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630 US ISSN 0271-9916 March 1993 RESEARCH EXTENSION SERIES 141

FIELD TOMATO PRODUCTION GUIDELINES FOR HAWAII

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The Library of Congress has catalogued this serial publication as follows:

Research extension series / Hawaii Institute of Tropical Agriculture and Human Resources.—001-—[Honolulu, Hawaii]: The Institute, [1980–
v. : ill. ; 22 cm.
Irregular.
Title from cover.
Separately catalogued and classified in LC before and including no. 044.
ISSN 0271-9916 = Research extension series - Hawaii Institute of Tropical Agriculture and Human Resources.
1. Agriculture—Hawaii—Collected works. 2. Agriculture—Research—Hawaii—Collected works. I. Hawaii Institute of Tropical Agriculture and Human Resources. II. Title: Research extension series - Hawaii Institute of Tropical Agriculture and Human Resources.
S52.5R47 630'.5—dc19 85-645281
AACR 2 MARC-S
Library of Congress [8506]

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INTRODUCTION

The tomato, *Lycopersicon lycopersici*, is the number one vegetable crop in Hawaii in terms of popularity and market value. This unique vegetable, a member of the family Solanaceae along with the peppers and the Irish potato, is a native of Central and South America. Nutritionally, a medium-sized tomato (5.3 oz) contains 35 calories and is rich in vitamin C, vitamin A, potassium, and fiber. It is a warm season crop, grown in Hawaii from sea level up to 6000 ft in elevation.

In 1991, 14 million lb (6400 MT) of tomatoes were consumed in Hawaii, of which 23 percent were produced locally on 230 acres (95 ha). The farm value of local production of tomatoes in Hawaii for 1991 was about $3.1 million, with production concentrated in Kona, Mountain View, Kula, and on Molokai. Local production has decreased substantially over the past few years due to crop losses caused primarily by the tomato spotted wilt virus (TSWV).

Flowering and Fruiting

The tomato is self-pollinated. Flowers are borne in clusters located on the stem between the nodes. Tomatoes, especially the large-fruited varieties, are sensitive to high nighttime temperatures, which may lead to lower fruit set or to development of small, seedless fruit. Optimum temperature for fruit set is 60–70°F (15–20°C). Fruits reach the mature green stage about 27 days after fertilization. Environmental stress such as poor nutrition, unfavorable weather, or insect and disease pressure may result in abscission during or after flowering.

Cultivars

Cultivar selection is one of the most important decisions made during the crop production process. Selection of cultivars adapted to local growing conditions and seed quality are significant production factors that deserve careful planning and consideration. Cultivars developed by the University of Hawaii, now over 15 years old, have resistance to bacterial wilt, vascular browning, fusarium wilt race 1, common races of root-knot nematode (gene Mi), spotted wilt virus (gene Swa), *Stemphylium solani*, and spider mites. Growth characteristics to consider during cultivar selection include plant habit, jointlessness, and fruit size, shape, color, firmness, and smoothness. Market traits to consider include pack-out, fruit size and shape, ripening, firmness, and flavor.

In Hawaii, 'Celebrity' is the industry standard for bush-type tomato, but production of this semideterminate cultivar has decreased dramatically over the last few years due to its susceptibility to TSWV. PetoSeed has recently released hybrid cultivar 'PSR 55289' with resistance to TSWV and with horticultural traits similar to those of 'Celebrity'. Its future availability will depend on local grower demand. See Table 1 for a list of cultivars adapted to Hawaii.

Table 1. Cultivars adapted to Hawaii

Cultivar	Large fruited	Plum or paste type	Cherry type
Open pollinated			
Healani	+		
Tropic*	+		
8222	+		
8248	+		
Roma		+	
San Marzano		+	
Large Red Cherry			+
Royal Red Cherry			+
Hybrid cultivars			
PetoSeed PSR 55289	+		
Celebrity	+		
N-52*	+		
N-65*	+		
N-69*	+		
BWN-21	+		
Small Fry			+
Cherry Challenger			+
Cherry Grande			+
Sweet Million			+

*Requires staking and pruning.

Cultivars that have performed well in Hawaii based on Molokai winter trials (where spotted wilt has not been detected) include 'Milagro', 'Celebrity', 'Carmen', 'Cavalier', and 'Carnival'. On Molokai, 'Celebrity' was the most productive, with experimental yields of over 50,000 lb/acre (56 MT/ha).

FERTILIZER RECOMMENDATIONS

Optimum pH

The optimum pH is 6.0–6.5. Liming to raise the pH to 6.0–6.5 may aid in reducing fusarium wilt in the field.

Nutrient Rates

Fertilizer applications should be based on crop nutrient demands and stage of crop growth. Tissue and soil analysis will help to determine how much fertilizer to apply to complement the nutrient levels already available in the soil. