Strawberry Production, IPM and Postharvest Handling Manual

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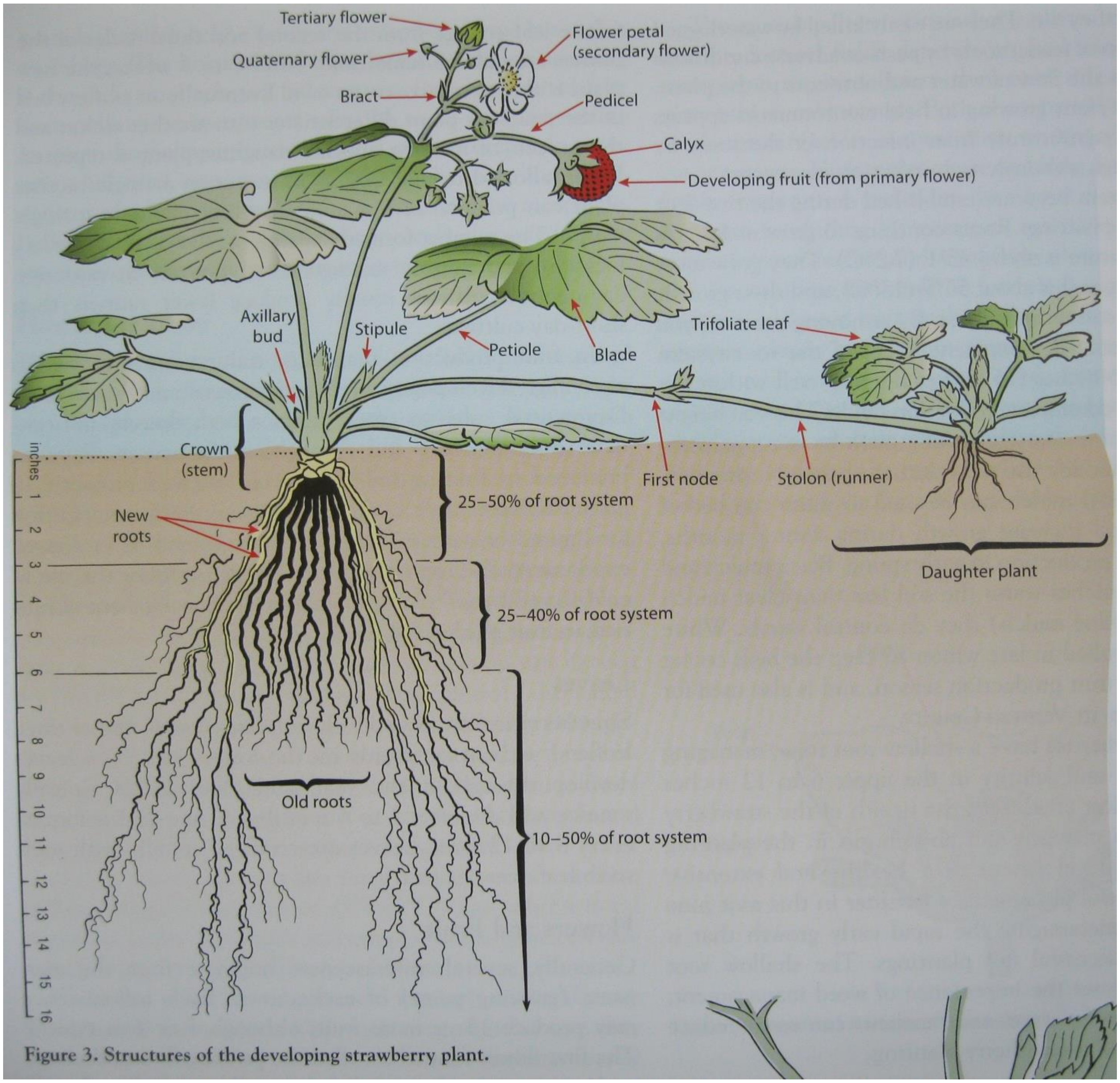


