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High Tunnel Pepper Production

Tiffany Maughan, Graduate Student, ***Dan Drost,*** Extension Vegetable Specialist
and ***Brent Black***, Extension Fruit Specialist

Introduction

Peppers are a popular warm-season vegetable with many culinary uses and fruit that contain three to six times as much vitamin C as an orange (Bosland and Votava, 2007). Peppers require similar growing conditions as tomatoes and eggplants and perform best in a long, frost-free season. Consumers are interested in the unique fruit shapes, flavors and colors found in peppers. Growing peppers in high tunnels can be advantageous because tunnels extend the growing season, increase opportunities for color development, and can improve the quality of the fruit. In particular, colored peppers produced in high tunnels will have higher percentage of first and second quality fruit compared to field grown peppers due to less bacterial rot, sunscald and European corn borer damage (Reid et. al., 2010).

High tunnels are temporary structures constructed with either galvanized steel or PVC pipe framing and covered with greenhouse grade plastic. High tunnels are passively heated and cooled which helps to keep operating costs low. During the day, high tunnels can be 15-30˚F warmer than the ambient outside air temperature (Figure 1). This temperature increase allows peppers to be planted 4-6 weeks before outside plantings, depending on location. Another benefit for growing in high tunnels is the shielding of plants from wind. Tunnel protected pepper plants will grow larger and produce more fruit then field-grown plants and remain productive for a longer time. Detailed information on constructing a low-cost high tunnel and other high tunnel production options can be found at https://tunnel.usu.edu.

Variety Selection

Peppers are categorized by fruit shape, size, color, flavor, and pungency (Bosland and Votava, 2007; Noble, 2007). Peppers vary greatly within these categories and varieties should be selected to meet production goals and market demands. Some factors to consider when choosing varieties are: growing environment, available space, market requirements, and desired use. No pepper variety evaluations have been conducted in Utah State University high tunnels. However, other universities have successfully grown different pepper varieties in high tunnels. Pepper variety comparisons can be found at: http://blogs.cce.cornell.edu/cvp/files/2011/01/Harris-Seed-HT-Peppers.pdf . Consult your seed provider or other reputable source and use them to help identify pepper varieties that meet your production criteria and are suitable for high tunnel production.

Site Selection

Peppers grow best in a well-drained, sandy loam soil because sandy soils warm rapidly in the spring. Heavier soil types can be very productive, provided the drainage is good and irrigation is properly managed. Soil type and fertility should be determined by a soil test. It is also important to select a site with a year-round water source. Due to the season extension provided by the high tunnel, culinary water may be required when secondary irrigation water is unavailable. When selecting the site for a high tunnel, external environmental conditions such as prevailing winds, sun exposure, unique climatic conditions and soil types should be taken into account before constructing a high tunnel. In Utah, high tunnels should be constructed with an east to west orientation in order to maximize low-angle light of early spring and late fall (Nelson, 2003). In areas prone to heavy wind however, there may be benefits to orienting the tunnel according to wind direction. High tunnels oriented parallel to wind direction can withstand high winds provided they have well-reinforced end walls.

Site Preparation and Fertility Management

If the selected field site has not been recently farmed (or cultivated) or if past yields have been low, it is a good idea to have the soil tested. The Utah State University Analytical Laboratories conducts soil testing for a variety of nutrients, and information on sampling procedures, cost structures, and tests performed can be found at http://www.usual.usu.edu/. Soil in the high tunnel will be intensely managed; therefore, the addition of organic matter before planting will help improve nutrient levels, increase soil water holding capacity, and mitigate drainage issues. Apply 20-30 lbs of high quality compost per 100 sq. ft. of tunnel space to enrich the soil.

