unbagged fruit (**E**) (Photo credit: A. Hurtado, University of Florida Institute of Food and Agricultural Sciences).

Jiang et al. (2022) reported that fruit bagging had a significant effect on peel color but less of an effect on sugars, acid, and other constituents in the fruit and its juice. Three different types of bags were used, and each was capable of blocking out biologically active light wavelengths. Although the grapefruit cultivar was not named, bagging accelerated the degradation of chlorophyll at certain time points, thus affecting the green color of the peel compared with that of the control, thus causing the bagged fruit to turn yellow approximately 45 d earlier compared to the control treatments. However, the bagged and unbagged treatments became similar in color toward the end of the experiment in December, contrary to what was observed with ‘914’; the bagged treatment resulted in a much deeper orange-red color than that of the control at the final harvest. Additionally, Jiang et al. (2022) reported that the juice TSS was unaffected by bagging grapefruit, but the flavor compounds, pigments, and other secondary metabolites of the peel were significantly affected by bagging. This study demonstrated an effect on TSS between treatments for the first harvest fruit at the CREC CUPS site, but that effect disappeared by the second CREC harvest date.

Another study of ‘Star Ruby’ indicated that bagging also had a significant effect on the external fruit color (Lado et al. 2015). As in the study by Jiang et al. (2022), this experiment also showed that bagging resulted in a faster breakdown of chlorophyll. Their work was stimulated by observations that red lycopene-accumulating grapefruit were darker inside of the canopy compared with the fruit outside of the canopy, and that the leaf cover of the fruit caused increased color where the fruit was shaded by the leaf. Despite bagging fruit in very different locations, the effect of bagging was similar across sites. It was determined that bagging was effective at accelerating fruit color development of ‘Star Ruby’ grapefruit similar to that reported by Lado et al. (2015).

Regarding internal fruit quality, it is important to note that the TSS and TA of the fruit were significantly affected by the site and harvest date. Unbagged fruit from the first harvest at the CREC site had a significantly higher TA than that of the other treatments. Possible explanations for these differences could be the rootstock, tree age, or horticultural effects (potted vs. unpotted plants). It is possible that soil fertility and, thus, tree nutrition could cause these large differences between sites. Regarding the harvest date, it appeared that the effects of bagging on TSS and TA may only occur during a short window of fruit development, as was seen with the fruit from the first harvest date at the CREC. During the December harvest at the CREC, there were differences between bagged and unbagged fruit; however, these differences were not detected during the February harvest. There were no significant differences between treatments at the Alturas site in terms of internal fruit quality; however, there were significant differences between treatments at the CREC site (both TSS and TA) for the first harvest date. The larger fruit size at Alturas may explain why the TSS and TA were significantly lower there because such a relationship between larger fruits and lower TSS and TA has been reported for mandarin (Khalid et al. 2017). Other causes may be the rootstock, tree age, or other environmental factors.

Conclusions

Fruit bagging of ‘914’ grapefruit-like hybrid effectively improved external fruit flavedo color at two experimental sites in Florida. These results are in agreement with those of other studies of citrus fruit bagging. However, it is important to acknowledge that fruit bagging does not have the same effects across all citrus species, and that grapefruit and grapefruit-like hybrids may benefit from enhanced external color induced by bagging; additionally, other citrus cultivars may not respond well to bagging in terms of flavedo color or other important traits. Bagging of ‘914’ also affected internal quality, size, and weight of fruit. These factors are important to consider, and further evaluation of the sensory perception of untrained consumer panelists may be required to determine whether bagging fruit affects the flavor and texture in a significant manner in comparison with unbagged fruit. The results of these experiments indicate that fruit bagging is a useful method of improving external color within a short timeframe for ‘914’ grapefruit-like hybrid. However, more research is needed to optimize the methodology and understand how bagging affects flavor, postharvest quality, fruit physiology, shelf life, and consumer preference.

References Cited

Ali MM, Anwar R, Yousef AF, Li B, Luvisi A, De Bellis L, Aprile A, Chen F. 2021. Influence of bagging on the development and quality of fruits. Plants. 10(2):358. https://doi.org/10.3390/plants10020358.

Bailey DG, Malcolm J, Arnold O, Spence JD. 1998. Grapefruit juice–drug interactions. Br J Clin Pharmacol. 46(2):101–110. https://doi.org/10.1046/j.1365-2125.1998.00764.x.

Cancalon PF, Gmitter FG Jr. 2013. New grapefruit and pummelo cultivars with very low furanocoumarin contents are good candidates to provide a solution to the drug interaction problem. Fruit Process. 23(4):126–129.

Chen C, Cancalon P, Haun C, Gmitter FG Jr. 2011. Characterization of furanocoumarin profile and inheritance toward selection of low furanocoumarin seedless grapefruit cultivars. J Am Soc Hortic Sci. 136(5):358–363. https://doi.org/10.21273/JASHS.136.5.358.

Chen C, Yu Q, Wei X, Cancalon PF, Gmitter FG Jr. 2014. Identification of genes associated with low furanocoumarin content in grapefruit. Genome. 57(10):537–545. https://doi.org/10.1139/gen-2014-0164.

