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# TRENDS IN FRUIT YIELD AND QUALITY, SUSCEPTIBILITY TO POWDERY MILDEW (*SPHAEROTHECA MACULARIS*), AND APHID (*APHIS GOSSYPII*) INFESTATION FOR SEVEN STRAWBERRY CULTIVARS GROWN WITHOUT PESTICIDES IN A PASSIVELY VENTILATED GREENHOUSE USING PINEBARK AS SOILLESS SUBSTRATE

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*Abstract.* **Strawberry (*Fragaria × ananassa* Duch.) cultivars are almost exclusively bred for field production, and limited information on their performance under protected cultivation in the U.S. is available. Seven strawberry cultivars were grown in a passively ventilated greenhouse in north-central Florida to evaluate their fruit yield and quality potential, and susceptibility to powdery mildew and aphid infestation. In October, plug transplants were planted at a density of 22 plants per m² in Polygal® troughs filled with pine bark. No insecticides or fungicides were used, but the biological control agents *Aphidius colemani* Viereck and *Lysiphlebus testaceipes* Cresson were used for controlling cotton aphids (*Aphis gossypii* Glover), and *Neoseiulus californicus* McGregor for controlling two-spotted spider mites (*Tetranichus urticae* Koch.). Early season yield (November-January), from FL97-39 was significantly greater than that of 'Strawberry Festival', 'Sweet Charlie' and 'Earlibrite', but not significantly different than that obtained from 'Carmine', 'Camarosa' and 'Treasure'. Total season yields (November-March) from FL97-39 and 'Carmine' were significantly higher than 'Camarosa' and 'Sweet Charlie', but not significantly different from 'Strawberry Festival', 'Treasure', and 'Earlibrite'. Percent marketable yield of 'Treasure' was higher than 'Camarosa' and 'Sweet Charlie', but not significantly different from the other cultivars. FL97-39 was very highly susceptible to powdery mildew (*Sphaerotheca macularis*), 'Earlibrite' had high susceptibility, whereas the rest of the cultivars showed moderate susceptibility. Aphid infestations were most severe in 'Sweet Charlie' and 'Carmine', whereas significantly lower number of aphids was observed on the other cultivars. Fruit quality variables such as firmness, soluble solids content, titratable acidity, and ascorbic acid concentration were excellent during the early part of the season (November-January), but declined during the latter part of the season (February-March), with the exception of fruit color, which was more red during the mid-season (January-February) compared to the early and later part of the season. Thus, Florida strawberry cultivars such as FL97-39, 'Carmine', 'Treasure', and 'Strawberry Festival' evaluated in this study performed well under protected culture in north-central Florida, however, cultivar selection should be made after considering susceptibility to fungal diseases and insect pests.**

In Florida, strawberries (*Fragaria × ananassa* Duch.) are grown commercially on approximately 6,900 acres, with more than 95% of the acreage located in the Plant City area of west-central Florida. The mild winter climate of the region allows Florida growers to produce strawberries from mid-November to the end of January, a period when strawberry production in California is low and market prices are high.

In recent years, the Florida strawberry industry has been facing a number of challenges that could, in the near future, make it difficult for Florida strawberry growers to remain competitive. Methyl bromide, used as a soil fumigant by the majority of the strawberry growers, is scheduled to be phased-out in the U.S. by 2005 (U.S. EPA, 2002). So far, no alternative has been identified with an efficacy similar to that of methyl bromide in killing weed seeds, nematodes, and other soil-borne pathogens. For Florida strawberry producers, the most promising alternative to methyl bromide is a combination of 1,3-dichloropropene + 17% chloropicrin. However, this alternative may reduce strawberry yields by 15 percent (VanSickle, 2000). The sap beetle (*Stelidota geminata*), which has been quite inconspicuous until now, has emerged as a potentially serious pest of the strawberry crop, especially in the latter half of the season (Chip Hinton, Fla. Strawberry Growers Assoc., personal communication). Other problems faced by the strawberry industry include severe cold weather during winter, restrictions on water usage for freeze protection, high labor costs, and urban sprawl.

In the context of these difficulties faced by the Florida strawberry industry, soilless cultivation under protective structures could provide a viable alternative for strawberry production by enhancing early yield and quality of strawberries and eliminating the need for methyl bromide. Specialized trough systems designed for protected strawberry culture can be raised or lowered for more efficient harvesting, which reduces labor costs significantly. These growing systems can accommodate up to 244,444 plants per ha (104,544 plants per acre), approximately five times more plants per unit area compared to conventional field culture, making it possible to produce greater yields on a smaller surface area. Strawberries grown under protected culture are cleaner since they do not come in contact with soil or splashing water. They can also be easily harvested with the stem intact for specialty marketing. The greenhouse vegetable industry in Florida is growing every year and is presently estimated at 40 ha (Hochmuth, 2003), with only 0.5 ha of strawberries under protected culture (Tyson,

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2001). However, the area under protected strawberry culture may increase as growers seek alternative methods to produce a profitable strawberry crop. Although protected culture can overcome most of the problems that are generally associated with field production, it may also provide a more desirable environment for powdery mildew (*Sphaerotheca macularis*). Moreover, insect pests such as two-spotted spider mites (*Tetranichus urticae* Koch.), cotton aphids (*Aphis gossypii* Glover), and thrips (*Frankliniella* spp.) may cause substantial yield losses in protected strawberry culture. However, biological control methods can be used more effectively to control these pests under a protected environment, which can potentially enable strawberry growers to market their product as 'pesticide-free'.

The success of conventional as well as protected strawberry production often depends on the selection of appropriate cultivars. Presently, the most popular strawberry cultivars used in Florida's annual hill culture are 'Strawberry Festival', 'Camarosa', 'Earlibrite', 'Treasure', 'Carmine', and 'Sweet Charlie'. These cultivars were bred for field production and information on their performance under protected culture is limited. Also, the susceptibility of these cultivars to fungal diseases and insect pests when grown under protected culture needs to be established. Therefore, the objective of our study was to test the fruit yield and quality potential of seven strawberry cultivars grown under protected culture in north-central Florida, and to evaluate the susceptibility of these cultivars to powdery mildew and insect pests under a 'pesticide-free' program.

## Materials and Methods

On 15 Sept. 2002, greenhouse-grown plug transplants of seven strawberry cultivars were conditioned (25 °C day/10 °C night temperature, 9-h photoperiod for 14 d) in a walk-in growth chamber since low temperatures and short photoperiod are known to interact in inducing early flowering in strawberry (Heide, 1976) and may increase early yield from plug transplants (Bish et al., 2002). The strawberry cultivar treatments were 'Strawberry Festival', 'Earlibrite', 'Carmine', FL-97-39, 'Treasure', 'Sweet Charlie', and 'Camarosa'.

On 2 Oct. 2002, the conditioned plug plants were transplanted in a passively ventilated greenhouse located in Gainesville, Fla. Specialized Hanging Bed-Pack® troughs (10 cm bottom width × 12 cm wall height, with 5 cm diameter planting holes) (Polygal Industries, Ramat Hashofet, Israel) were used as growing containers. Troughs were suspended 1.8 m above the ground and spaced 50 cm apart. Pine bark (2.54 $cm^2$ sieved) (Elixon Wood Products, Inc., Starke, FL) was used as soilless substrate. Plants were irrigated 8 to 10 times daily with a drip tape (5-cm emitter spacing, 0.24 GPH discharge) (Chapin Watermatics, Inc., Watertown, NY). Plants received nutrients with every irrigation and all treatments were provided with the same concentration and volume of nutrient solution throughout the growing season. The nutrient solution was formulated by making modifications to the hydroponic tomato formula described by Hochmuth and Hochmuth (2001). The concentration of elements in the final solution was: N = 65 $mg \cdot L^{-1}$ ($NO_3$-N = 55 $mg \cdot L^{-1}$, $NH_4$-N = 10 $mg \cdot L^{-1}$), P = 50 $mg \cdot L^{-1}$, K = 85 $mg \cdot L^{-1}$, Ca = 95-100 $mg \cdot L^{-1}$, Mg = 40 $mg \cdot L^{-1}$, S = 56 $mg \cdot L^{-1}$, Fe = 2.8 $mg \cdot L^{-1}$, B = 0.6 $mg \cdot L^{-1}$, Mn = 0.4 $mg \cdot L^{-1}$, Cu = 0.1 $mg \cdot L^{-1}$, Zn = 0.2 $mg \cdot L^{-1}$, Mo = 0.03 $mg \cdot L^{-1}$.