Planting into unfavorable soil conditions can result in poor plant health. Based on the soil test recommendations, soil amendments (compost and fertilizer) should be uniformly applied and incorporated into the top 6 inches of soil. Peppers have high fertility needs but yield, earliness, or fruit quality may suffer if over fertilized. Soil potassium (K) and phosphorus (P) applications should be based on soil test results. Soils with extractable K less than 150 ppm should be fertilized with 50-150 pound per acre (1.15-3.45 lb K_2O/1000 ft^2) of K_2O. Soils with extractable P less than 15 ppm should be fertilized with 50-200 pound per acre (1.15-4.60 lb P_2O_5/1000 ft^2) of P_2O_5. Higher rates of P may be needed for early plantings when soils are cold or if soil pH is 7.5 or above. Generally, peppers require 50-75 lb N/acre (1.15-1.70 lb N/1000 ft^2) of pre-plant nitrogen (N) with additional N applications of 150-200 lb N/A (3.45-4.60 lb N/1000 ft^2) added over the course of the growing season injected through the drip irrigation system (Image 1A; Table 1). Following this fertilization protocol will ensure plants keep growing for the whole season.

Table 1. General N fertigation approach for high tunnel peppers.

GROWTH STAGE	Duration (weeks)	N fertigation rate* (lb/1000 ft^2/week)
2 weeks post-transplant to early (first) fruit set	4	0.5§
Early fruit set to first mature green harvest	4	0.75-1.0
Mature green to first red fruit	4	0.5
Main season fruiting period through end of season	variable	0.25

* in tunnels with substantial residual NO_3-N, lower rates may be adequate.
§ based on urea (46% N); multiply N rate by 2.2 if using ammonium sulfate (21% N)

Image 1. A) Fertilizer injector used in high tunnels. B) Transplanted peppers growing under low tunnels on plastic mulch.

Irrigation Management

In Utah's arid, desert climate, peppers require regular watering. Inconsistent watering can result in poor early vigor, inadequate leaf cover, and increase the incidence of flower drop, blossom-end rot, and sunburn. Water peppers deeply and infrequently to encourage deeper root growth. As temperatures increase and plants grow, irrigation rates should be increased to meet plant needs. High tunnels dramatically increase the air temperature on sunny days and soils need to be monitored closely to avoid water stress to plants. Soil moisture content should be determined by the use of soil moisture sensors. Soil type greatly effects water holding capacity and will influence how often watering is required. For more information on soil moisture monitoring visit: https://attra.ncat.org/water_quality.html.

The use of plastic mulch in the high tunnel provides many advantages. Plastic mulch increases early yields by increasing soil temperatures, inhibiting weeds which compete with pepper growth, increasing moisture retention by reducing evaporative losses, and protects pepper fruit from soil deposits and soil microorganisms (Image 1B). Plastic mulch should be used in conjunction with drip irrigation. Always install the drip irrigation system before laying out the plastic mulch. Install one drip line containing 4-8 inch emitter spacings per bed. Make sure the plastic mulch is installed on a smooth soil surface to achieve maximum plastic to soil contact (Bosland and Votava, 2007). This aids in increasing soil temperatures at the root zone. The edges of the plastic should be buried 2-3 inches in the soil to hold the plastic in place. Since peppers will be planted in double rows, use plastic that is at least three feet wide. Install the plastic and water the beds at least one week prior to transplanting to help increase soil temperature.

Transplant Production

Peppers are rarely direct seeded due to high cost of disease resistant and hybrid pepper seed. The added cost of growing or purchasing transplants ensures early planting and allows precise plant populations to be established. Pepper transplants are ready 8-10 weeks after seeding and should be 6-8 inches tall. Thicker stemmed plants have a higher survival rate. Sow seeds directly into 50 or 72 cell plug trays containing a high quality soilless mix. Pepper seed germinates best at 86˚F, and the use of heating mats will increase speed of germination and the percentage of seedlings that emerge. Lower temperatures result in decreased germination rates and emergence percentage. Peppers grow best at temperatures of 75˚F/65˚F (day/night) and plants should be watered regularly. Apply a complete soluble fertilizer (20-20-20) diluted to 100 ppm once or twice a week. Gently brushing the plants each day once the second true leaf emerges helps peppers grow stocky plants. Harden the plants by decreasing the day temperature to 60-65˚F for 1 week before transplanting to the high tunnel.

