Figure 10 Horizontal air-flow fan for circulating air in greenhouse.

growers' face can occur in greenhouses, and sometimes the problems can be more serious. Greenhouses afford favorable growing conditions for the plant, and the pests also benefit from favorable environmental conditions. The keys to managing greenhouse crop pests fall into several categories: selecting pest resistant varieties (this pertains to diseases), controlling the environment to reduce diseases (**Figure 10**), constructing the greenhouse to maximize insect exclusion, practicing good sanitation in and around the greenhouse (**Figure 9**) and applying appropriate chemical or manual control measures. Greenhouses present special challenges for pest control, e.g., rapidly growing crop, tall crops, enclosed growing space (special challenges for worker protection), and mostly manual operations for pest control practices. It is critical to stay abreast of preventative measures, rather than to get into situations of crop rescue. More information on pest management is available from the references listed at the end of this guide.

Harvesting and Handling

For maximizing yields and fruit quality, fruits must be harvested at the optimum stage of ripeness. Careful handling and transport from the greenhouse to grading and packing area is very important. Workers must be trained in all aspects of proper harvesting and handling procedures. Fruits for market must be packed in proper boxes which are appropriate for the size of the fruits and properly and attractively labeled.

Finishing Up The Season

Clean Up. Media can be dried out near the end of the season by letting plants draw out the water. Just turn off the irrigation system. It will take four to six days for wilting to begin. Remove plants before they become brittle to reduce the mess for the clean up crew. Drying out the bags will make them easier to handle.

Perlite media should be disposed of properly. Although, we have had success using the old media for a second crop, the practice is risky. Perlite can be distributed on a field and incorporated into the soil. Perlite can be used for soil mixes for container production of woody plants.

Irrigation lines and emitters should be cleaned with acid to remove lime deposits and fertilizer precipitates. A 1 percent acid solution should work in most situations. Acidification should be done at end of season since acidic solutions might injure plants. Flush system following acidification.

Additional Information

More information on hydroponic vegetable production is available from the Cooperative Extension Service of UF/IFAS. The following is a listing of sources for this information.

Visit the North Florida Research and Education Center-Suwannee Valley (NFREC-SV) Web site at http://nfrec-sv.ifas.ufl.edu.

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Vegetable Insect Identification and Control, HS798

Yellow pepper fruits harvested with the entire peduncle and ready to be graded, labeled and packed into 11lb cartons.

Production of Greenhouse-grown Peppers in Florida

By Elio Jovicich, Daniel J. Cantliffe, Nicole L. Shaw, and Steven A. Sargent

In the U.S., the consumption of high quality red, yellow and orange bell peppers (*Capsicum annuum*) has been increasing dramatically in the past decade. To satisfy consumers' demand, Mexico, The Netherlands, Canada, Israel and Spain have been exporting high quality greenhouse-grown peppers into the U.S. In Florida, high market prices, consumer demand, and a suitable environment for growing colored peppers under protected agriculture have encouraged greenhouse growers to consider the economic viability of this crop. With mild winter regions, Florida's greenhouse industry benefits from growing plants and producing fruits under a relatively optimal plant environment during much of the year.

The total area in Florida with greenhouse-grown peppers expanded to 25 acres in the year 2002 and this area is predicted to increase in the near future, in part as a consequence of greater demand for specialty vegetable crops, the ban of methyl bromide, and increases in urban sprawl and subsequent high prices for arable land. For the past five years, pepper ranked first in production area in the state's total greenhouse area dedicated to food crops (followed by tomato, cucumber, herbs, and lettuce).

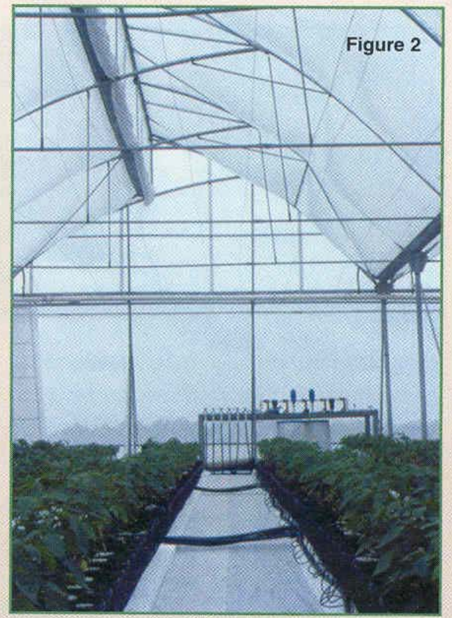

Figure 1 High-roof, passive-ventilated greenhouse at the Horticultural Sciences Protected Agriculture Center (HSPAC), UF/IFAS Gainesville. **Figure 2** Pepper growing in soilless media and irrigated with a complete nutrient solution in a high-roof greenhouse with screened roof-vents and sidewalls HSPAC, UF/IFAS, Gainesville. **Figure 3** High quality colored peppers are the most commonly grown in greenhouses. **Figure 4** Pepper plants grown in 3-gal nursery pots filled with pine bark.

A greenhouse production system of peppers differs greatly from the traditional field pepper cultivation system where plants are grown on polyethylene-mulched beds and with drip irrigation, and where fruits are typically harvested at the mature green stage of development. Depending on the region's climate and crop-growing season, greenhouses can be a means to economically maintain a warm environment during cool seasons, to protect pepper plants from rain, wind and high solar radiation, and to retain pollinators and beneficial insects while excluding unwanted insect pests.

In greenhouses, pepper fruits are harvested with full maturation color, and fruit yields are greater, of higher quality and usually produced at a time of the year when production in the field is not possible and market prices for peppers are highest. Marketable fruit yields will vary with greenhouse location, growing season, plant density, trellis system, cultivar, irrigation and fertilizer management. Current marketable fruit yields of 1.6 to 3.0 lb per square foot and potential yields of 4 lb/ft^2 can be obtained in Florida in passive ventilated greenhouses with low use of fuel for heating. However, because of the higher costs involved with greenhouse growing systems compared to growing in the open field, greenhouse growers have to manage their crops to maximize fruit yield and quality while minimizing production costs per unit of greenhouse floor area.

The production of soilless greenhouse-grown bell peppers, along with the production of other specialty crops such as strawberries, Galia melons and Beit Alpha cucumbers, have been and continue being researched at the Horticultural Sciences Protected Agriculture Center (www.hos.ufl.edu/ProtectedAg) at the UF/IFAS, to provide information and assist existing and intending hydroponic greenhouse growers.

Greenhouse Structures

In Florida, there is a trend currently for using high-roof, passive-ventilated greenhouse structures (13-ft height or more to the roof gutter) for protected vegetable production (**Figure 1**). In contrast to the low-roof structures used in the past (mainly adaptations of greenhouse structures designed for nursery and ornamental crops), high-roof greenhouse structures with roof vents and side curtains lead to lower inside air temperatures during the warm season and permit high vertical training of crops such as pepper, tomato, cucumber and melon.

The greenhouses are covered with polyethylene, which is replaced every three to four years. The polyethylene is a UV-absorbing type of film which can reduce the spread of insect pests and virus diseases in covered crops. The polyethylene film also prevents water condensation from forming on the film surface. The side walls and roof vents can be covered with insect screens (50 mesh) to keep beneficial insects, such as bumblebees (*Bombus* spp.), within the greenhouse and to restrict the entrance of pest insects (**Figure 2**). These high-roof greenhouse designs are less expensive and more suited to be used in regions with subtropical and tropical climates than structures covered with glass or polycarbonate. Costs of passive-ventilated heated greenhouses can range as much as 80 percent less per square foot than the types of greenhouses that seek maximum climate control. Passive-ventilated heated greenhouses provide a level of climate control that enables plants to survive and produce at economically sufficient yields.

Cultivars

The sweet-pepper cultivars most commonly used in greenhouse production are hybrids that have bell-shaped or blocky-type fruits, with red, orange or yellow color when they are mature (**Figure 3**). Cultivars which produce purple, brown or white fruit are less commonly grown, as they have less market demand. Cultivars should be selected for a grower's ability to market them as well as pest and disease resistance or tolerance, low susceptibility to fruit disorders and yield and quality performance. Some of the commonly used cultivars are Parker, Triple 4, Cubico and Lorca for red; Kelvin, for yellow; and

Neibla and Emily, for orange fruits.