Treatments were arranged using a randomized complete block design, with nine plants per plot planted at a density of 22 plants per $m^2$ (2.2 plants per $ft^2$) and three plots per cultivar. No fungicides or insecticides were used throughout the season. *Neoseiulus californicus* predatory mites (Biotactics, Inc., Perris, CA) were released for controlling two-spotted spider mites. Parasitic wasps *Aphidius colemani* (IPM Laboratories, Locke, NY and Koppert Biological Systems, Inc., Romulus, MI) and *Lysiphlebus testaceipes* were released at regular intervals to control aphids. Bumble bees (*Bombus terrestris* L.) (Koppert Biological Systems) were introduced into the crop 14 d after transplanting (DAT) for achieving good pollination.

*Data collection and analysis.* Fruit with 80% red color development were harvested at 4- to 5-d intervals. Fruit that weighed more than 10 g (0.35 oz) and were not deformed or diseased were considered marketable. For each plot, the number of fruit and fruit weight were recorded for marketable and non-marketable fruit. The presence or absence of powdery mildew was recorded once a week by a random sampling of 10 leaflets per plot. The infestation of aphids was estimated by taking weekly counts of adults and nymphs on 10 randomly selected leaflets from each plot.

From 23 Dec. 2002 to 26 Mar. 2003, representative weekly samples of five fruit were collected from each plot for measurement of fruit quality. Individual fruit firmness based on the resistance of the fruit flesh to a 3-mm deformation by a probe was measured in newtons (N) at the fullest part of the fruit, perpendicular to the long axis, with an Instron Automated Materials Tester (Model 4411, Instron Corp., Canton, MA). A 50-kg load cell was used for firmness determinations. Crosshead speed was 50 $mm \cdot min^{-1}$ and an 11-mm diameter convex tip Magness-Taylor type probe was used.

Replicate samples of five fruit per treatment were homogenized in a laboratory blender for 2 min. The homogenates were centrifuged at 17,600 × $g_n$ for 20 min, filtered through cheesecloth, and the soluble solids content (SSC) in the filtrate was determined with an Abbé refractometer. Aliquots (6.00 g) of the filtered juice were diluted with 50 mL distilled water and titratable acidity was determined by titration with 0.1 n NaOH to an end point of pH 8.2 with an automatic titrimeter (Titrimiter II, Fisher Scientific Co., Pittsburgh, PA). The results were converted to percent citric acid [(mL NaOH × 0.1 n × 0.064 meq per 6.00 g of juice) × 100].

For total ascorbic acid (AA) analysis, 3 g of homogenized fruit tissue were combined with 100 mL of a mixture of 6% metaphosphoric acid and 2 N acetic acid. The fruit-acid mixture was centrifuged at 17,600 × $g_n$ for 20 min. The analysis was performed by the dinitrophenylhydrazine method of Terada et al. (1978). The concentration of total AA was calculated from absorbance measured at 540 nm using a standard curve.

The surface color of five fruit per replicate was measured with a hand-held tristimulus reflectance colorimeter (Model CR-200b, Minolta Corp., Ramsey, NJ). Color was recorded using the CIE-L*a*b* uniform color space (CIE-Lab), and numerical values of a* and b* were converted into hue angle ($\tan^{-1} b^*/a^*$) and chroma [$(a^{*2} + b^{*2})^{1/2}$].

Statistical differences between treatments and harvest dates were calculated using SAS (SAS Institute, Inc., 1999-2001).

## Results and Discussion

*Early yield.* Fruit were harvested 21 times from 25 Nov. 2002 to 26 Mar. 2003. The first 11 harvests from 25 Nov. to 27 Jan. were considered early yield (Table 1). FL97-39 early yield per plant was significantly greater than 'Strawberry Festival',

Table 1. Early (25 Nov. to 27 Jan.) yield of seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

| Cultivar | Early marketable yield | | | | |
|---|---|---|---|---|---|
| | Average fruit weight (g/fruit) | No. of fruit per plant | Marketable yield (%) | Marketable yield (g/plant) | Marketable yield (12-lb flats/acre) |
| FL 97-39 | 23.1 a | 10.7 ab | 96.6 a | 247.9 a | 4048 a |
| Carmine | 18.0 cd | 12.4 a | 91.2 b | 227.8 ab | 3720 ab |
| Camarosa | 18.3 cd | 10.1 ab | 93.2 ab | 184.5 abc | 3013 abc |
| Treasure | 21.0 b | 8.5 ab | 97.4 a | 180.1 abc | 29.41 abc |
| Earlibrite | 19.0 bc | 7.8 b | 91.2 b | 147.9 bc | 2415 bc |
| Sweet Charlie | 17.1 cd | 8.5 ab | 80.5 c | 143.9 bc | 2350 bc |
| Strawberry Festival | 16.2 d | 7.3 b | 82.4 c | 118.3 c | 1932 c |
| R-square | 0.84 | 0.46 | 0.89 | 0.56 | 0.56 |

Means followed by the same letter within each column are not significantly different according to Duncan's Multiple Range Test, P ≤ 0.05.

'Sweet Charlie' and 'Earlibrite', but not significantly different from 'Carmine', 'Camarosa' and 'Treasure'. The percent marketable yield of FL97-39 was significantly higher than 'Carmine', 'Earlibrite', 'Sweet Charlie', and 'Strawberry Festival' but not significantly different from 'Camarosa' and 'Treasure'. The number of fruit produced per plant was higher for 'Carmine' than for 'Earlibrite' and 'Strawberry Festival' but not significantly different from the rest of the cultivars. FL97-39 average fruit weight was significantly greater than all other cultivars.

*Total yield.* FL97-39 and 'Carmine' total season yields (25 Nov. 2002-26 Mar. 2003) (Table 2) were significantly higher than 'Camarosa' and 'Sweet Charlie', but not significantly different from 'Strawberry Festival', 'Treasure', and 'Earlibrite'. The percent marketable yield of 'Treasure' was higher than that of 'Camarosa' and 'Sweet Charlie' but not significantly different from the rest of the cultivars. The number of fruit produced per 'Carmine' plant was significantly higher than 'Treasure', 'Earlibrite' 'Camarosa', and 'Sweet Charlie', but not significantly different from FL97-39 and 'Strawberry Festival'. 'Earlibrite', 'Treasure', and FL97-39 average fruit weight was similar, and was significantly higher than 'Strawberry Festival', 'Carmine', and 'Sweet Charlie'.

From Nov. 2002 to Jan. 2003, the minimum temperature in north-central Florida dropped below 0 °C (32 °F) for a total of 36 d, and the strawberry industry lost more than 15% of the early production. On the other hand, the minimum temperatures in the greenhouse where the present study was conducted were maintained at 4.5 °C (40 °F) on days when outside temperatures were below the freeing point (Fig. 1). Although plant growth slows down considerably at 4.5 °C, the adverse effect of the low temperature on strawberry yields under protected culture was much less compared to its effect on the yields of field-grown strawberries. Thus, even though most cultivars evaluated in this study were bred for the mild winter conditions typical of west-central Florida, they produced high early and total yields in the greenhouse during an unusually cold north-central Florida winter.

*Pests and diseases.* Aphid infestation levels were very low at the beginning of October. However, within 45 DAT, the aphid population started increasing rapidly, particularly on 'Sweet Charlie' and 'Carmine' (Fig. 2). By December, the aphid population on 'Sweet Charlie' peaked at 55 aphids per leaflet. Overall, 'Sweet Charlie' and 'Carmine' had the highest aphid infestations, whereas significantly lower levels of aphid infestation were observed on the rest of the cultivars.