Planting

As in-row spacing increases, yield per plant and fruit size increases. However, total high tunnel production decreases due to decreased plant numbers. Space inside the high tunnel is valuable and plants should be arranged to utilize all available space. Depending on the type of pepper planted, in-row and between-row spacing recommendations vary. Generally, plants should be placed 12 to 18 inches apart in the row with approximately 15 inches between rows, with two rows on a 30 inch wide bed (Image 1B). Beds can be spaced on 36 to 42 inch from center to center, leaving 6 to 12 inches between beds. A 14'x 96' high tunnel would accommodate about 600 plants if there are four beds on 36 inch centers with two rows of plants spaced 15 inches apart. Plants are generally staggered down the rows to better utilize the space. Plants may need to be staked as they grow since high tunnel peppers grow taller and are productive for a longer time than field grown peppers.

Transplants should be set so the soil level reaches the cotyledon leaves or the first true leaf. Plants placed at these depths grow larger and produce more leaves. Total fruit weight has been shown to be 26% higher on plants set to cover the cotyledons than on plants set to cover just the top of the root ball (Vavrina et al., 1994). Use a sharp trowel to punch a hole through the plastic mulch making sure not to cut the drip tape underneath the plastic. Fill in the hole with soil and apply sufficient water through the drip system to wet the soil. Monitor the tunnel daily to ensure plants are not water stressed during the establishment period.

High Tunnel Temperature Management

Optimal growing temperatures for sweet peppers are 75-85˚F. When temperatures exceed 90˚F during flowering, pollination, fruit set, and yield is reduced (Swaider and Ware, 2003). High tunnels should be ventilated when inside temperatures exceed 80˚F and vents, doors, and sidewalls should be closed again when inside temperatures fall to 60˚F.

Planting dates can be determined based on freeze-free dates (Table 2). Local freeze-free dates for additional cities can be found under climate reports at the Utah Climate Center website (climate.usu.edu). Determine the earliest, average, and latest recorded spring freeze dates for your production area. Peppers can be planted into high tunnels about three weeks earlier than the earliest last spring freeze. For example, in Logan we have

successfully planted peppers during the first week of April. Early planting allows peppers to flower and fruit 4-6 weeks before outdoor planted peppers. Some frost protection will be needed even when planting early in high tunnels. Low tunnels constructed inside high tunnels help keep night temperatures warmer than the high tunnel alone (Image 1B). Low tunnels must be vented during the day to avoid excessive heat buildup. The total cold temperature protection provided by low tunnels within high tunnels is 3-10°F when outside temperatures are near freezing (Figure 1).

Table 2. Climate information for cities throughout Utah (climate.usurf.usu.edu).

	Last Spring Freeze Date			First Fall Freeze Date			Freeze-Free (Days)		
LOCATION	Early	Ave.	Late	Early	Ave.	Late	Early	Ave.	Late
Bear Lake	10-May	29-May	21-Jun	24-Aug	20-Sep	18-Oct	82	114	160
Brigham City	9-Apr	4-May	2-Jun	4-Sep	11-Oct	13-Nov	111	159	206
Cedar City	29-Apr	14-May	5-Jun	24-Sep	9-Oct	26-Oct	128	147	158
Delta	15-Apr	17-May	19-Jun	2-Sep	28-Sep	28-Oct	75	133	183
Logan	25-Apr	14-May	21-Jun	30-Aug	26-Sep	24-Oct	94	135	182
Moab	8-Mar	17-Apr	18-May	16-Sep	17-Oct	9-Nov	136	184	239
Ogden	18-Apr	13-May	16-Jun	10-Sep	7-Oct	26-Oct	92	147	182
Park City	8-Jun	14-Jun	21-Jun	27-Aug	6-Sep	14-Sep	78	83	98
Richfield	18-Apr	27-May	20-Jul	23-Aug	20-Sep	16-Oct	49	116	164
Salt Lake City	19-Mar	12-Apr	30-Apr	11-Oct	31-Oct	21-Nov	175	203	233
St George	12-Feb	6-Apr	20-May	21-Sep	28-Oct	24-Nov	135	205	268
Vernal	21-Apr	27-May	4-Jul	27-Aug	22-Sep	23-Oct	62	118	158

