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Influence of Orchard Design on 'Owari' Satsuma Mandarin *Citrus unshiu* (Marcovitch) Fruit Quality, Physiology, and Productivity

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Abstract

Satsuma mandarin growers in Alabama attempt to mitigate freeze damage by using various orchard designs such as interplanting between pecan or pine trees, planting in open fields with microsprinkler irrigation, and planting behind windbreaks. The goal of this research was to determine the influence of different orchard designs on canopy temperature, photosynthesis, leaf area, specific leaf area, yield, and fruit quality of satsuma mandarins. Satsuma canopy temperature under dense pine tree canopy was warmer than control trees in an adjacent open field. All trees in orchard designs that experienced shading had reduced photosynthesis. Satsuma trees grown under pine tree and pecan tree canopies had greater leaf area, and tended to have thinner leaves (greater specific leaf area) when compared to trees grown in full sun. Fruit from trees under dense pine tree canopies had reduced fruit size, rind thickness, and vitamin C concentration. There were no differences in fruit soluble solids concentration due to the dense pine tree canopy treatment; however, fruit from moderate pine tree shading had increased soluble solids concentration when compared to trees grown in full sun. There was no reduction in photosynthesis, fruit size, rind thickness, juice weight, or juice volume for trees planted behind a windbreak. In addition to freeze protection, the effects on photosynthesis and fruit quality should also be considered when selecting an orchard design for satsuma mandarin production.

Satsuma mandarin (*Citrus unshiu* Marc.) is one of the most cold hardy citrus species grown commercially (Ferguson, 1996; Hodgson, 1967), though freeze damage remains the ultimate limiting factor in satsuma mandarin production in south Alabama. Growers take different precautions to insure freeze damage is minimized. In addition to active control measures, such as microsprinkler irrigation, growers use passive methods such as site selection and orchard design. Different orchard designs include planting behind existing windbreaks, interplanting among pecan trees, or interplanting among pine trees. The perceived benefit of enhanced cold protection from these orchard designs has not been proven, and the subsequent effects on fruit quality, photosynthesis, and leaf architecture have not been established.

Planting satsuma mandarin trees between both pecan trees (*Carya illinoinensis* [Wangenh.] K. Koch) and pine trees is practiced in south Alabama to maximize land use and for perceived protection from damaging freezes. Pine species for interplanting include longleaf pine (*Pinus palustris* Mill.), loblolly pine (*Pinus taeda* L.) or slash pine (*Pinus elliottii* Engelm.). Similarly, citrus has been interplanted with 'Deglet Noor' date palms (*Phoenix dactylifera* L.) in California where the trees flourished, but fruit production was reduced in the shaded groves (Turrell, 1973). Although the effects on satsuma mandarin fruit production have not been reported, it seems that pine trees offer protection during radiational freezes, but provide little protection during more severe advective freezes (Ebel et al., 2005). Fruit ripening is generally delayed when satsuma mandarin trees are grown under pine tree canopies; how-

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ever, final fruit quality appears to be similar to that of trees in full sun groves (Nesbit et al., 2008).

Satsuma fruit quality is determined by peel color, fruit size, rind thickness, soluble solids concentration (SSC), titratable acidity (TA) and the ratio between SSC and TA. There are many factors that influence fruit quality including shading (Jifon and Syvertsen, 2001; Ono and Iwagaki, 1987; Verreynne et al., 2004; Yen and Lin, 1966) and canopy position (Fallahi and Moon, 1989; Syvertsen and Albrigo, 1980; Verreynne et al., 2004). In a 3-year study in which tonkan orange (*Citrus tankan* Hayata) was interplanted with acacia (*Acacia confusa* Merr.), Yen and Lin (1966) reported that shaded fruit tended to be more attractive in color and had thinner rinds. There were no differences between semi-shading, full shading, and full sun with either SSC or SSC:TA ratio (Yen and Lin, 1966). Satsuma mandarin peel coloring and SSC were reduced when relative light intensities were reduced to 65% or less for one growing season (Ono and Iwagaki, 1987). Fruit size was not affected by 50% shade when 'Spring' navel orange (*Citrus sinensis* L.) crop load was 100%, but resulted in larger fruit when the crop load was halved (Syvertsen et al., 2003). There were also no differences between fruit exposed to full sun and 50% shade for SSC, rind thickness, and SS:TA ratio of 'Spring' navel oranges (Syvertsen et al., 2003). In contrast to seasonal or short-term shade, continuous shade resulted in reduced SSC in 'Hamlin' orange (*Citrus sinensis* L.) and 'Ruby Red' grapefruit (*Citrus paradise* L.) (Jifon and Syvertsen, 2001). Fruit weight of grapefruit was greater, but the fruit weight of orange was reduced under continuous shade. Jifon and Syvertsen (2001) noted that peel color development of grapefruit was delayed by shaded treatments. Though some of the results of these previous studies are consistent, the trees were only shaded for 1-3 years and not continuously throughout the life of the trees.