*A. colemani* parasitic wasps were released at an average rate of approximately 10 wasps per $m^2$ per week at bi-weekly intervals to control aphids. However, due to one sub-standard shipment that probably lacked viable female wasps, and due to the reduced wasp activity at low temperatures during November and December, a delay in controlling the aphid population occurred. Despite the initial delay, more than 95% of aphids were parasitized by the end of January, and the aphid populations remained at very low levels (<2-3 aphids per plant) until the end of the season. Once the *A. colemani* wasps were estab-

Table 2. Total (25 Nov. to 26 Mar.) yield of seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

| Cultivar | Total marketable yield | | | | |
|---|---|---|---|---|---|
| | Average fruit weight (g/fruit) | No. of fruit per plant | Marketable yield (%) | Marketable yield (g/plant) | Marketable yield (12-lb flats/acre) |
| FL 97-39 | 21.5 a | 24.0 ab | 89.8 ab | 517.2 a | 8445 a |
| Carmine | 18.6 bc | 26.2 a | 89.3 ab | 488.5 a | 7977 a |
| Strawberry Festival | 19.7 b | 22.2 abc | 89.9 ab | 438.3 ab | 7157 ab |
| Treasure | 21.8 a | 19.4 bc | 94.3 a | 423.4 ab | 6913 ab |
| Earlibrite | 22.5 a | 18.0 c | 88.9 ab | 404.5 ab | 6605 ab |
| Camarosa | 19.2 b | 18.0 c | 83.7 bc | 344.3 b | 5622 b |
| Sweet Charlie | 17.6 c | 18.4 c | 80.6 c | 325.6 b | 5317 b |
| R-square | 0.86 | 0.62 | 0.68 | 0.63 | 0.63 |

Means followed by the same letter within each column are not significantly different according to Duncan's Multiple Range Test, P ≤ 0.05.

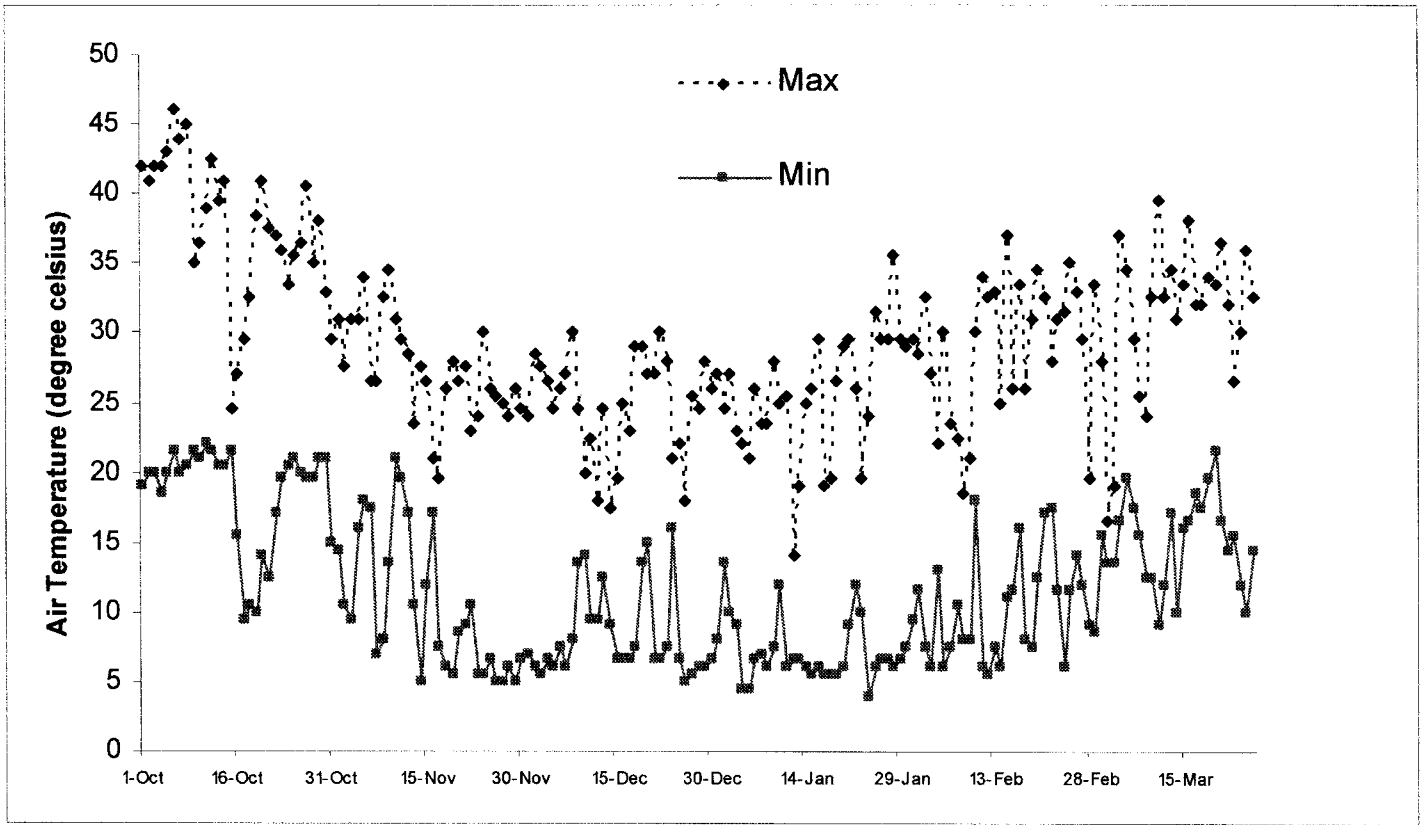


Fig. 1. Maximum and minimum temperatures inside the greenhouse during Oct. 2002 through Mar. 2003 (UF Protected Ag Project, Gainesville, Fla.).

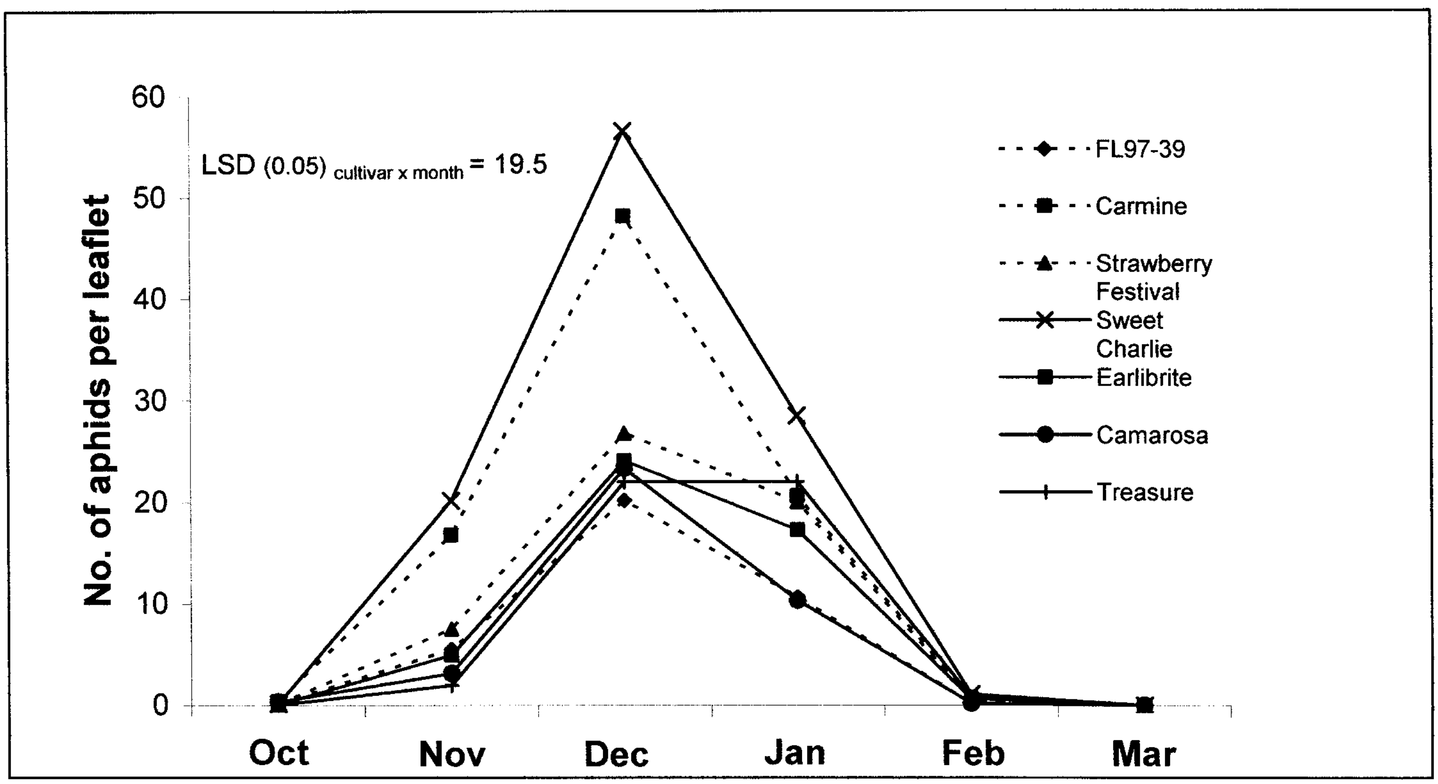


Fig. 2. Monthly changes in aphid (*Aphis gossypii*) infestation for seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