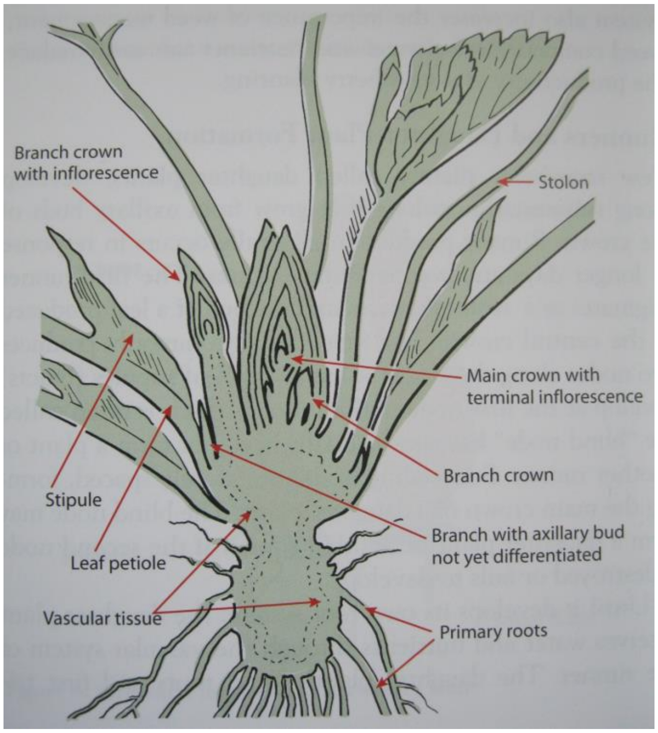
Figure 3. Structures of the developing strawberry plant.

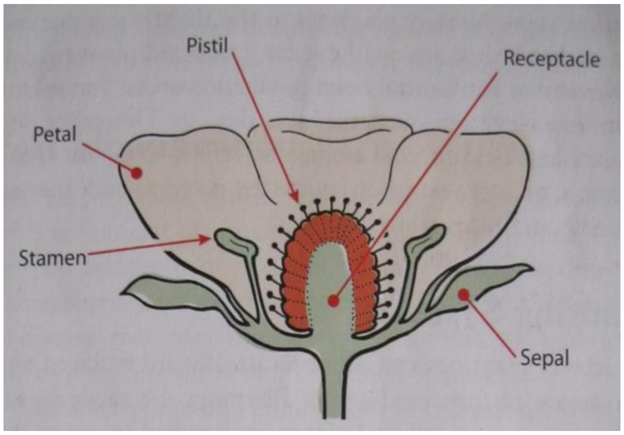
Strawberry plant belongs to the family of Rosaceae. It is propagated by stolons or runners. Leaves are trifoliate (have three leaflets) and are produced from the crown. Strawberries are self-pollinated. Strawberry plants have adventitious root system which is grown from the stem tissue of the crown. It is important that most of the crown of a transplant should be in contact with soil that is kept moist. Otherwise roots are produced at higher levels of the crown and affect the productivity. Primary roots are also called structural or peg roots which are usually 20-30 per plant. They can live for 1 to 2 years. Secondary roots are fine roots that develop from the primary roots and are called feeder or white roots. They live only for a few days or weeks. While primary roots store starch produced by the plant, secondary roots absorb water and nutrients from the soil.