Citrus can have pronounced differences in fruit quality related to bearing position on the tree. According to Reitz and Sites (1948), fruit of 'Valencia' oranges (*Citrus sinensis* L.) had higher SSC from the outer portions of the canopy and lower SSC from the inner canopy. Similar results were reported in mandarin (Fallahi and Moon, 1989; Iwagaki, 1981; Verreynne et al., 2004), grapefruit (Fallahi and Moon, 1989; Syvertsen and Albrigo, 1980), navel orange (Fallahi and Moon, 1989; Sites and Reitz, 1949), and lemon (Fallahi and Moon, 1989). The differences in fruit quality were attributed to differences in light quality and quantity, which could be related to photosynthetically active radiation (PAR) (Reitz and Sites, 1948). The development of fruit color can also be attributed to bearing position. Iwagaki (1981) reported an increase in peel color with increased light intensity with satsuma. In a study in the southern hemisphere, Verreynne et al. (2004) reported that the north sector of satsuma, clementine, and temple canopies had greener peel color than the south sector of the canopy.

Vitamin C, or L-ascorbic acid, is very important nutritionally in humans and is found in many horticultural crops (Block, 1991) such as, but not limited to, banana, blackberry, cantaloupe, citrus, kiwifruit, and strawberry (Lee and Kader, 2000). The amount of vitamin C found in mandarins is approximately 34 $mg \cdot 100\ g^{-1}$ fresh weight (FW). Variation in vitamin C can be attributed to environmental conditions such as light and temperature (Klein and Perry, 1982; Sites and Reitz, 1950). In grapefruit, higher temperatures in Arizona resulted in lower vitamin C concentration when compared to fruit from the cooler coastal climate of California (Rygg and Getty, 1955). Light interception as a result of canopy bearing position can influence vitamin C levels in citrus fruit. In 'Dancy' tangerine, fruit exposed to full sun were shown to be 27% higher in vitamin C when compared to fruit from shaded areas (Winston, 1948). Navel and temple oranges grown in full sun had 20.9 and 16.7% more vitamin C, respectively than those grown in shaded areas (Winston, 1948). Sites and Reitz (1950) reported that vitamin C differed based on "light classes" which correlated with PAR. Fruit from areas of the canopy that received the most light had the highest concentration of vitamin C, while fruit from the inner canopy had the lowest concentrations (Sites and Reitz, 1950).

Shading can have an effect on many leaf characteristics including photosynthesis (Pn), leaf area (LA), and specific leaf area (SLA). Light intensities related to PAR can influence Pn (Bjorkman and Holmgren, 1966; Boardman, 1977). Plants grown in shaded conditions have lower photosynthetic rates but they perform more efficiently at low light intensities (Boardman, 1977). In a 1-year study with 'Ruby Red' grapefruit (*Citrus paradisi* L.) and 'Hamlin' sweet orange (*Citrus sinensis* L.), trees grown under moderate shade had higher mid-day Pn when compared to those grown in full sun (Jifon and Syvertsen, 2001). This was reportedly due to reduced stress from lower leaf temperatures and leaf-to-air vapor pressure during mid-day, and the low irradiance required (600-700 $\mu mol \cdot m^{-2} \cdot s^{-1}$) to saturate citrus leaves (Jifon and Syvertsen, 2001; Syvertsen, 1984). Sun and shade leaves often differ in LA and leaf thickness. Compared to leaves in full sun, shaded leaves are typically broader and thinner, i.e. have greater SLA. Leaf thickness plays a partial role in the amount of light absorbed by a leaf and the diffusion pathway of CO_2 through its tissues (Agusti et al., 1994; Syvertsen et al., 1995). Thinner shaded leaves typically have larger chloroplasts and greater chlorophyll concentrations than the leaves from full sun (Boardman, 1977).

This purpose of this study was to evaluate the effects of various orchard designs and canopy positions on satsuma mandarin physiology, fruit quality, and canopy temperature. The orchard designs used in this study were implemented primarily to enhance freeze protection by influencing canopy temperature. Some of these orchard designs provide shading to the trees, thus altering growth habits. Shading can reduce photosynthesis and other aspects of leaf physiology that may result in differences in fruit quality. By using adjacent plantings in full sun without windbreaks for comparison, the effects of each orchard design on leaf architecture, Pn, canopy temperature, and fruit quality could be determined.

Materials and Methods

Plant materials and treatment applications. Satsuma (*Citrus unshiu*) mandarin trees planted in Grand Bay, AL (lat. 32° 28' N, long. 88° 20' W) and Irvington, AL (lat. 30° 26' N, long. 88° 12' W), USDA Hardiness Zone 9, were utilized in this study. The cultivar evaluated was 'Owari' budded onto trifoliate orange (*Poncirus trifoliata*) 'Rubidoux' with tree ages ranging from 4 to 20 years. Trees were fertilized based on current recommendations for this region (Powell and Williams, 1998). The experimental design was a split-plot design with orchard design being the whole plot factor and either tree quadrant (direction) or date of data collection being the subplot factors. For Pn and leaf temperature, the experimental design was a split-split plot design with orchard design being the whole plot factor, date as a subplot factor, and quadrant as a sub-subplot factor.