lished in the crop, they were very effective in controlling aphids, however, factors such as air temperature and quality variations among shipments of wasps should be taken into consideration. Purchasing wasps from more than one supplier and making preventive rather than curative releases may result in better control of aphids. Two-spotted spider mites were controlled successfully by making preventive monthly releases of *N. californicus* predatory mites at the rate of approximately 40 mites per $m^2$ per month. Throughout the season, almost no adults of two-spotted spider mites were seen during weekly scouting.

During the fall, there was no incidence of botrytis fruit rot (*Botrytis cineria*). However, powdery mildew, which can significantly reduce marketable yields, infected the leaves, petioles, flowers, and fruit of all cultivars. Moderate to high relative humidity without free moisture combined with low light intensity and low temperatures (15-27 °C) are conducive for the growth of powdery mildew (Xiao, 2001). Incidence of powdery mildew in most cultivars increased from late October to mid-January, and then began decreasing, in some cases sharply, during February and March (Fig. 3). FL97-39 and 'Earlibrite' were very highly and highly susceptible, respectively, whereas the other cultivars were moderately susceptible. Although differences observed in powdery mildew susceptibility could be influenced by the genetic differences among cultivars, the overall trends and severity of powdery mildew incidence during this season may have been amplified by the low temperatures (Fig. 1), high relative humidity without free moisture (Fig. 4), and low light intensity (Fig. 5) from November to the end of January.

The visibility of powdery mildew on the strawberry fruit surface could negatively impact consumer preference. The visibility of powdery mildew was most pronounced on mature fruit of 'Treasure' due to the contrast with the reddish-purple color of the fruit, whereas powdery mildew was least visible on mature fruit of 'Strawberry Festival'. Although fungicides were not applied during this study, sulfur and potassium or sodium bicarbonate, which have a mild toxicity towards beneficial insects, could be used to control powdery mildew.

*Fruit quality.* Fruit firmness (Fig. 6) declined from about 9.5-10.5 N in December to 5.5-6.5 N in March in all cultivars except 'Sweet Charlie', which was less firm and declined from 6.8 to 4.7 N over the season. In strawberry, fruit firmness is believed to be reduced under conditions of increased N nutrition (Mukkun et al., 2001) and high temperatures (Wang and Camp, 2000). In our study, however, the N concentration was relatively low, and the concentrations and quantity of the nutrient solution delivered to the plants was kept constant throughout the season. Therefore, the increased softness of fruit in our study during February and March may be largely attributed to high temperatures rather than nutrient supply.

Soluble solids content levels (Fig. 7) declined through the season, from 9-11% to 3-5%; and TA (Fig. 8) declined from 1.1-1.5% to 0.4-0.7%, except for 'Camarosa', which maintained higher acidity (1.0%) late in the season. Ascorbic acid concentrations (Fig. 9) also declined over the season, from 76.5 mg·100g$^{-1}$ to 70 mg·100g$^{-1}$, but there were no significant differences between cultivars. The reductions in SSC, TA, and AA towards the end of the season may be related to high temperatures during February and March. This is consistent with findings from a previous study conducted by Wang and Camp (2000).

The change in fruit color (Figs. 10 and 11) over the season was more gradual than changes in fruit firmness and chemical composition. However, the color differences among cultivars were more distinct than for other quality traits mea-

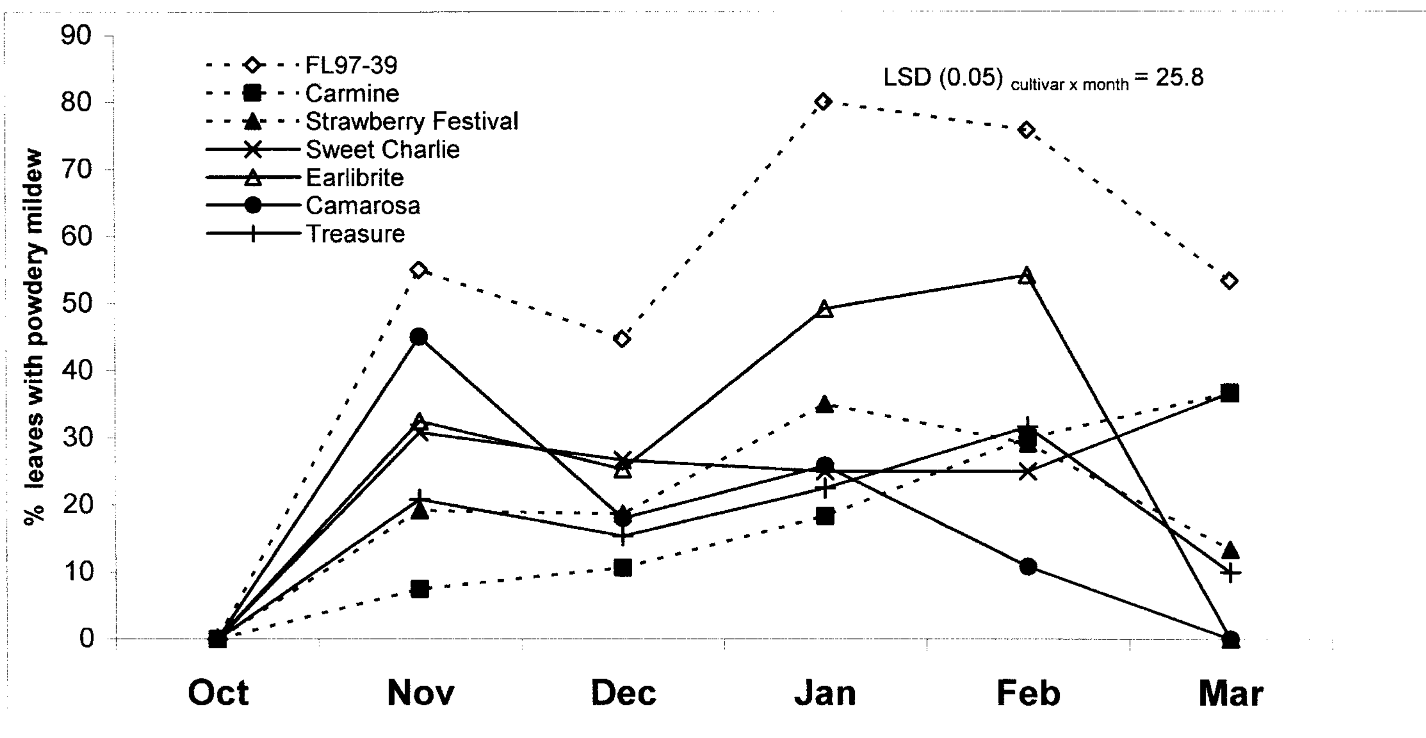


Fig. 3. Susceptibility to powdery mildew (*Sphaerotheca macularis*) for seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