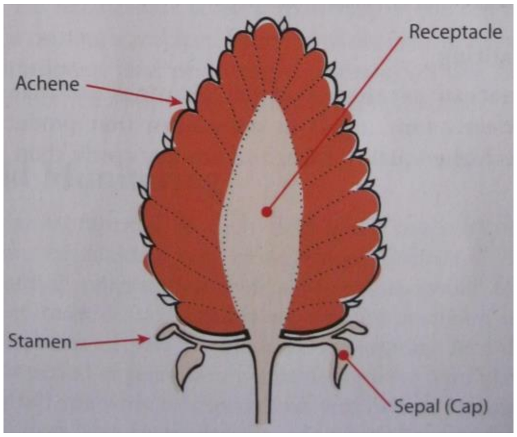
Root system establishes during the first 2-3 months after planting. Rapid growth occurs at 13 °C (55 °F). Most of the root system is in the upper 15 cm (6 inches) of the soil. Maximum net growth of the strawberry plant occurs at temperatures between 15 to 26 °C (59-79 °F)

Crown: Strawberry crown is a shortened stem. Leaves and nodes are produced from the crown. Axillary buds are embryonic tissues between the stem and a leaf. They can develop into stolons with long days (day length >14 hours) and warm temperatures (>15 °C or 59 °F). Removing runners promotes branch crown formation which are similar to the main crown and produce inflorescence. Day lengths <14 hours and temperatures cooler than < 15 °C stimulate inflorescence development. Optimal number of inflorescences provides good sized berries. Crown growth and development are at the best at > 10 °C (50 °C).

Flower and fruit: White flowers with 25-30 yellow stamens and 50-500 yellow pistils on a raised receptacle. It is self-pollinated and does not require honeybees. Receptacle and ovary tissue develop into the horticultural fruit. The true botanical fruit is the seed called achene.







California strawberries: About 87% of the strawberries produced in the US are from California with a value of about $1.8 billion according to the 2010 data. About 75% of these berries are for the fresh market and the remaining for processing that includes frozen, canned and other forms of processed berries. California strawberries are exported to Australia, Canada, Hong Kong, Japan, Mexico, UK and other countries. In 2010, strawberries were grown in 15,225 ha with an average production of 78.8 tons/ha. Strawberry production is a refined process that requires intensive management at every step from the selection of cultivars to the harvesting and marketing of the berries. The estimated average production cost is about $110,000-120,000/ha which includes $54,000-62,000 of non-harvesting cost and $57,000 of harvesting cost. Depending on the yields and market value, profit can be estimated to be about $50,000/ha.

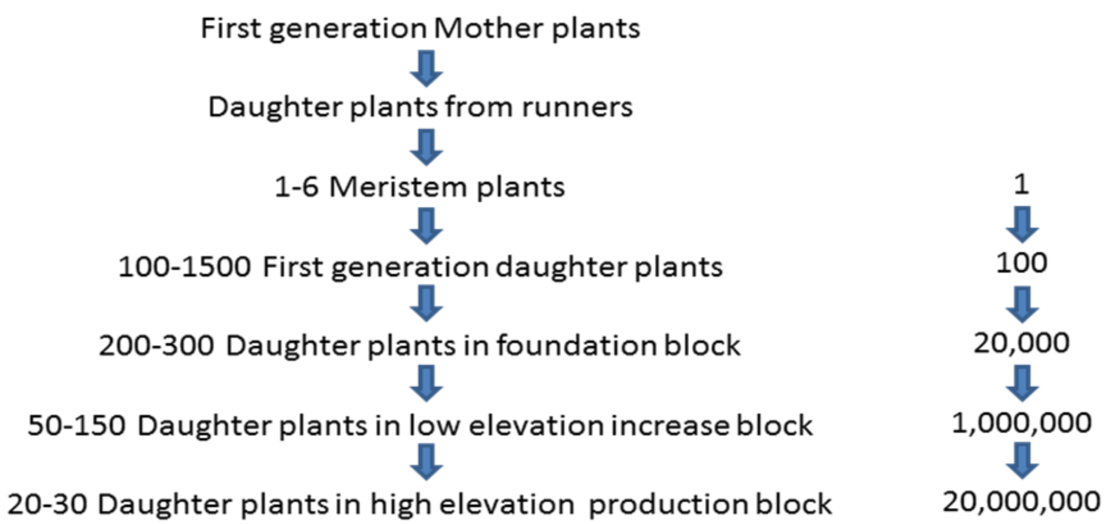
Strawberries in California are grown mainly in the central and southern coastal areas. With earlier production in warmer southern areas to later production in cooler northern area, strawberries are harvested throughout the year. Growing short-day and day-neutral cultivars during two planting seasons contribute to this yearlong availability of strawberries. Fall planting takes place from late September to mid November and summer planting takes place from the end of May to early August.