Treatments included four different satsuma mandarin orchard designs and control trees planted in adjacent open-field orchards for each treatment: (1). pine trees 1: 6-year-old trees interplanted with loblolly pine (40 – 60 % shade) with 8-year-old control trees; (2). windbreak: 14-year-old trees planted behind a living windbreak with 8-year-old control trees; (3). pecan: 5-year-old trees interplanted with pecan trees with 8-year-old control trees; and (4). pine trees 2: 20-year old trees interplanted with loblolly pine (70 – 90 % shade) with 10-year-old control trees. The windbreak treatment had a living screen of mostly oak trees (*Quercus sp.*) and underbrush on the north and west side of the orchard. In the pecan orchard design, the mandarin trees were shaded by 40-60% during the active growing season of the pecan trees. Tree ages listed are ages as of the beginning of the study (2010). The growing season climate was typical in 2010 and tree age was unlikely to have impacted the results of this 1-yr study. In each of the orchard designs and control orchards, four randomly selected trees were tagged and used for data collection. Fruit were harvested on November 16, 2010. Trees were divided into four quadrants for data collection, related to north, south, east, and west directions.

Leaf physiology analysis. In the summer of 2010, Pn, LA, SLA, and leaf greenness were measured. Photosynthesis was measured using a LI-COR 6400 (Model 1000, LI-COR Biosciences, Inc., Lincoln, Nebraska, USA) in May, July, and September. Photosynthesis measurements were taken on the sun-sky setting on the LI-COR 6400. Photosynthesis of the treatment trees and their respective control trees were measured within a 1.5 h time frame. One leaf per quadrant was measured. Measurements were collected from the fourth to sixth leaf from the terminal leaf on full sun days with no cloud cover. Photosynthesis was measured based on the amount of photosynthetic active radiation (PAR) each leaf received. PAR was measured using a portable light meter (Apogee Instruments model QMSS, Logan, UT, USA). Leaf greenness measurements were taken with a Konica Minolta chlorophyll meter (model SPAD-502, Konica Minolta Sensing Americas, Inc., Ramsey, NJ, USA) on the same leaves that were used for Pn measurements. Leaves were then placed in properly labeled bags and brought back to the lab for LA and SLA measurements. Leaf area was measured using a LI-COR 3100 leaf area meter (LI-COR Biosciences, Inc., Lincoln, NE, USA). Specific leaf area was determined using the formula ($LA \times DM^{-1}$) where DM was the dry mass of the leaves.

Fruit quality analysis. Four fruit from each quadrant were randomly selected from the exterior canopy for harvest and subsequent fruit quality analysis. Fruit were harvested on November 16, 2010. Data collection for fruit quality included weight, length, width, titratable acidity (TA), pH, SSC, SSC:TA ratio, juice weight, juice volume, number of seeds, internal color, and external color. Individual fruit weight was measured using an A & D EJ-610 scale (A & D Engineering, San Jose, CA, USA) and both fruit length and width were measured using a digital caliper (Mitutoyo U.S.A., Aurora, IL, USA).

Fruit were cut in half and both halves were juiced for the juice weight, juice volume, SSC, pH, and TA measurements. Fruit samples were juiced using a Black and Decker citrus juicer model CJ630 (Stanley Black and Decker, New Britain, CT, USA). Juice was poured into graduated cylinders to measure weight and volume and filtered through grade 50 cheesecloth to separate pulp from juice. Juice (1 mL) was maintained at room temperature and SSC was measured using a Leica Mark II Abbe Refractometer (Kernco Instruments, El Paso, TX, USA). From the remainder of the juice, 5 mL of juice was placed in 100 mL beakers and 25 mL of double-distilled water, having an electrical conductivity of 18.2 $M\Omega \cdot cm^{-2}$ obtained through a Millipore Direct-Q™ 5 filter system (Millipore Corp., Bedford, MA, USA), was added to bring the final volume to 30 mL. Titratable acidity and pH were measured using an automated titrimeter (Metrohm Titrino Model 751 and Metrohm Sample Changer; Metrohm Corp., Herisau, Switzerland) and software (Brinkmann Titrino Workcell 4.4 Software; Brinkmann Corp., Westbury, NY, USA). The automatic titrimeter was housed in a Fisher Scientific refrigerated chromatography chamber maintained at 10°C (Model Isotemp Laboratory Refrigerator; Fisher Scientific, Raleigh, NC, USA). A 0.1 M solution of NaOH was titrated to the endpoint of pH 8.1 and the results were expressed in citric acid equivalent using the formula: $[(\text{mL NaOH} \times 0.1\text{N} \times 0.064\ \text{meq} \cdot \text{g}^{-1} \text{ of juice}) \times 100]$.