High tunnels provide significant daily temperature increases and additional temperature increase can be obtained by covering the peppers with low-tunnels. Low tunnels can be constructed using U-shaped metal frames and draping plastic over the frames (Image 1B). Low tunnels should be ventilated when temperatures next to the plant exceed 80˚F. When growing high tunnel vegetables, the use of a good maximum/minimum thermometer is helpful to determine temperature conditions throughout the tunnel (in the soil, under low tunnels and in the high tunnel).

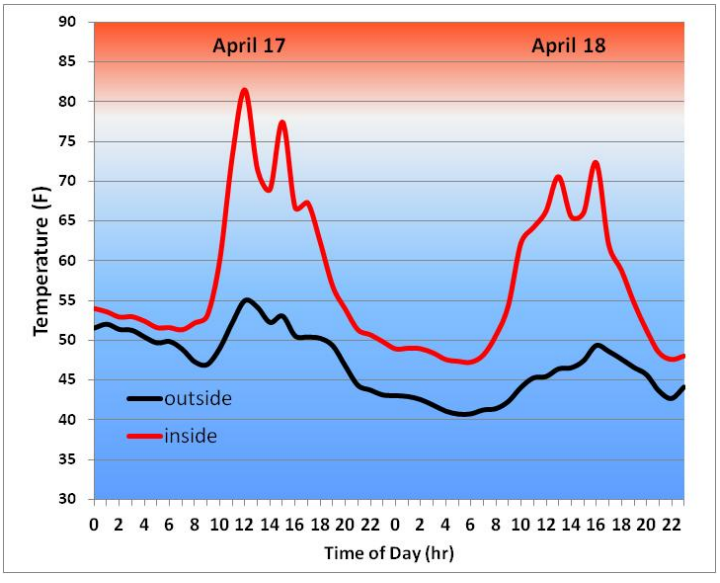

Figure 1. Diurnal changes in air temperature outside and inside (under a low tunnel) a high tunnel over 2days in mid-April 2011. The temperature range for pepper growth is 55 to 86°F (13 to 30°C) with optimum growth occurring at 80°F (27°C).

Beyond passively heating the high tunnel with sunlight, another strategy for avoiding frost inside the high tunnel in the early spring is to provide a supplemental heat source. A back up propane heater, buried soil heating cables or hanging incandescent light bulbs under low tunnels can provide added frost protection. However, they also increase the cost of production and should be considered in light of production goals. As temperatures increase each morning, it becomes necessary to ventilate the high tunnel. This can be done by simply opening a door vent (Image 2A) or one end door, opening both doors, or raising the sides of the tunnel (Image 2B). Tunnels should be closed again when temperatures fall below 60°F to retain heat over night. When night temperatures remain above 50°F, remove the plastic from the high tunnel and replace it with 30-50% shade cloth (Image 2C). Plastic should be stored and re-attached to the tunnel in the fall when temperatures cool off again.