Majority of the cultivars grown in California are developed by the University of California breeders. Strawberries have two types of cultivars – short-day or June-bearing cultivars and day-neutral or everbearing cultivars. Short-day cultivars require short days of 14 hours or less. They produce berries during mild coastal California winters. Benicia, Camarosa, Camino Real, Chandler, Mojave, Palomar, and Ventana are examples of University of California short-day cultivars. Day-neutral varieties are not sensitive to the day length and produce berries throughout the year with favorable temperatures. Albion, Aromas, Diamante, Montrey, Portola, San Andreas, and Seascape are some examples of day-neutral cultivars.

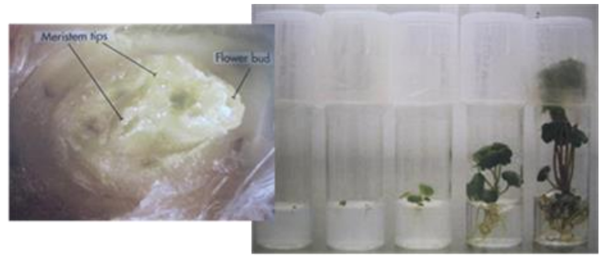
Propagation of strawberries: Strawberries are propagated by stolons. Producing strawberry transplants is a carefully crafted procedure which is refined over years. It involves producing millions of transplants for the production fields from a few clean plants from the breeding stock. Strawberry transplants need to be hardened through chilling (or exposure to cold temperatures) before they are ready to be planted in the production fields. Cold temperatures in the high elevation nurseries slow the plant growth, transfer the nutrients (carbohydrates) from the leaves and stems to the crown and root. Once the transplants are planted in the production fields where the temperatures increase as the season progresses, the stored carbohydrates will promote the new growth. High elevation nurseries in northern California allow adequate chilling of the plants in the field before digging them for the production fields.

Adequate chilling is very important for optimal plant growth. Excessive chilling results in increased plant vigor (vegetative growth) and reduced flowering branches, which means fewer berries. Insufficient or no chilling reduces vigor, fruit production and quality. It also increases the susceptibility to diseases and pests.

The chart below shows different stages of producing nursery plants.



First generation Mother plants -Daughter plants



Meristem tips in tissue culture

First generation daughter plants

Daughter plants in low elevation increase block

First field generation plants in foundation block

Daughter plants in high elevation production block

Selection of the field: Choosing an ideal field with desirable characteristics and minimum of potential pest problems is important to reduce management costs. Deep, well-drained, sandy loam soils are preferred for strawberry production because field preparation is easier, fumigation is more effective, accumulation of salts is less, drainage is better, and the soil is better suited to the frequent irrigation and field activity that strawberries require. Choose fields that are easy to grade to the proper slope and have good air drainage so cold air doesn't settle in the field. Avoid poorly drained soils to minimize problems with root diseases and those infested with stubborn weeds. Ensure an adequate supply of good-quality water.

Have the soil and water tested for salts and salinity. If the water supply has more than 900 to 1000 ppm total salts, special precautions will be needed to avoid injurious salt buildup. If salt levels are too high you may want to avoid planting strawberries or plan extra irrigations to rinse excess salts away from the strawberry root zone. Irrigations to reduce soil salinity are best done before preparing fields for fumigation and planting and can take years to improve conditions measurably.