Peel color was determined using a method described by Jifon and Syvertsen (2001) in which four measurements along the equator of the fruit were taken. Internal color was determined by cutting the fruit in half along the equator, and measuring the color of each halved segment. A Minolta CM-700d Spectrophotometer (Konica Minolta Sensing Americas, Inc., Ramsey, NJ, USA) using CIELAB color space coordinates (L*, a*, b*, C, h°) was utilized to measure peel and internal segment color. Only hue angle (h°) is reported. The h° can be visualized on a 360° color wheel where red-purple corresponds to 0°, yellow corresponds to 90°, bluish-green corresponds to 180°, and blue corresponds to 270° (McGuire, 1992). Calibration was done using a white calibration tile. Data were recorded using SpectraMagic™ NX CM-S100w software (Konica Minolta Sensing Americas, Inc., Ramsey, NJ, USA).

Vitamin C analysis. To determine vitamin C concentration, four 2.5 g samples from four different fruit segments were taken and homogenized using an Omni International GLH homogenizer (Omni International, Kennesaw, GA, USA) and an Omni International model G10-95 sawtooth probe (Omni International, Kennesaw, Georgia, USA). Samples were homogenized in 15 mL of m-phosphoric acid-acetic acid (MPA) buffer for 1 min on a setting of 70%. Homogenates were transferred to 50 mL centrifuge tubes, followed by a 10 min sonication (Branson Model 5510, Branson Ultrasonic Corporation, Danbury, CT, USA). Sonicated samples were centrifuged (Beckman Centrifuge Model J2-21, San Antonio, TX, USA) at 13,000 g_n for 15 min and filtered with Miracloth (EMD Millipore, Darmstadt, Germany). Clarified supernatants were transferred to 2 mL micro Eppendorf (Eppendorf, Hauppauge, NY, USA) centrifuge tubes and stored at -80°C until further analysis.

Vitamin C was determined according to a procedure reported by Gossett et al. (1994) with modifications (Hodges et al., 1996) that allow for adaptations for micro-plate determinations. In 2 mL micro Eppendorf centrifuge tubes, 50 µL of Milli-Q water and 100 µL of appropriately diluted sample were added to 250 µL of KH_2PO_4 (150 mM, pH 7.4 and 5 mM EDTA) to determine the ascorbic acid concentration. After 10 min room temperature incubation, 50 µL of Milli-Q water were added, along with 200 µL trichloroacetic acid (TCA), 200 µL of O-phosphoric acid, 200 µL of 4% (w/v) 2, 2-dipryridyl dissolved in 70% HPLC grade ethanol, and 100 µL of 3% (w/v) $FeCl_3$. A standard curve was generated using six concentrations of L-ascorbic acid (0, 20, 40, 60, 80, and 100 µM). This was performed in parallel with appropriately diluted samples. Microcentrifuge tubes were vortexed (Fisher Scientific Genie 2, Pittsburg, PA, USA) and incubated in a water bath (Fisher Scientific model ISOTEMP 210, Pittsburg, PA, USA) maintained at 40°C for 60 min. Samples were then clarified by centrifugation (Thermo, Micromax Centrifuge, Milford, MA, USA) at 10,000 g_n for 15 min at 4°C and 200 µL aliquots were pipetted into a 96 well flat bottom plates (Costar cat # 3370, Corning, Inc., Corning, NY, USA). The absorbance was read at 525 nm in a microplate reader (Synergy HT, BIO-TEK Instruments, Inc., Winooski, VT, USA) maintained at 25°C. Vitamin C concentration was expressed as $mg \cdot 100^{-1}$ g fresh weight.

Canopy temperature analysis. Canopy temperature was determined beginning in May 2010. Temperature data loggers (Spectrum Technologies, Inc., Model 100 Watchdog Data Logger, Plainfield, IL, USA) were placed approximately 1.5 m high in the outer canopy of the north facing side of the treatment trees and, similarly, in the control trees in an adjacent open field orchard for comparison. The canopy temperatures were measured every 30 minutes to observe differences among treatments and control trees. After a severe freeze event (December 27 – 29, 2010), recorded temperatures were analyzed to compare canopy temperature among treatment trees with their respective control trees.

Analysis of variance was performed using PROC GLIMMIX in SAS version 9.2 (SAS Institute, Cary, NC, USA). The normality assumption for ANOVA was tested using the tests for normality statistics in PROC UNIVARIATE. Data were considered non-normal when the Shapiro-Wilk, the Kolmogorov-Smirnov, the Anderson-Darling, and the Cramér-von Mises tests were all significant. Data were analyzed with locations in a CRD with directions and months treated as repeated measures when appropriate. Appropriate steps were taken to correct within-group correlation and heterogeneous variance to minimize the Akaike Information Criterion (AIC) goodness of fit values when compared to no corrective steps. Paired contrasts were used to compare least squares means among directions and between locations and the controls. Linear and quadratic orthogonal contrasts were applied over months. All tests were considered significant at $P \leq 0.05$.