In a pepper cultivar trial conducted in a passive-ventilated greenhouse in Gainesville, the total marketable yield was acceptable for all 23 cultivars tested when grown and harvested during the winter months in north central Florida. The red and yellow cultivars produced fruit yields of 1.8 to 2.2 lb per ft^2, the orange cultivars had yields of 1.4 to 2 lb per ft^2 and the chocolate and purple cultivars produced 1.6 lb per ft^2. When comparing cultivars for those with the highest yield and fruit quality characteristics with low amounts of culls or other disorders, the best red cultivars were: Lorca, Torkal, Triple 4 and Zambra; yellow cultivars were: Pekin, Kelvin, Neibla, Bossanova and Taranto; and orange cultivars were: Paramo, Lion and Boogie. Both Choco and Mavras produced high yields and quality fruit, which may be desirable for specialty market production.

Growing Seasons

The most common greenhouse pepper production season extends from mid-July or early August to May. Long crops of up to 300 days are transplanted during the second week of July with a first harvest about the middle of October, ending in late May. Depending on fruit prices and on the quantity and quality of the fruits harvested, production may be extended until June. In **Table 1**, three production schemes for greenhouse-grown peppers that have been used in Florida are presented.

High temperatures and humidity during July and August adversely affect production but are excellent for young plant growth. With some cultivars, percentages of unmarketable fruits increase during the late spring, mainly due to a higher incidence of blossom-end rot and fruit cracking. Fruit set can also be low during summer due to high rates of flower abortion under high temperatures. Air ventilation and shade materials for 30 percent shade help reduce high temperatures during the late spring, summer, and early fall. Cold weather during winter can also adversely affect the set of marketable fruits due to poor pollination, and delay maturation and earliness in production. In central and north Florida, optimum daytime temperatures required for pepper production can be easily achieved in winter while optimum night temperatures cannot and, therefore, heating during the night may be necessary to increase fruit yield and improve fruit quality.

Soilless Culture Systems

Greenhouse pepper crops in Florida are grown in soilless culture. Thus methyl bromide is not needed, yet problems with soil borne diseases, and insect and nematode pests are avoided. The plants are grown in containers filled with soilless media such as perlite, pine bark or peat mixes. The media can be reused for several crops (two to three) if disease contamination is not apparent. The containers used are nursery pots (3 and 4 gal) with one plant per pot (**Figure 4**), or flat polyethylene bags of about 3 ft long (5 gal) with three to four plants per bag . The plant containers can be aligned in single or double rows, one next to the other one, leading to plant population densities of 0.27 to 0.36 plants per square foot.

In local trials with greenhouse-grown peppers, fruit yields from plants grown in 3-gal pots or 5-gal flat bags have been similar. Also, similar marketable fruit yields were harvested from plants grown in various substrates, such as perlite, pine bark, or peat-perlite mixes. Pine bark, milled and sieved to particle sizes smaller than 1 inch square, has shown to be a promising medium because of its low cost, availability, lack of phytotoxicity and excellence as a plant production media.

Irrigation and Fertilization

Pepper plants in soilless culture are frequently fertigated with a complete nutrient solution. Nutrient solution concentrations are similar to those used for tomatoes grown in soilless culture. The concentrations of most of the nutrients required by pepper plants in larger quantities are increased with plant growth. For example, in the irrigation solution used with soilless culture, the concentration of nutrients in parts per million (ppm, being 1 ppm = 1 mg per L ≈ 1 oz per 7,462.7 gal) can be for N: 70, P: 50, K: 119, Ca: 110, Mg: 40 and S: 55, starting when transplanting the seedlings. In plants at full production, the nutrient concentration levels can reach N:

Figure 5 Pepper plants transplanted in perlite to the depth of the first true leaf. **Figure 6** Pepper plants grown in flat bags and trellised with the "V" system. **Figure 7** A double-row of pepper plants growing in 3-gallon nursery pots and trellised with the "Spanish" system. **Figure 8** Pollination of pepper flowers using bumblebees to improve fruit set and shape.