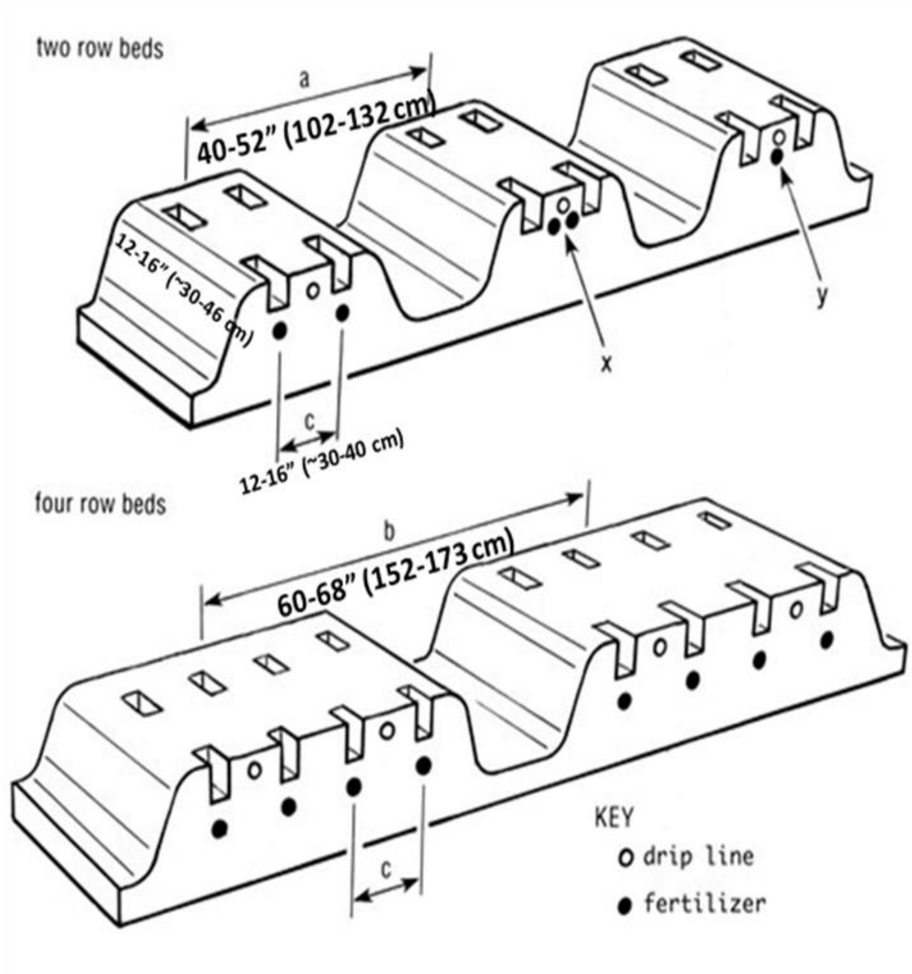
Crop Rotation: Rotating strawberries with a cover crop such as rye, barley, or a mix of barley and bell beans may enhance pest control and helps improve soil structure. A heavy stand of cereal rye or barley provides additional weed control because these crops are very competitive with weeds and broadleaf herbicides may be used to control weeds that can be serious problems in strawberries. In addition, rye and barley do not host pests that attack strawberries and can help reduce root knot nematode populations and soil levels of *Verticillium.* Mustards generally are the best weed competitors among commonly used cover crops, and their residue breaks down faster compared to cereals. Additionally, mulched mustard residue reduces viability of *Phytophthora* in the soil.

Fumigation: Fields are fumigated to manage weeds, diseases and soilborne pests.