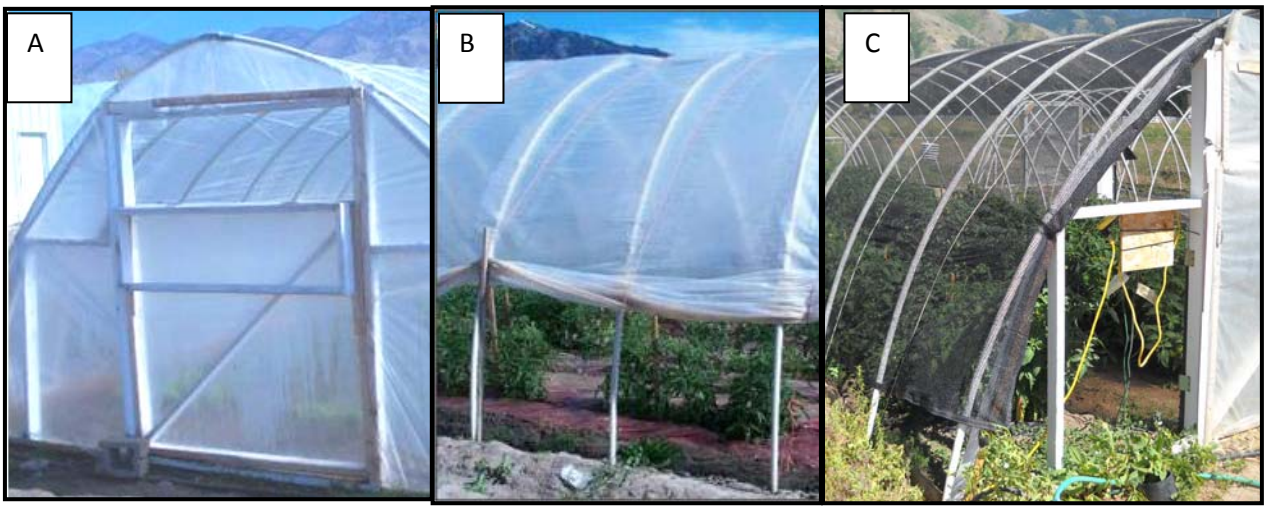

Image 2. Ventilating a high tunnel by opening the door vent (A), raising the side walls (B), or covering with shade cloth for the summer (C).

Pest Management

High tunnels provide excellent conditions for growing plants, unfortunately pest also enjoy the increased temperature and humidity found there. Pests can greatly reduce plant yield and health. Principles of an Integrated Pest Management (IPM) program should be applied which starts with the correct identification of the pest or problem. For help diagnosing specific pests, visit http://utahpests.usu.edu/uppdl/ or contact your county extension agent. It is important to closely monitor high tunnels for potential pest threats and only apply chemicals if pests reach the action threshold. This is when a pest control action must be taken to prevent unacceptable damage to the plant. Since high tunnels are an enclosed space, applying chemicals according to label directions is particularly important. Always read and follow pesticide labels. Pesticides applied should be labeled for greenhouse use. Also, wearing proper personal protection equipment and clearly post warnings showing that a pesticide has been applied and when it is safe to re-enter the tunnel are both critical for worker safety. A complete guide on greenhouse pest management and IPM practices can be found at: http://pested.osu.edu/documents/CommStudy/6d%20Greenhouse%20Pest%20Control2007.pdf

There are several insect pests that may attack peppers. Some of the more common are aphids, hornworms, fruitworms, and grasshoppers.

Aphids

Aphids are light-green, soft bodied insects with piercing mouthparts. Aphids commonly attack peppers, clustering on the undersides of leaves. They multiply quickly, cause wilting and leaf distortion, act as disease vectors, and reduce plant vigor and fruit quality. Removing weeds in and around the high tunnel can dramatically reduce the risk of aphid outbreaks. Natural predators can help maintain aphids and there are several common insecticides that can be applied in high tunnels to control aphid infestations.

Worms

Hornworms are the larval stage of the sphinx moth. They have a prominent horn on the rear end and diagonal green lines on their sides. These large caterpillars (up to 4 inches) have an insatiable hunger and can rapidly defoliate a pepper plant (Bosland and Votava, 2007). Fruitworms (also called corn earworms) can be green or brown and grow up to 2 inches long. They damage peppers by eating holes in the fruit. Hand removal is an effective control method for light infestations of hornworms but more difficult for fruitworms. Various insecticides can be applied for worm control in high tunnels.

Grasshoppers

Grasshoppers can quickly strip the foliage from pepper plants. Proper weed management inside and around the high tunnel can keep grasshopper numbers low and discourage them from entering the high tunnel. Hand removal works well when grasshopper populations are low. The best time for applying insecticides is after the eggs have hatched (late May through early July) and before grasshoppers are half grown (Roe, 2000).