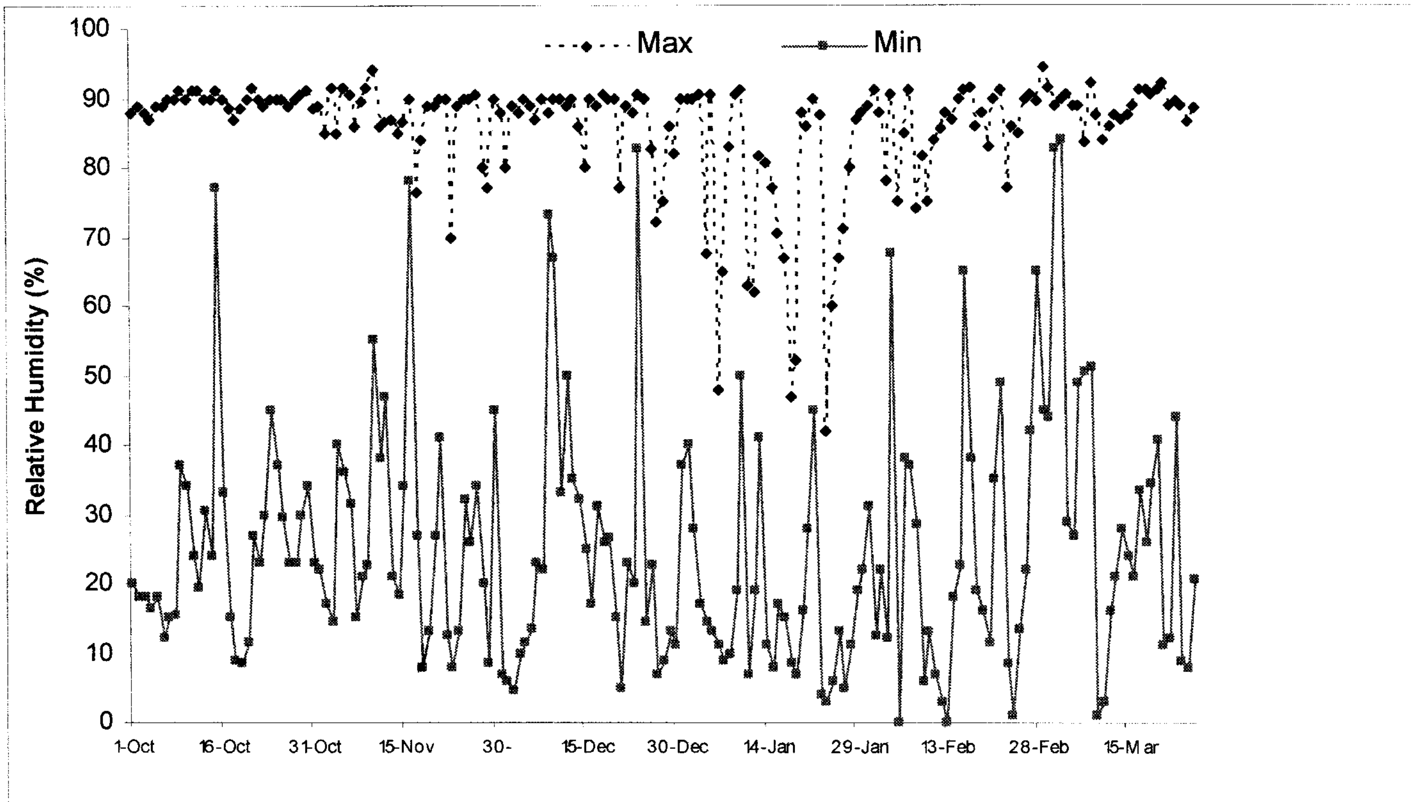


Fig. 4. Maximum and minimum relative humidity inside the greenhouse during Oct. 2002 through Mar. 2003 (UF Protected Ag Project, Gainesville, Fla.).

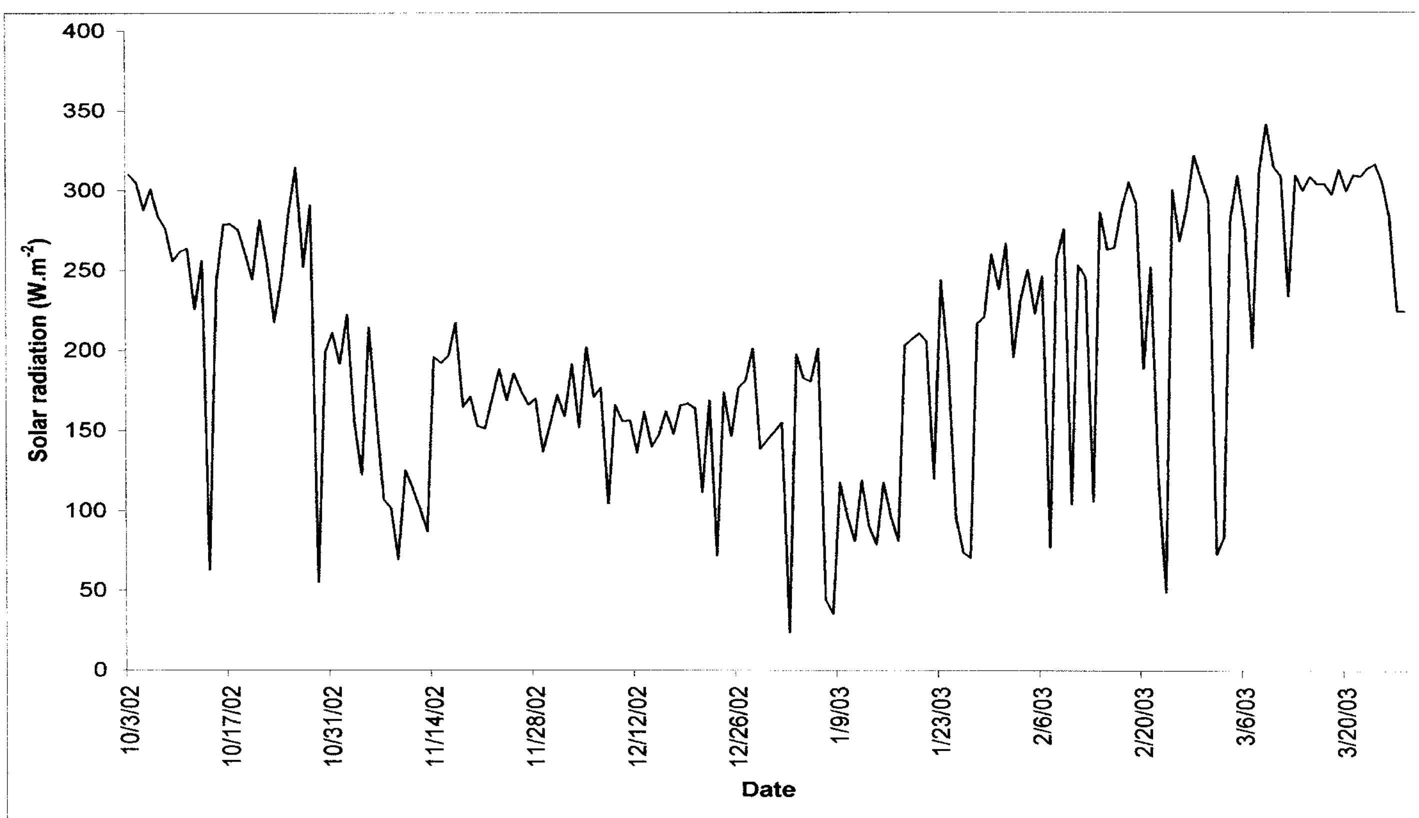


Fig. 5. Solar radiation (daily maximum values) measured inside the greenhouse during Oct. 2002 through Mar. 2003 (UF Protected Ag Project, Gainesville, Fla.).