Figure 5


Figure 8


Figure 6


Figure 7

Table 1. Commercial production schemes of greenhouse-grown bell pepper used in Florida.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fall to Summer					E			T			H	
Winter to Spring			H			E					T	
Spring to Summer &		T			H		E					
Fall to Spring (2 crops)	E							T			H	

T: Transplant, H: Harvest and E: End of the crop.

160, P: 50, K: 200, Ca: 190, Mg: 48 and S: 65 ppm, respectively. The irrigation solution also provides the plants with micronutrients. The pH of the irrigation solution is maintained at values between 5.5 and 6.5, and the EC, depending on the nutrients concentration levels, will have values between 1.5 and 2.5 mS per cm.

At the time of transplanting, seedlings can be irrigated about 10 times per day delivering about 1.3 fl oz per irrigation event. As plants grow and season temperatures increase, irrigation frequency and volume per irrigation event can be increased up to 40 times per day and 2.5 fl oz per irrigation event, respectively. During full production and under intense sunlight (warm weather), volumes of nutrient solution per plant per day may reach up to 1.5 gal.

Irrigation events can be scheduled by using different control systems such as a time clock, a starter tray or a controller that irrigates based on solar radiation. An excess of irrigation leading to 15 or 20 percent drainage from the container ensures sufficient solution delivery throughout the crop and avoids a high concentration of salts in the soilless media. Systems for recycling the fertigation solution are available and provide a more sustainable use of water and nutrients. With these "closed" irrigation systems, the solution that drains from the pots is sanitized and then the pH and EC are corrected to meet the plant needs. Subsequently, the nutrient solution can be recycled on the same pepper crop.

Transplanting

Deposits of salts at high levels and excessive irrigation near the cotyledonary node level can promote localized epidermal injuries on a swollen stem base where fungal infections then lead to basal stem rots and sudden plant wilts. This phenomenon (symptoms of basal stem swelling and epidermal wounds at the base of the stem) has been called 'Elephant's foot.' To avoid injuries to the plant stem below the cotyledonary leaves, seedlings (about 35 days-old, five to seven true leaves) should be transplanted into the soilless culture substrate to the depth of the first leaf node. To reduce creating a humid environment close to the base of the stem, irrigation emitters placed near the seedling stems at transplanting can be gradually moved back (2 to 3 inches) from the base of the pepper plants over a three week period. (**Figure 5**).

Pruning and Training

Greenhouse pepper cultivars generally have an indeterminate pattern of growth. Because the plants can grow up to 6-ft tall during a growing season of 250 days, they need to be supported vertically. Pepper plants can be trellised to the Dutch "V" system or to the "Spanish" system.

Trellising plants with the "V" system consists of forming a plant with two main stems by removing one of the two shoots developed on each node and leaving one or more adjacent leaves per node (**Figure 6**). The pairs of stems are kept vertically by the use of hanging twines that are wound around the stems as they grow. The "V" trellis system is used by Dutch and Canadian growers. Spanish, Israeli, and some Mexican growers generally trellis the pepper plants using the "Spanish" system. In the "Spanish" trellis system, the plant canopy is allowed to grow without pruning (**Figure 7**). The plants are vertically supported by a structure of poles and horizontal twines extended on both sides of the plant rows.

Labor requirements for the Spanish system are reduced minimally by 75 percent of the labor used compared with the "V" trellis system. Total marketable fruit yields under Florida conditions were similar regardless of the trellis system. However, the total number and weight of extra large fruits were actually greater in the plants trellised to the "Spanish" system. The percentage of fruits with blossom-end rot at the end of the spring was also lower in the nonpruned plants.

Pollination

Pepper flowers are self pollinated but the use of bumblebees inside the greenhouse help to ensure the set of high quality fruits especially during the cool season, when pollen viability is lower (**Figure 8**). Bumblebees feed on nectar and pollen and their daily activity is naturally timed with the period when flowers are ready to be fertilized. Although a bumble bee hive (containing about 60 bees) per 16,000 square feet might seem costly to the grower, the labor of pollinating would be inefficient and much more expensive. The expected life span of the colony is eight to 12 weeks. The hive should be placed under a shade in summer and in the sun in winter and isolated from ants. The hives contain a supplement food for the bees during periods of low abundance of flowers because 'overvisited' flowers may lead to fruits with cork-like spots at the blossom-end.