Results and Discussion

The influence of orchard design on leaf architecture was notable for the shaded orchards. In the summer of 2010, which was typical for this region, LA was much larger under a dense pine tree canopy (pine trees 2) when compared to its respective control across three different months (Table 1). Individual leaf area from the pine trees 2 orchard

Table 1. Influence of orchard design on 'Owari' satsuma mandarin leaf greenness (SPAD), leaf area (LA), and specific leaf area (SLA) for pine tree canopy (Pi1), windbreak (Wb), interplanted pecans (Pe), and dense pine tree canopy (Pi2) treatments compared to their respective controls, south Mobile County, AL, 2010.[z]

	SPAD						
	Date				Control		
Treatment	May	July	Sept.	Sign.[y]	May	July	Sept.
Pi1	47.3	73.9	81.0 a[x]	Q***	51.7	78.1	77.0 b
Wb	46.3	71.9	74.9	Q***	50.9	69.2	73.3
Pe	43.2	77.4 a	80.6	Q***	47.0	70.7 b	77.1
Pi2	42.3 b	76.3	76.8	Q***	47.7 a	74.8	75.0
	LA (cm^2)						
	Date				Control		
	May	July	Sept.	Sign.	May	July	Sept.
Pi1	27.3 a	25.4	24.7	NS	20.6 b	25.3	21.8
Wb	25.9 a	20.6 a	26.1 a	Q**	21.4 b	15.7 b	18.8 b
Pe	26.7	20.8	24.9	Q**	28.6	21.3	25.4
Pi2	45.1 a	45.0 a	47.1 a	NS	26.5 b	22.8 b	29.1 b
	SLA ($cm^2 \cdot g^{-1}$)						
	Date				Control		
	May	July	Sept.	Sign.	May	July	Sept.
Pi1	135.4 a	85.8 a	82.3	Q***	119.4 b	72.0 b	76.6
Wb	135.1	76.7	79.8	Q***	127.6	76.2	78.9
Pe	155.3	85.5 a	83.1	Q***	149.8	74.7 b	80.1
Pi2	145.2 a	88.7 a	95.9	Q***	125.0 b	77.5 b	83.8

[z] Based on 16 leaf samples.
[y] Not significant (NS) or significant quadratic (Q) trend over dates using contrasts at $\alpha = 0.01$ (**) or 0.001 (***).
[x] Least squares means comparison among treatments and controls (lower case) in rows using paired contrasts at $\alpha = 0.05$.

design, with 70 to 90 % shade, was approximately 1.5-times larger than for leaves from trees grown in full sun during each of the same three months. These leaves also had greater SLA (thinner leaves) than the control trees in May and July. The pine trees 1 orchard was less densely shaded (40 to 60% shade), which was reflected in the leaf architecture. Leaf area was greater in leaves collected in May, but there were no differences in LA in July and September when compared to control trees. Similar to leaves from the pine trees 2 orchard, the SLA was greater in leaves collected in May and July from the pine trees 1 orchard. There were no differences in SLA among any of the treatments and their respective controls in September, as the leaf samples were extremely variable in SLA. The windbreak orchard design resulted in greater LA for all months tested when compared to its control. This increase in LA may have been due to afternoon shading provided by the oak tree borders. However, the SLA of leaves from the windbreak orchard was not different from its control (Table 1). This indicates that even though there were differences in LA due to the windbreak treatment, the leaves were as thick as the leaves from trees grown in full sun (control). There appeared to be no effect on LA due to the pecan tree canopy (pecans), though in July the SLA was higher than the control. The SPAD measurements did not demonstrate any specific trend in response to shaded or non-shaded treatments in terms of leaf greenness (Table 1).

Shaded orchards experienced reductions in light interception and Pn. Photosynthesis (Table 2) and leaf temperature (Table 3) under the dense pine tree canopy (pine trees 2) were both reduced due to shading. Sylvertsen (1984) reported that citrus trees under shade treatments had higher mid-day Pn due to a decrease in leaf temperature. However, leaves from the pine trees 2 orchard did not reach the suggested light saturation point for citrus leaves of 600-700 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Jifon and Syvertson, 2001; Syvertsen and Albrigo, 1980). Hence, satsuma trees in the pine trees 2 orchard were more severely shaded than those used in the experiment conducted by Syvertsen (1984). Even though leaves reached the light saturation point reported by Syvertsen (1984) in the orchard interplanted with pecans, Pn was reduced compared to the control. The same was true for the pine trees 1 orchard in May (Table 3). Trees were only shaded for one growing season in the study by Sylvertsen (1984), whereas the shaded treatments in the present study had been shaded throughout their entire growth and development. Photosynthesis was reduced in May and July in the pine trees 1 orchard (Table 2), but not in September when light interception was similar to control trees when the Pn measurements were taken (Table 3). There were no differences in Pn between the windbreak orchard and the control trees, which had the same amount of light interception as the control (Table 2, Table 3). There were some differences in Pn due to quadrant (direction) in the pecan and windbreak orchards, which likely resulted from different levels of light interception (Table 2, Table 3). There were no specific trends in the differences for stomatal conductance (Table 2).