Disease Control

Due to the enclosed characteristic of high tunnels, humidity levels can be quite high, which increases the chance of diseases development. Disease resistant varieties, proper soil drainage, good ventilation, and crop

rotation are useful IPM practices that aid in disease prevention. Most hybrid pepper varieties have some degree of disease resistant or tolerant and are obvious choices for high tunnels.

It is important to correctly diagnose the problem before deciding on control measures. Information on common and obscure pepper diseases can be found at www.ipm.usdavis.edu. Peppers are susceptible to several disorders and diseases which can reduce fruit quality and yield. Some of the most common abiotic disorders include blossom end rot, chilling injury, flower and bud drop, and sunscald. Common biotic diseases are bacterial canker and soft rot.

Blossom-End Rot

Blossom-end rot (BER) first appears as a water-soaked spot on the bottom of the fruit. The spot first turns brown and eventually turns black as fruit size increases. Blossom-end rot occurs when plants are unable to translocate enough calcium to the fruit. Blossom-end rot is caused by fluctuating soil moisture (drought and over-watering), excessive heat, root pruning during cultivation, or from excessive N fertilizer applications. Fruit affected by BER are not marketable.

Chilling Injury

Chilling injury occurs when pepper plants or fruits are exposed to above-freezing temperatures of 32-36°F. Plants may appear wilted, leaf tips and margins may be water-soaked or dried out, and the growing points blackened. Fruits may have pits, surface scald, or non-disease related discoloration. Selection of appropriate planting dates, use of low tunnels, and modest heat additions can reduce but not totally eliminate the incidence of chilling in high tunnels.

Flower and Bud Drop

Heat stress, insufficient water, and excessive or deficient nutrient levels can all cause peppers to abort their flower buds, flowers or immature fruits. Avoiding over-fertilization and maintaining constant soil water conditions are the most effective methods of control. Ventilation of the high tunnel is critical to avoid heat stress, and shade cloth helps keep daily temperatures several degrees below ambient air temperatures (Images 2A, 2B, & 2C). Soil water sensors help determine irrigation schedules and are useful tools to maintain more favorable soil moisture levels.

Sunscald

Fruit exposed to direct sunlight after being shaded can be sun burnt. This can occur in a high tunnel when plastic is removed from the structure, or when plants are exposed to extreme heat. Affected areas are sunken, wrinkled and white in color. As the tissue dries, it becomes thin and papery and may get infected with secondary diseases. Shade cloth should be put on as soon as plastic is removed (Image 2C). Regular N applications ensure plants continue to grow leaves which helps minimize sunscald. Appropriate plant spacing and regular N applications ensures plants produce sufficient foliage to cover or shade the fruits. Be careful during harvesting not to remove or damage leaves, as pepper plants are quite brittle and branches easily break during harvest.

Bacterial Canker

Bacterial canker can occur on all parts of the pepper plant. Symptoms expressed include stunting, black streaks on stems and leaves, cankers, spotting, blistering, and bacterial ooze on pepper stems, leaves, and fruit. The pathogen survives in plant tissue (living and dead), in infected soil, and on contaminated stakes, tools, and harvest containers. The disease is promoted by humid, warm conditions and things that favor succulent growth (low light, high nutrient levels). The disease is spread by wind, water and common production practices like pruning, cultivation, and harvest. Primary control methods include good sanitation, use of disease free plant materials, working when plants are dry and through the application of copper sprays.

Bacterial Soft Rot

Bacterial soft rot can be the most destructive of diseases. Rot symptoms start as small spots near the stem that rapidly spread until the entire fruit collapses into a soft, watery mass that produces an undesirable odor. Humid conditions perpetuate the growth of this bacterium. Diseased fruits should be carefully removed and disposed of. Harvest when plants are dry and minimize injury to fruits as the bacteria enters through cuts, bruises and insect feeding sites.