Whole field fumigation


Bed fumigation

Bed configuration: Center-to-center spacing of beds is 40 to 52 inches for two-row beds (a) and 60 to 68 inches for four-row beds (b). Row spacing (c) is 12 to 16 inches and plant spacing within rows is 12 to 18 inches). Slow-release fertilizer or monoammonium phosphate type fertilizer may be placed 1 to 1 1/2 inches below the level of transplant roots. Fertilizer may also be placed to the side of the planting slot and slightly above the level of the transplant roots (x) or below the drip line (y), positioned so that irrigation will move nutrients into the root zone. Placing the fertilizer to the side of the planting slot decreases the risk of fertilizer burn, while placing fertilizer higher in the bed increases the likelihood of salinity problems. Fertilizer also may be broadcast and incorporated into the bed.



Plant density is 22,000 to 28,000/acre for 4-row beds (common is 24,000/acre) and 16,000-20,000/acre for 2-row beds.

Bed preparation: Two or four row beds are commonly used.










Plastic mulches: Strawberries are cultivated in raised beds covered with polyethylene mulches. Mulch conserves soil moisture, reduces weeds, regulates soil temperature and thus influences plant growth and fruit production, and reduces salinity buildup. Mulch also helps keep the fruits clean by avoiding contact with soil and irrigation water. Additionally, they facilitate fumigation of the beds before planting. Mulches are available in a variety of colors and are suitable for a variety of situations.

Clear: Heats up soil by allowing the sunlight to penetrate. Useful during cooler seasons of the year or in cooler regions. Warm temperatures early in the season help to stimulate crown development and enhance yields. Weed growth can be a problem with clear mulches.

White: Cools soil significantly. Slows down early growth, but helps with larger fruit production and to extend fruiting season in some cultivars. Does not inhibit weed growth. Reflects insect pests like whiteflies.

Green, brown or black: Provide soil warming, but less than clear mulches. Control weed growth. Fruit can burn during hot weather with black mulch.

White top and black sides: Cools the soil, but can control weed growth. White part reflects insects.

Clear top and black sides: By allowing sunlight, the top part promotes the early plant growth. Afterwards, expanded canopy and black sides work more like black mulch.

Silver: Cools the soil. Reflects insects.

Plastic mulches in different colors

Transplanting: For fall planting, freshly dug transplants from high elevation nurseries are used with some supplemental chilling as needed. Plants from the low elevation nurseries are dug in December or January and refrigerated at -2 ^{o}C, which will be used for summer planting. Transplanting is done manually. It is important to keep the roots straight (avoid ‘J’ root) while transplanting to ensure good establishment and proper plant growth.

Transplanting

Fertilizer management: Proper fertilizer management is important for a healthy plant growth and good yields. Preplant application of 100, 44 and 72 kg/ha of nitrogen phosphorus and potassium, respectively is ideal. After the planting, fertilizers are applied as needed. Micronutrients are provided through foliar application at weekly intervals. Approximate seasonal and daily uptake of nutrients is as follows:

- Seasonal uptake

	Plant	**Fruit**	**Total**
• Nitrogen	144 kg/ha	100 kg/ha	244 kg/ha
• Phosphorus	22 kg/ha	22 kg/ha	44 kg/ha
• Potassium	100 kg/ha	155 kg/ha	255 kg/ha

Irrigation management: Good quality of irrigation water is important as high salinity can be detrimental to the plant growth. Proper spacing of the drip tapes and irrigation regimen are required to provide adequate water supply for the plants and to avoid salt deposits in the root zone. After transplanting, sprinkler irrigation is generally provided for 4-6 weeks to help establish the plants and move the salts away from the root zone. This is especially more common in warmer areas. However, recent research suggests effective irrigation management with drip irrigation alone. Drip irrigation is typically provided 1-3 times a week depending on the crop needs.

Cultural practices: Regular monitoring of the fields to detect disease and pest problems or examine plant growth is critical. Removal of dead plant material and decaying fruit will minimize disease issues. In California, drive ways around the field are frequently sprayed with water to prevent dust build up on the plants. At the edge of the beds, barley or similar grasses or planted as live fences to prevent dust. This will help with maintaining clean berries as well as reduce mite infestations, which become serious in dusty conditions. Flowering plants like wild mustard, wild radish, and alyssum are grown near the fields to attract and support natural enemy populations. Where soil erosion is a problem, certain plants like barley and trios are grown in the furrows.