Canopy temperature was affected by only one orchard design during a freeze event (Table 4). During a severe freeze event that took place during December 27-29, 2010, only satsuma trees under a dense pine tree canopy (pine trees 2), which provided some insulation from the cold temperatures, had higher canopy temperatures when compared to the open field control (Table 4). No other orchard cover provided an insulating effect during this particular freeze.

Satsuma fruit quality was affected by orchard design treatments. Fruit weight was reduced on trees interplanted with either pecans or the dense pine tree canopy (pine trees 2) (Table 5). Heavy shading provided by the dense pine tree canopy greatly affected the fruit size in terms of weight, length, and width. Fruit weight was 108.2 g in the pine trees 2 orchard compared to 159.4 g from the

Table 2. Influence of orchard design on 'Owari' satsuma mandarin photosynthesis and stomatal conductance for treatments compared to their respective controls, south Mobile County, AL, 2010.[z]

	Photosynthesis ($\mu mol \cdot m^{-2} \cdot s^{-1}$)							
	Date				Direction[y]			
Treatment	May	July	Sept.	Significance[x]	East	North	South	West
Pine Trees 1	8.68 b[w]	4.29 b	12.12	Q**	7.99 b	8.62	8.44 b	8.40 b
Control	11.80 a	8.76 a	12.59		11.46 a	9.82	11.40 a	11.52 a
Windbreak	10.55	10.9	9.45	Q**	10.82 A[v]	10.59 A	10.46 A	9.37 bB
Control	9.95	10.81	9.99		9.89	10.45	9.68	10.99 a
Pecans	7.98 b	13.04 b	11.29	NS	7.88 bB	10.77 bA	12.13 A	12.30 A
Control	12.41 a	14.11 a	12.83		12.83 a	13.04 a	13.23	13.37
Pine Trees 2	5.64 b	8.97 b	5.31 b	Q*	6.98 b	5.86 b	6.11 b	7.59 b
Control	11.02 a	14.98 a	10.90 a		12.40 a	12.18 a	12.84 a	11.76 a

	Stomatal conductance ($mmol \cdot m^{-2} \cdot s^{-1}$)							
	Date				Direction			
Treatment	May	July	Sept.	Significance	East	North	South	West
Pine Trees 1	0.12 b	0.16	0.24	L***	0.18 b	0.18	0.17 b	0.16 b
Control	0.16 a	0.27	0.27		0.23 a	0.20	0.23 a	0.28 a
Windbreak	0.09	0.14	0.14	Q**	0.14 aA	0.13 A	0.13 A	0.09 B
Control	0.11	0.13	0.10		0.08 b	0.13	0.11	0.13
Pecans	0.13	0.24	0.24 a	NS	0.22 a	0.19	0.21	0.20 a
Control	0.14	0.20	0.15 b		0.15 b	0.18	0.17	0.16 b
Pine Trees 2	0.09	0.13	0.14	L***	0.14 A	0.09 B	0.11 bA	0.14 A
Control	0.10	0.17	0.14		0.14	0.13	0.15 a	0.11

[z] Based on 16 leaf samples from each date. Location by date and location by direction interactions were significant at $\alpha = 0.05$.
[y] Based on four leaf samples per each direction.
[x] Not significant (NS) or significant linear (L) or quadratic (Q) trend over dates using contrasts at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***).
[w] Least square means comparison between locations and controls (lower case) in columns using paired contrast at $\alpha = 0.05$.
[v] Least square means comparison among directions (upper case) in rows using paired contrasts at $\alpha = 0.05$.

Table 3. Influence of orchard design on 'Owari' satsuma mandarin leaf temperature and light interception for treatments compared to their respective controls, south Mobile County, AL, 2010.[z]