Fruit Disorders

Optimal environmental conditions for the crop may not always be possible to reach during late spring or during winter with no heaters. Pepper fruits may develop physiological disorders such as "color spots," cracking, blossom-end rots and flat-shaped fruits. Most of these disorders are caused by environmental stresses during fruit development but can be minimized by using cultivars that have less susceptibility to stress.

Yellow spots can occur on the outer surface of the fruit. The "color spots," sometimes already visible on green fruits, turn yellow as the fruit matures, reducing the visual quality of the fruits for consumers. High incidences of this disorder occurred in summer, and in plants grown at high densities, under shade or fertilized with high levels of N. Fruit cracking results from ruptures on the cuticle at the blossom-end (radial cracking) or all over the fruit surface (russeting). Pepper plants which receive too much water can have higher incidences of fruit cracking. Flat pepper fruits are caused by low temperature. Night temperatures of around 64 F ensure an ideal seed set and fruit shape. Low-night temperatures decrease pollen viability in pepper flowers and modify flower structure. Use of bumblebees for pollination can help greatly to improve fruit shape. Blossom-end rot can be caused by reduced absorption and translocation of calcium into the fruit. Ca deficiency in the fruit occurs as a result of one or more factors, such as low Ca concentration in the solution or media, excessive salinity in the irrigation solution or media, extreme moisture fluctuations in the media, and rapid plant growth due to high temperatures and solar radiation. The localized deficiency of Ca, which occurs at the sides and lower parts of the pepper fruit, manifest itself as regions with collapsed tissue that gradually turn black, making the fruit unmarketable. Pepper cultivars have different levels of susceptibility to the disorder. The disorder in pepper is difficult to prevent with foliar applications of Ca.

Harvesting, Packing, and Maintaining Postharvest Fruit Quality

Throughout the harvest season, pepper plants will have ripened fruits in flushes or waves of production. Under warm environments, ripened fruits can be picked once or twice a week (up to three fruits per plant at each harvest). Sharp pruning scissors or knives should be used to cut the fruits at the level of the abscission zone on the fruit's peduncle. Pepper fruits with intact peduncles are more resistant to bacterial soft rot than those with torn or partial peduncles. Nonmarketable fruits should be removed from the plants as soon as they are observed.

Marketable fruits are graded by diameter (maximum distance across shoulders). Fruits with greater size bring higher prices. Fruit grades can follow the USDA standards for field-grown peppers or can be based on classifications based on diameter ranges similar to greenhouse peppers imported from Holland (extra-large, diameter >3.3 in; large, 3 to 3.2 in; medium, 2.5 to 2.9 in; and small, 2.2 to 2.4 in). Extra large fruits generally weigh about half a pound, although individual fruit weight will vary with cultivar.

Peppers should not be submerged in water during the transfer to the packing line since water can easily infiltrate the hollow pod and cause postharvest decay. Overhead spray with clean water works well for washing; free water should be removed prior to packing. Pepper fruits are often individually labeled and packed in single or double layers in 11-lb corrugated cartons.

Pepper fruit respiration rate can be reduced to a minimum by lowering the product temperature. Optimal storage conditions are 45 F and 90 to 95 percent relative humidity. To avoid chilling injury, fruits should not be stored at temperatures below 45 F. Maximum pepper fruit storage life is two to three weeks under the most favorable conditions. Symptoms of chilling injury are water-soaked spots, pitting, or tissue collapse. Extensive decay develops on chilled peppers when they are removed from low-temperature storage. Temperatures above 55 F enhance ripening and spread of bacterial soft rot.

Rapid cooling of harvested sweet peppers is essential in reducing marketing losses. Pre-cooling by forced-air is the preferred method. Peppers are very susceptible to water loss. Symptoms of shriveling may become evident with as little as 3 percent weight loss. Pre-cooling and storage in a high relative humidity (90 to 95 percent) will minimize weight loss. Peppers can be waxed, but only a thin coating should be applied. Waxing provides some surface lubrication which reduces chafing in transit. Water loss can also be limited by packing peppers into cartons with moisture-retentive liners or into perforated polyethylene bags.