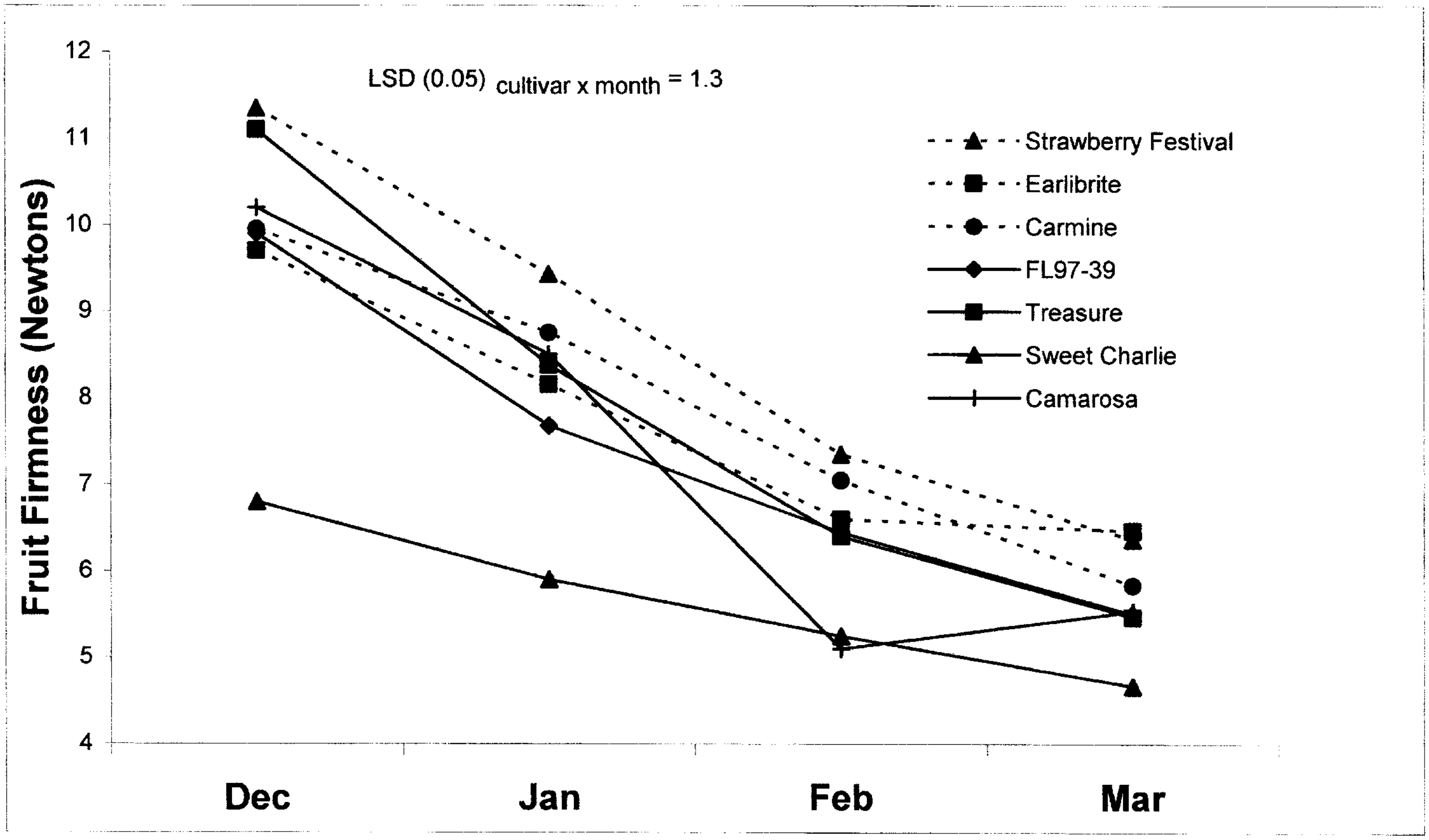


Fig. 6. Monthly changes in fruit firmness (at 3 mm deformation) of seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

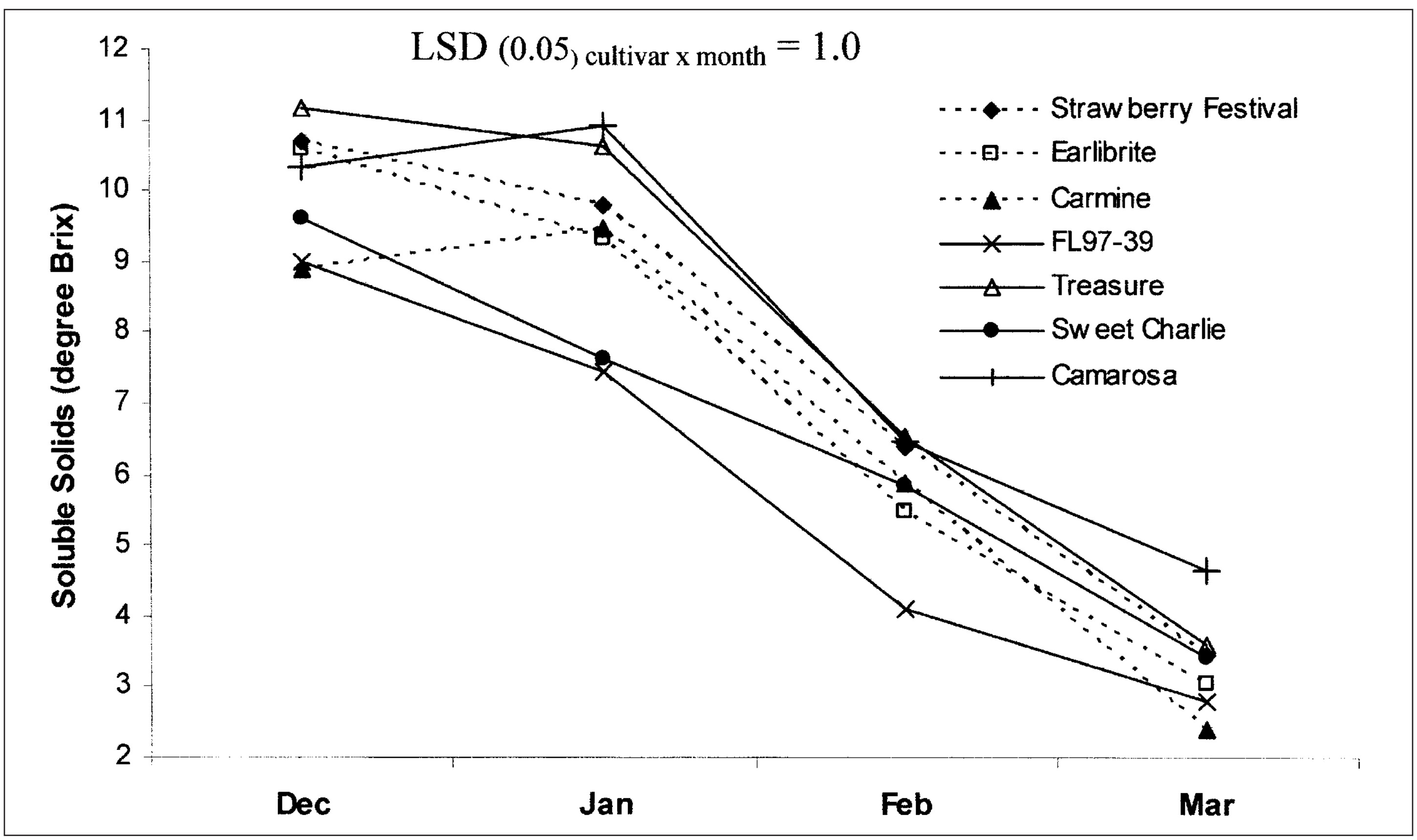


Fig. 7. Monthly changes in soluble solids (°Brix) of seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