	Leaf temperature (°C)							
	Date				Direction[y]			
Treatment	May	July	Sept.	Significance[x]	East	North	South	West
Pine Trees 1	36.09 b[w]	30.18 b	37.49	Q***	34.39 b	34.54 b	34.83 b	34.58 b
Control	38.86 a	33.50 a	37.67		36.82 a	36.42 a	36.80 a	36.69 a
Windbreak	41.41	39.18	38.91	Q***	39.57 B[v]	39.58 B	39.85 B	40.35 A
Control	40.21	39.58	40.35		40.43	40.01	39.99	39.74
Pecans	38.05 b	37.37	36.05 b	Q*	35.47 bC	37.34 bB	37.98 bA	37.85 bAB
Control	41.13 a	37.85	41.50 a		40.20 a	39.92 a	40.14 a	40.38 a
Pine Trees 2	34.11 b	35.83 b	33.69 b	NS	34.66 b	34.39 b	34.31 b	34.81 b
Control	40.20 a	40.56 a	40.52 a		40.16 a	40.21 a	40.38 a	40.97 a
	Light interception ($\mu mol \cdot m^{-2} \cdot s^{-1}$)							
	Date				Direction			
Treatment	May	July	Sept.	Significance	East	North	South	West
Pine Trees 1	1165.62 b	115.75 b	1174.50	Q***	768.75 b	836.92 b	891.83 b	777.00 b
Control	1949.25 a	712.87 a	1423.94		1372.67 a	1393.17 a	1362.50 a	1319.75 a
Windbreak	918.62	1266.69	1359.69	Q***	1196.42 AB	1279.17 A	1257.75 AB	993.33 B
Control	941.25	1286.00	1232.94		1154.00	1205.75	1161.50	1092.33
Pecans	854.19 b	910.94 b	1016.44 b	NS	314.50 bC	893.67 bB	1346.67 bA	1153.92 A
Control	1341.69 a	1627.50 a	1642.25 a		1550.75 a	1565.92 a	1583.92 a	1448.00
Pine Trees 2	365.19 b	215.06 b	171.69 b	NS	291.92 bA	98.08 bB	80.92 bB	531.67 bA
Control	1656.75 a	1545.56 a	1772.94 a		1622.75 a	1703.5 a	1658.17 a	1649.25 a

[z] Based on 16 leaf samples from each date. Location by date and location by direction interactions were significant at $\alpha = 0.05$.
[y] Based on four leaf samples per each direction.
[x] Not significant (NS) or significant linear (L) or quadratic (Q) trend over dates using contrasts at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***).
[w] Least square means comparison between locations and controls (lower case) in columns using paired contrast at $\alpha = 0.05$.
[v] Least square means comparison among directions (upper case) in rows using paired contrasts at $\alpha = 0.05$.

Table 4. Influence of various 'Owari' satsuma mandarin orchard designs on the minimum canopy temperature compared to their respective controls during a severe freeze event, December 27-29, 2010.

Orchard design	Minimum temperature (°C)	
	Treatment[z]	Control[y]
Pine Trees 1	-6.17	-6.29
Windbreak	-6.01	-5.56
Pecans	-6.29	-6.04
Pine Trees 2	-5.42 b[x]	-6.60 a

[z] Based on one data logger placed approximately 1.5 m high in the canopy of four trees.
[y] Based on one data logger placed approximately 1.5 m high in an adjacent open field orchard.
[x] Least square means comparison among treatment and controls (lower case) in rows using paired contrast at $\alpha = 0.05$.

control trees. This reduction in fruit size corresponds with that reported for orange, but was different from results reported for grapefruit when fruit were heavily shaded (Jifon and Syvertsen, 2001). Shade from both orchards interplanted with pine trees (pine trees 1 and 2) resulted in satsuma fruit with reduced rind thickness (Table 5), which is a desirable characteristic. These results for rind thickness were consistent with the results reported by Yen and Lin (1966). Juice weight and juice volume were reduced only on the orchards that yielded smaller fruit (pecans and pine trees 2) (Table 5). There were no differences in external peel color due to shading provided by either pine tree canopy treatment (Table 6). Results reported from the present study are not consistent with previous studies of shaded satsuma trees (Ono and Iwagaki, 1987) and grapefruit (Jifon and Syvertsen, 2001). However, the windbreak and pecan orchard designs did alter external peel color when compared to their respective controls (Table 6). With the exception of internal fruit color, canopy orientations (quadrants) did not influence fruit quality characteristics (Table 6). Satsuma fruit harvested from the southern quadrant, which was similar to fruit from the western quadrant, were more advanced in terms of internal color. This is likely due to increased light and temperature throughout the day (Table 3). Internal fruit from fruit grown under pine tree canopies (pine trees 1 and 2) was darker orange in color than that in the respective controls (Table 6). Satsuma fruit from the windbreak control orchard had darker internal color in comparison to the windbreak orchard treatment. Interestingly, the dense pine tree canopy (pine

Table 5. Influence of orchard design on 'Owari' satsuma mandarin fruit weight, length, width, rind thickness, juice volume, and juice weight for treatments compared to their respective controls, south Mobile County, AL, 2010.[z]

Treatment	Weight (g)	Length (mm)	Width (mm)	Rind thickness (mm)	Juice volume (mL)	Juice weight (g)
Pine Trees 1	117.8	49.7 b[y]	64.6	3.0 b	45.6	46.4
Control	137.8	55.8 a	68.0	3.8 a	48.6	49.3
Windbreak	162.1	57.2	71.2	3.2	68.9	70.3
Control	150.8	57.2	68.6	3.1	60.7	62.6
Pecans	141.7 b	57.4	67.3 b	3.7	47.8 b	48.7 b
Control	197.6 a	59.7	74.7 a	3.1	73.6 a	75.4 a
Pine Trees 2	108.2 b	49.0 b	62.3 b	2.2 b	47.6 b	48.4 b
Control	159.4 a	59.7 a	70.2 a	3.6 a	59.7 a	60.7 a

[z] Based on 16 fruit samples. Only location was significant at $\alpha = 0.05$.
[y] Least square means comparison between locations and controls (lower case) in columns using paired contrast at $\alpha = 0.05$.