Moinitoring

Sanitation

Dust control

Trap crops

Erosion control

Harvesting and postharvest handling: Stage of ripening of the fruit, cleanliness, and temperature are three major factors that influence harvesting and postharvest quality of the strawberries.

Fruit: Strawberries do not ripen after harvesting. They need to be harvested when they are ripe, red and fresh. Time of harvest depends on the readiness of the fruit and market demand. Plant nutrition can contribute to the firmness and keeping quality of the fruit.

Cleanliness: Keep the fruits clean as much as possible. Watering the roads to keep the dust off the fruits and minimize the exposure to the soilborne microorganisms. Handle the fruit with clean hands or use gloves to minimize microbial contamination. Educate the harvest workers about sources of contamination, potential implications (health issues, damage to the reputation, loss of revenue, etc.), and measures to minimize contamination.

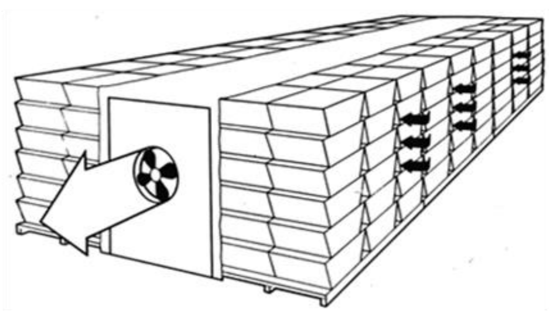
Temperature: Temperature plays a major role on the shelf life of the fruits. Keep the fruits at optimal temperatures as much as possible. If possible, pick the fruits early in the day before temperature rises. Keep the fruit in the shade before moving to the cold storage. Use forced air cooling system to circulate the cool air and bring down the fruit temperature to optimum level. Transport in appropriate containers and in optimal conditions. Delay in transportation to cooler beyond two hours after harvest reduces marketability. Shelf-life is longer at 0-2 °C.

Other factors: Pack the berries in appropriate containers. Minimize vibration damage during transportation. Minimize the time of exposure to unfavorable conditions.

Typical strawberry harvesting scene in California where strawberries are picked by hand, examined before the trays are transported (above). Strawberry trays with eight 1 lb boxes (below left) or four 2 lb boxes (below right).

Harvesting strawberries for the processing market. Berries are picked, the top part is cut off, and they are transported in bins.

Storage: Fresh market strawberries are cooled to 0 ^{o}C and usually shipped in refrigerated trucks within 24 hours of storage. Forced-air cooling inside the tunnels (see below) allows uniform cooling of all the berries in the trays.



California tunnel

Abiotic disorders: Nutritional imbalance, adverse growing conditions and phytotoxicity of chemicals causes certain disorders.

Nitrogen, phosphorus, and potassium deficiency symptoms

Iron, zinc, and boron deficiency symptoms

Low temperature injury, white tip and sun scalding in strawberries

Nitrogen deficiency: Older leaves are affected first. Uniformly yellow or reddish orange coloration. May reduce flower and fruit size. Fruit can be excessively sweet.

Phosphorus deficiency: Older leaves turn dark green with shiny upper surface, purplish lower surface and blue veins. Fruit size is reduced.

Potassium deficiency: Older leaves turn purplish black with scorched appearance. Area between leaves is discolored. The youngest leaves are not affected. Fruit tasteless and doesn't develop full color.

Zinc deficiency: Young leaves turn yellow and abnormally narrow with green veins and margins. Fruit size and number reduced.

Iron deficiency: Young leaves yellow with bright green veins. Bleached white leaves with brown margins with severe deficiency. Fruits look normal, but yield is reduced.