Cubero S, Albert F, Prats-Moltalbán JM, Fernandez-Pacheco DG, Blasco J, Aleixos N. 2018. Application for the estimation of the standard citrus colour index (CCI) using image processing in mobile devices. Biosyst Eng. 167:63–74. https://doi.org/10.1016/j.biosystemseng.2017.12.012.

Dow CA, Going SB, Chow HHS, Patil BS, Thomson CA. 2012. The effects of daily consumption of grapefruit on body weight, lipids, and blood pressure in healthy, overweight adults. Metabolism. 61(7):1026–1035. https://doi.org/10.1016/j.metabol.2011.12.004.

Gasic K, Preece JE. 2014. Register of new fruit and nut cultivars list 47. HortScience. 49(4):396–421. https://doi.org/10.21273/HORTSCI.49.4.396.

Gmitter FG Jr (inventors). 2015. Pummelo grapefruit hybrid tree named ‘914’. Florida Foundation Seed Producers Inc. (assignee). US Patent application no. 13/999,708. (Filed 14 Mar 2014, granted 1 Dec 2015).

Hiratsuka S, Yokoyama Y, Nishimura H, Miyazaki T, Nada K. 2012. Fruit photosynthesis and phosphoenolpyruvate carboxylase activity as affected by lightproof fruit bagging in Satsuma mandarin. J Am Soc Hortic Sci. 137(4):215–220. https://doi.org/10.21273/JASHS.137.4.215.

Jiang A, Zheng L, Wang D, Kang C, Wu J, Fang P, Cao J, Sun C. 2022. Effects of fruit bagging on the physiochemical changes of grapefruit (*Citrus paradisi*). Food Qual Saf. 6:fyac049. https://doi.org/10.1093/fqsafe/fyac049.

Khalid S, Malik AU, Khan AS, Khan MN, Ullah MI, Abbas T, Khalid MS. 2017. Tree age and fruit size in relation to postharvest respiration and quality changes in ‘Kinnow’ mandarin fruit under ambient storage. Sci Hortic. 220:183–192. https://doi.org/10.1016/j.scienta.2017.03.042.

Lado J, Cronje P, Alquézar B, Page A, Manzi M, Gómez-Cadenas A, Stead AD, Zacarías L, Rodrigo MJ. 2015. Fruit shading enhances peel color, carotenes accumulation and chromoplast differentiation in red grapefruit. Physiol Plant. 154(4):469–484. https://doi.org/10.1111/ppl.12332.

Lado J, Alós E, Manzi M, Cronje PJ, Gómez-Cadenas A, Rodrigo MJ, Zacarías L. 2019. Light regulation of carotenoid biosynthesis in the peel of mandarin and sweet orange fruits. Front Plant Sci. 10:1288. https://doi.org/10.3389/fpls.2019.01288.

Magwaza LS, Opara UL, Cronje PJ, Landahl S, Terry LA. 2013. Canopy position affects rind biochemical profile of ‘Nules Clementine’ mandarin fruit during postharvest storage. Postharvest Biol Technol. 86:300–308. https://doi.org/10.1016/j.postharvbio.2013.07.029.

Murphy MM, Barraj LM, Rampersaud GC. 2014. Consumption of grapefruit is associated with higher nutrient intakes and diet quality among adults, and more favorable anthropometrics in women, NHANES 2003–2008. Food Nutr Res. 58(1):22179. https://doi.org/10.3402/fnr.v58.22179.

Paine MF, Criss AB, Watkins PB. 2005. Two major grapefruit juice components differ in time to onset of intestinal CYP3A4 inhibition. J Pharmacol Exp Ther. 312(3):1151–1160. https://doi.org/10.1124/jpet.104.076836.

Promkaew P, Srilaong V, Wongs-Aree C, Pongprasert N, Kaewsuksaeng S, Kondo S. 2020. Lycopene synthesis and related gene expression in pummelo pulp increased in shade-grown fruit. J Am Soc Hortic Sci. 145(1):60–66. https://doi.org/10.21273/JASHS04814-19.

Rajan R, Ahmad MF, Pandey K, Solankey SS. 2020. Bagging of fruit crops: a low cost sustainable technology for quality fruit production, p 121–140. In: Singh HK, Solankey SS, Roy MK (eds). Farmers’ prosperity through improved agricultural technologies. Jaya Publishing House, Delhi, India.

Sharma RR, Reddy SVR, Jhalegar MJ. 2014. Preharvest fruit bagging: A useful approach for plant protection and improved post-harvest fruit quality–a review. J Hortic Sci Biotechnol. 89(2):101–113. https://doi.org/10.1080/14620316.2014.11513055.

Wang Z, Gmitter FG Jr, Grosser JW, Wang Y. 2022. Natural sweeteners and sweetness-enhancing compounds identified in citrus using an efficient metabolomics-based screening strategy. J Agric Food Chem. 70(34):10593–10603. https://doi.org/10.1021/acs.jafc.2c03515.