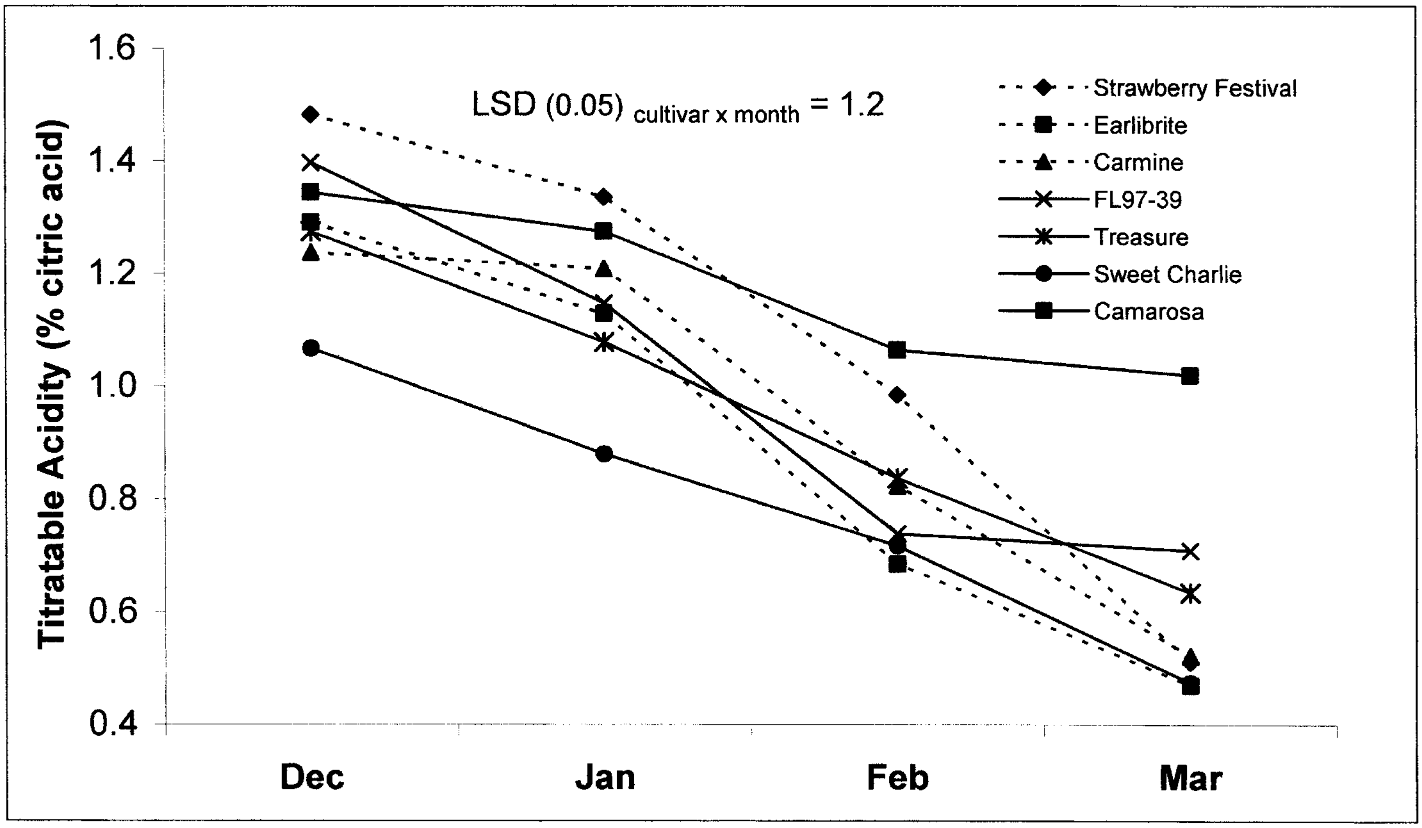


Fig. 8. Monthly changes in titratable acidity (% citric acid) of seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

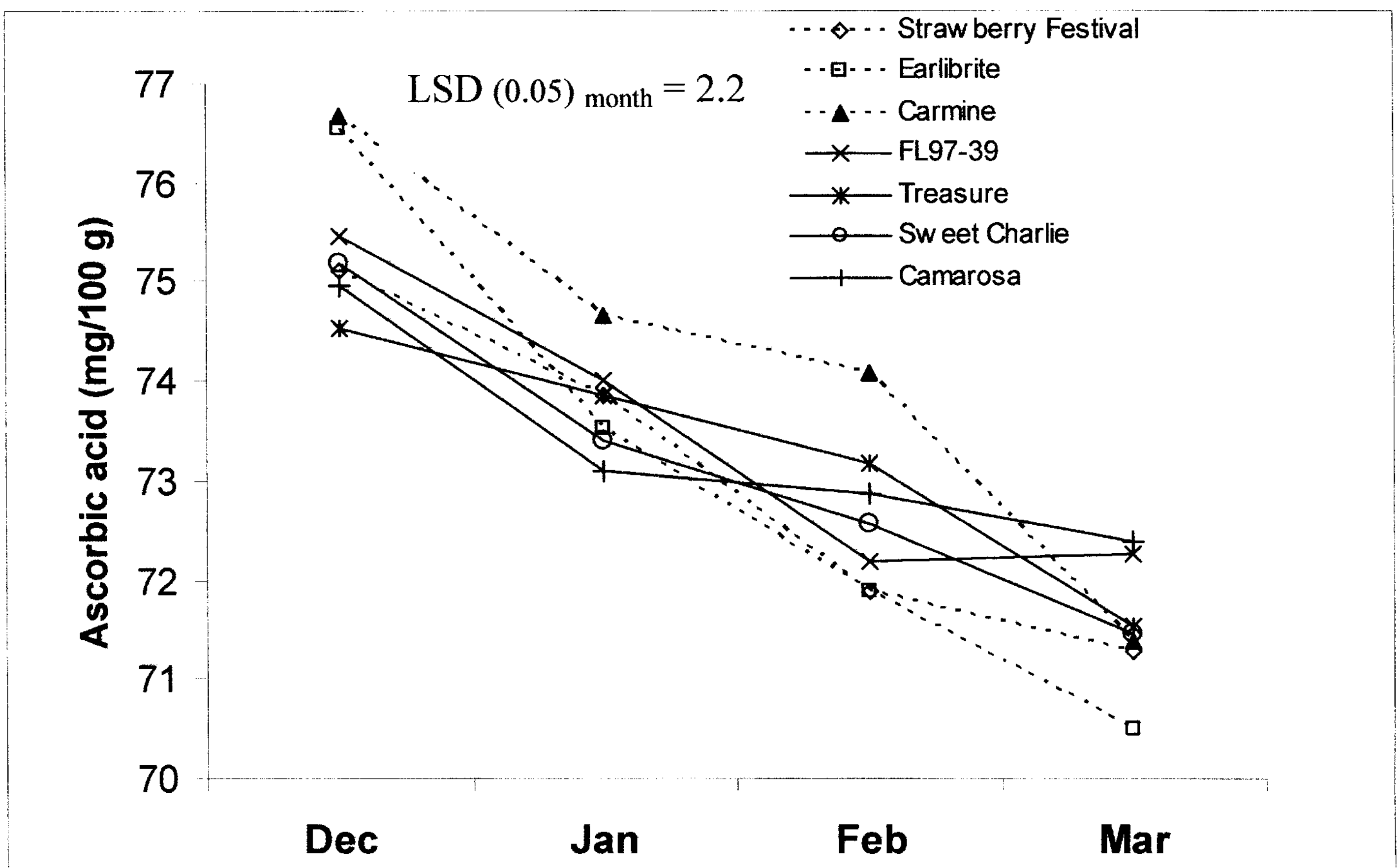


Fig. 9. Monthly changes in ascorbic acid content of seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