Boron deficiency: Young leaves crinkled with yellow or burnt tips. Small flowers producing small, lumpy fruits with few seeds. Short, stubby and darkened roots

Salt injury: Leaves become brittle with brown and dry margins. Causes include high salt content in irrigation water or soil (damage uniform in the field), poor drainage (damage in localized areas), and excessive fertilization (damage in distinct pattern). To remedy this problem, improve soil drainage and use drip irrigation to keep salts diluted and avoid moisture stress.

Low temperature injury: Cold and dry temperatures affect flower development and result in deformed berries with small or missing achenes. Frost during flowering or early berry development also causes berry malformation.

White tip: Exposure to cold temperatures early in the season results in white tip.

Sun scalding: High temperatures or contact with mulch that is too hot can result in sun burn.

Diseases: Strawberries can suffer from a variety of diseases. Choosing resistant cultivars, obtaining transplants from a clean source, proper irrigation, and timely detection and treatment are important in managing the diseases.

Angular Leaf Spot: Caused by the bacterium *Xanthomonas fragariae*. Can be a problem with rains. Infected transplants are primary source of infection. Light green to reddish brown, water soaked spots appear on the underside of the leaves between the veins. Thick fluid exudes from these spots and give a shiny appearance when it dries up.

Anthracnose: Appears as dark brown or black lesions on petioles and runners, deformed and yellowing of leaves, reddish brown crown tissue when cut open, root and crown rot with eventual wilting of plants. Caused by *Colletotrichum acutatum.* Can be a serious problem in production fields when infected transplants are used

Gray Mold or Botrytis Rot: Caused by *Botrytis cinerea* is a common and serious disease. Occur at all stages of fruit development and in storage. Symptoms appear as small, brown lesions near calyx and as the infection spreads powdery, gray fungal growth is seen all over the fruit. Flowers can also be infected when the fungus is aided by cool temperatures and water. Fungus can stay dormant in the floral tissue, in the soil and in the decomposing organic matter.

Phytophthora Crown Rot: Caused by several species of *Phytophthora.* Results in small leaves and stunted plants. When crown is cut open brownish discoloration is seen in the tissue. Excessive irrigation or poorly drained soils worsen the problem

Powdery Mildew: Podosphaera aphanis is the causal agent affecting leaves, flowers and fruits and resulting in yield loss. Symptoms include white, powdery fungal growth on the lower surface of the leaves, upward curling of the leaf edges, and dry, purplish patches on the upper leaf surface as the disease advances. Dry leaf surfaces, cool to warm temperatures and high humidity favor the infection.

Verticillium Wilt: Caused by *Verticillium dahliae*. Usually seen after fruit production begins as browning and wilting of the old leaves. Young leaves stay green, but severe infection results in plant death.

Charcoal Rot: Caused by *Macrophomina phaseolina*. Symptoms appear as wilting and collapsing of plants. Crown tissue, when cut open, shows reddish brown discoloration. Roots turn dark brown. Can be a problem with water stress when temperatures are high.

Angular leaf spot

Phytophthora crown rot

Anthracnose

Powdery mildew

Gray mold

Verticillium wilt

Charcoal rot

Integrated Pest Management: Integrated pest management or IPM is a strategy where all available management options are used for controlling pests in an economically and environmentally sustainable manner. Using resistant cultivars, appropriate cultural, biological, and chemical control practices are some of the common practices in IPM.

Cultural practices:

- Choosing disease and pest resistant cultivars and good nursery stock.
- Managing weeds and alternate hosts which harbor pests and diseases.
- Providing refuge for wild populations to reduce pesticide resistance.
- Field sanitation.
- Adequate chilling of transplants for robust growth.
- Irrigation and nutrient management to promote healthy growth and to avoid disease problems.

Chemical control:

- Choosing the right chemical
- Rotating different modes of action to reduce the risk of resistance.

Biological control:

- Conserving natural enemies.
- Providing refuge for natural enemies.
- Using chemicals that are less disruptive to natural enemies.