Pests and Diseases

Pests are reduced in screened greenhouse structures. Transplants must be free of pests and weeds must not be present inside the greenhouse. The major insect pests observed in greenhouse peppers in Florida are broad mite (*Polyphagotarsonemus latus*), twospotted mite (*Tetranychus urticae*), western flower thrips (*Frankliniella occidentalis*), melon thrips (*Thrips palmi*), green peach aphid (*Myzus persicae*), melon or cotton aphid (*Aphis gossypii*), silverleaf or sweet potato whitefly (*Bemisia tabaci*), pepper weevil (*Anthonomus eugenii*), fungus gnats (*Bradysia* spp.), and several lepidopterous pests.

Common fungal diseases are powdery mildew (*Leveillula taurica*) and Fusarium (*F. oxysporum* and *F. solani*). Western flower thrips can transmit tomato spotted wilt virus (TSWV).

Insecticides are available to control insect and mite pests. However, many chemicals negatively affect bumblebees, beneficial organisms, and the pepper plant itself. Also, crop reentry after using pesticides can complicate management when plants have to be accessed frequently for pruning, training, and harvesting. Some products, such as soaps and sulfur, often are phytotoxic to pepper plants in the greenhouse.

Research in the Protected Agriculture Project at the University of Florida is evaluating biological control practices used in other regions to minimize or avoid the use of pesticides. Augmented biological control involves the release of living organisms that will limit the abundance of other living organisms.

In pepper, melon aphids have been successfully controlled by releasing a parasitic wasp, *Aphidius colemani*. Twospotted spider mites were controlled by releasing a predatory mite, *Neoseiulus californicus*. The appearance of lepidopterous pests is greatly reduced by using insect screens on the greenhouse vents. When adult moths are present in the greenhouse, the larval stages can be controlled by repeated treatments with *Bacillus thuringiensis*. *B. thuringiensis* can also be applied near the base of the plants to control larvae of fungus gnats.

Releases of a parasitic wasp, *Eretmocerous eremicus*, were used to maintain low populations of silverleaf whitefly. Current research evaluates using predatory mites *N. californicus* and *Neoseiulus cucumeris* for the control of broad mites. *N. cucumeris* and big-eyed bugs, *Orius* spp., can be used to control western flower thrips.

Compared to the use of pesticides, with biological control, insects do not develop resistance as they do to certain insecticides. Also, restricted reentry periods to the greenhouse due to the use of insecticides are eliminated, the environment for workers is safer, and harvest products can be labeled "pesticide free" which can attract higher prices and/or increase consumer demand.

The use and success of biological control will require that the crop is scouted frequently to determine presence and to estimate population densities of crop damaging insects and their natural or introduced enemies. Combining the use of bumblebees with natural enemies does not present any problems but the use of chemicals may have direct or indirect effects on the bumblebees and/ or natural enemies. Information about the side effects that agricultural chemicals have on bumblebees and on biological control agents can be provided by the companies that supply these organisms.

The production of greenhouse-grown peppers represents an alternative crop in Florida. In the Protected Agriculture Project at the University of Florida, ongoing research on greenhouse-grown peppers on production systems, fruit quality, cultivars, nutrient and water management, integrated pest and disease management, post harvest and marketing are being evaluated. Current and past research, publications and links to products used for pepper greenhouse production and other specialty crops are posted in an up-to-date Web site: www.hos.ufl.edu/ ProtectedAg.

Elio Jovicich is a graduate student, Horticultural Sciences Department, UF; jovicich@ufl.edu. Daniel Cantliffe is chairman/professor/ team leader of the Protected Agriculture Project, Horticultural Sciences Department, UF; djc@mail.ifas.ufl.edu. Nicole Shaw is a biologist scientist, Horticultural Sciences Department, UF; colie@ufl.edu. Steven Sargent is professor, Horticultural Sciences Department, University of Florida; sas@mail.ifas.ufl.edu .