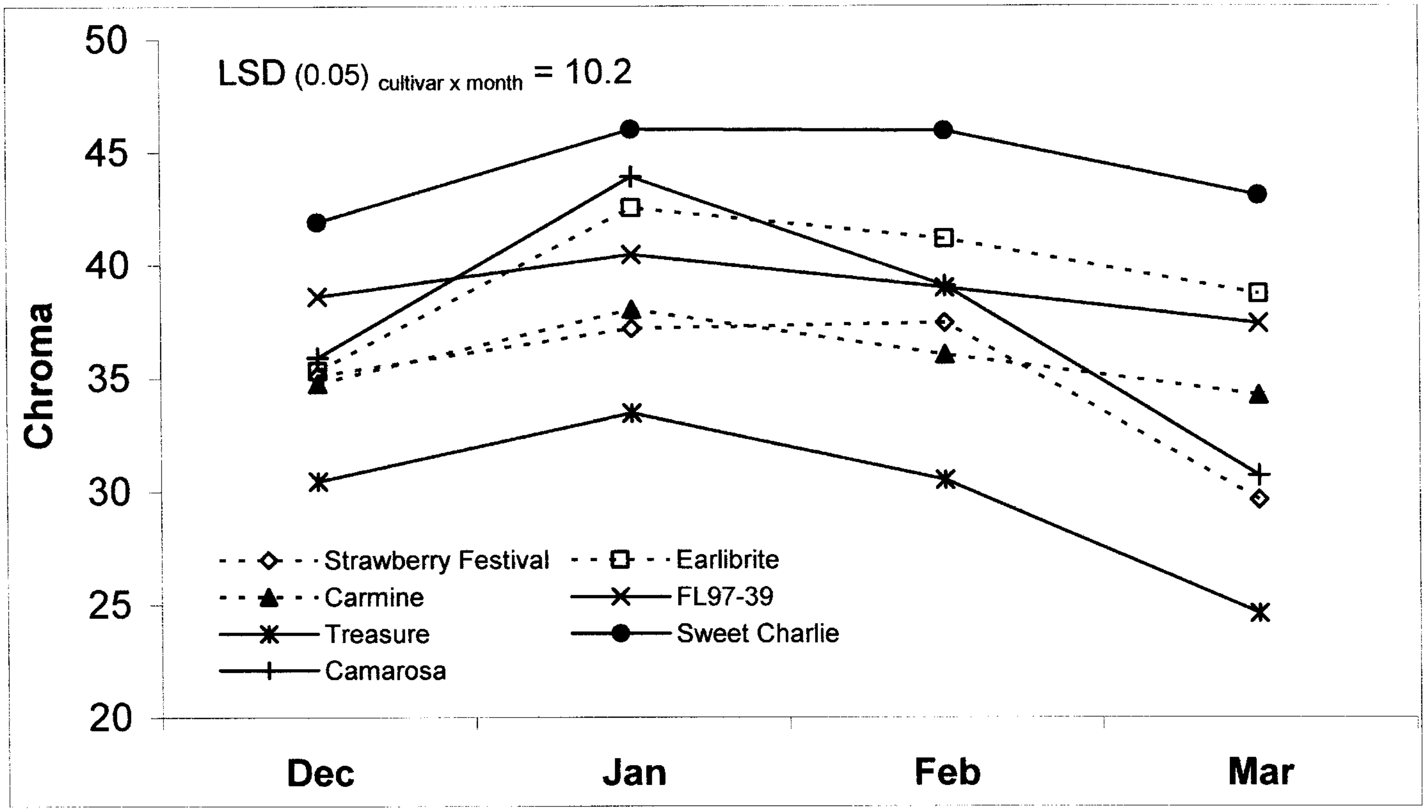


Fig. 10. Monthly changes in fruit color (chroma) of seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

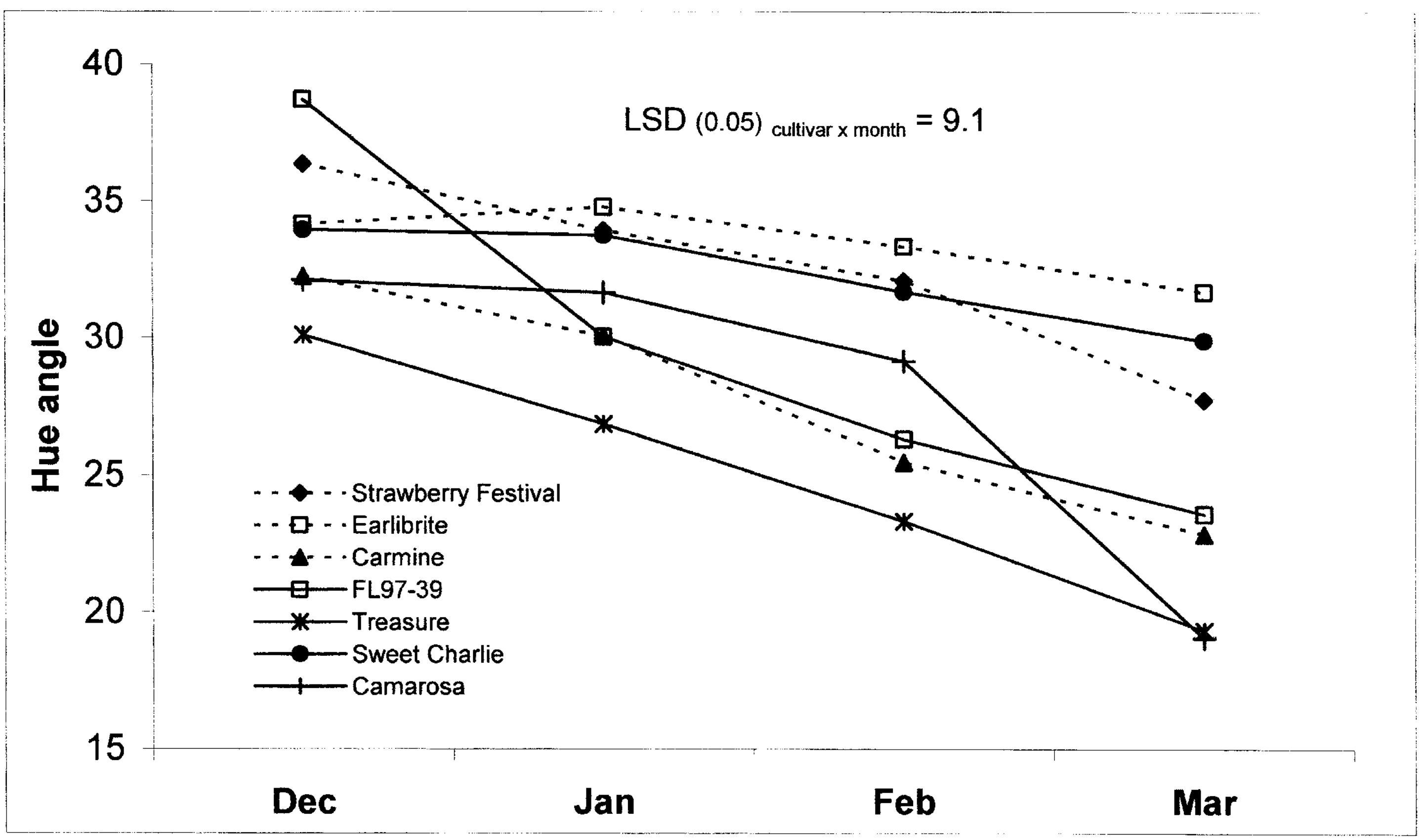


Fig. 11. Monthly changes in fruit color (hue angle) of seven strawberry cultivars grown under protected culture during 2002-03 (UF Protected Ag Project, Gainesville, Fla.).

sured. While fruit of all cultivars became darker red as the season progressed, there was a trend for fruit color to be more of a pure red in the middle of the season (January-February) than either earlier or later. 'Sweet Charlie' fruit were lighter red than the other cultivars while 'Treasure' fruit were darker than the others and more of a reddish-purple.

## Conclusion

When selecting cultivars for protected strawberry cultivation, susceptibility to powdery mildew and aphids should be considered. Of course, the climate (especially the range of temperature and humidity) during the production season plays an important role in the severity of these problems. The choice of cultivar also depends on the desired period for peak production. For protected strawberry cultivation in north-central Florida, a combination of 'Carmine' and 'Treasure', which produced high early yields, along with more steady-yielding cultivars such as 'Strawberry Festival' and 'Camarosa', may be good choices. Although FL97-39 produced high early and total yields, very high susceptibility to powdery mildew makes it less suitable for protected cultivation since it could serve as a source of inoculum and spread the disease to other cultivars that may not otherwise be very susceptible. Aphids can reproduce very rapidly when strawberries are grown under protected culture, and the highest level of aphid infestation was observed in 'Carmine' and 'Sweet Charlie'. Although *A. colemani* are effective in controlling aphids, starting the season with transplants that are free from aphids as well as two-spotted spider mites is critical for obtaining good yields in protected strawberry culture regardless of the cultivars used. Fruit quality as measured by SSC, TA, AA, and firmness was excellent during the early part of the season, however, adjustments in the nutrient solution and environmental factors such as temperature and humidity may need to be made during the latter part of the season when high temperatures may be adversely affecting fruit quality.

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