Weed Management

Peppers are poor competitors with weeds, and yields can be significantly reduced if weeds are not properly controlled. Weeds also increase the chances of pests such as aphids infesting the high tunnel. Planting into plastic mulch (Image 1B) will help decrease weed growth and minimize weeding. Weeds that grow in the planting hole should be removed by hand while they are still small in order to avoid disturbing pepper roots. Weed management around the edge of the tunnel (inside and outside) is also important. The use of herbicides is not recommended for high tunnels.

Harvesting and Handling

Peppers may be harvested at the immature (green) stage or after the mature color (red, yellow, etc., depending on variety) develops (Image 3A). Pepper harvest starts about 30 days after flowering (mature green) and it takes an additional 10 (partial color change) to 20 days before fruits are fully colored (Image 3B & 3C). Since peppers are perennial plants, with proper care (fertility, watering, staking, pest management), high tunnel grown peppers can be harvested for 3 or more months.

Inside a high tunnel, where space is limited, the best way to harvest peppers is by hand. Hand-picking peppers decreases damage to the plant. Harvesting involves carefully twisting the fruit to break the stem or cutting the stem to separate the fruit from the plant. Grading peppers can be done by separating damaged from undamaged fruit. The undamaged fruit are further sorted based on color and shape according to United States Department of Agriculture grading standards. Peppers are generally harvested once per week.

Post harvest handling is as important as the growing of the crop. A high quality, mature, fresh pepper is firm, bright, and has a fresh, green calyx (Image 3C). Fruit should be cooled quickly after harvest. The best time to harvest is in the early morning when temperatures are cool and plants are well hydrated. Most sweet peppers can be stored for 2-3 weeks if refrigerated at 44-49˚F. (Bosland and Votava, 2007).

In Cache Valley, high tunnel grown pepper harvest begins in June and can extend until mid November. Peppers are generally marketed at roadside stands, local farmers markets, and through wholesale and retail outlets. Pricing varies greatly depending on markets used, fruit size and quality, availability, seasonality, and consumer demand.

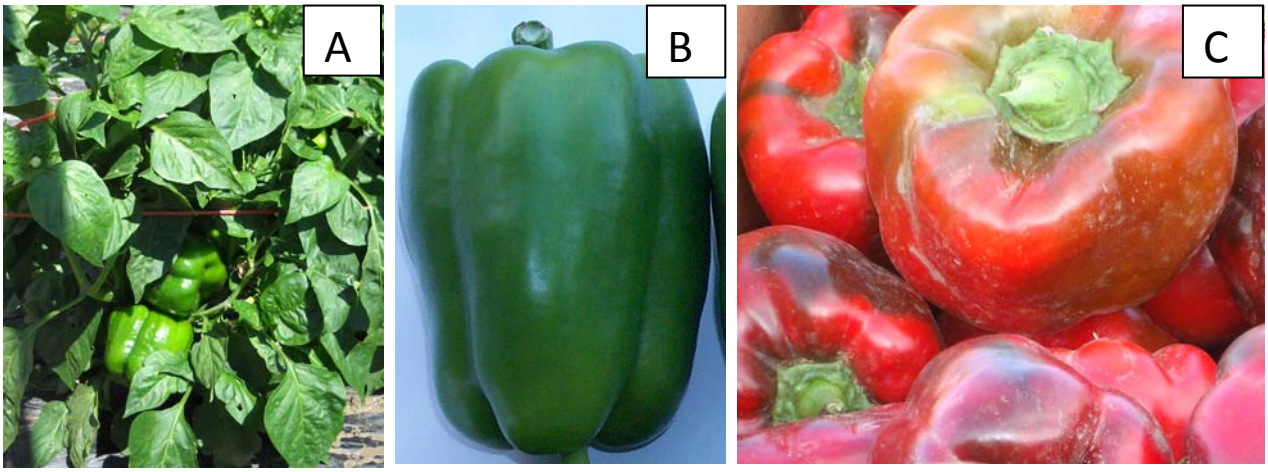

Image 3. Peppers ready for harvest (A), mature green pepper fruit (B), colored fruits (C) at various stages of maturity.

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