Table 6. Influence of orchard design on 'Owari' satsuma mandarin external hue (h°) and internal hue (h°) angles for treatments compared to their respective controls, south Mobile County, AL, 2010.[z]

Treatment		Control	Direction[x]	
		External h°[y]		
Pine Tree 1	65.8	65.9	East	74.84
Windbreak	79.8 b[w]	87.6 a	North	73.81
Pecans	83.0 a	70.2 b	South	75.83
Pine Tree 2	74.5	73.0	West	75.39
		Internal h°		
Pine Tree 1	61.1 b	66.1 a	East	63.0 B[v]
Windbreak	66.6 a	62.6 b	North	62.8 C
Pecans	64.9	64.6	South	64.2 A
Pine Tree 2	59.4 b	62.5 a	West	63.7 AB

[z] Based on 16 fruit samples.
[y] Measured in CIELAB. h° = hue angle (0° = red-purple, 90° = yellow, 180° = bluish-green, 270°= blue).
[x] Based on four fruit samples per direction.
[w] Least square means comparison between locations and controls (lower case) in rows using paired contrast at $\alpha = 0.05$.
[v] Least square means comparison among directions (upper case) in columns using paired contrasts at $\alpha = 0.05$. NS is not significant.

Table 7. Influence of orchard design on 'Owari' satsuma mandarin soluble solids concentration (SSC), total acidity (TA), SSC:TA, pH, and vitamin C for treatments compared to their respective controls, south Mobile County, AL, 2010.[z]

Treatment	SSC (%)	TA (%)	SSC:TA	pH	Vitamin C ($mg \cdot 100g^{-1}fw$)
Pine Trees 1	10.2 a[y]	0.95	10.9	3.8	23.22
Control	9.8 b	0.95	10.4	3.8	24.22
Windbreak	10.0 a	1.09 a	9.3	3.8	24.47 a
Control	9.1 b	0.98 b	9.4	3.8	20.78 b
Pecans	8.3 b	0.84 b	10.0	3.9 a	22.07
Control	9.3 a	0.93 a	10.1	3.7 b	23.04
Pine Trees 2	9.9	0.91	11.0 a	3.7 b	23.07 b
Control	9.7	0.96	10.2 b	3.9 a	26.10 a

[z] Based on 16 fruit samples. Only location was significant at $\alpha = 0.05$.
[y] Least square means comparison between locations and controls (lower case) in columns using paired contrast at $\alpha = 0.05$.

trees 2) did not affect satsuma SSC, while the pine trees 1 orchard design had higher SSC (10.2%) compared to the control (9.8%) (Table 7). These results are in contrast to the results reported for 'Ruby Red' grapefruit and 'Hamlin' orange, in which shaded fruit had lower SSC than fruit grown in full sun (Jifon and Syvertsen, 2001). Satsuma fruit harvested from the windbreak orchard treatment had higher SSC (10%) when compared to the control (9.1%). Only fruit from the densely shaded satsuma trees from the pine trees 2 orchard treatment showed differences in fruit SSC:TA ratio, with 11:1 compared to 10:1 for the control. The dense pine tree canopy design (pine trees 2) reduced fruit vitamin C concentration (Table 7). Results from the current study are consistent with previously reported results where fruit grown in shade had lower concentrations of vitamin C (Winston, 1948).

Conclusions

Orchard designs used for freeze protection affected 'Owari' satsuma mandarin plant physiology, leaf architecture, and fruit quality as a result of shading. Photosynthesis and production may be enhanced with short-term shade (Jifon and Syvertsen, 2001; Syvertsen and Albrigo, 1980), however, long-term shading reduces Pn and alters leaf architecture (i.e. LA and SLA). Fruit quality characteristics such as rind thickness, fruit weight, and soluble solids concentration may be enhanced with shaded orchard designs. In the present study, only canopy temperature for satsuma mandarin trees under the dense pine tree canopy was higher than the corresponding control trees planted in an adjacent open field during a freeze event. Warmer temperatures experienced under such canopies may result in less freeze damage and provide adequate environmental conditions conducive for damaged trees to recover faster than others. However, the potential effects on physiology, leaf architecture, fruit quality, and yield should also be considered when choosing an orchard design.

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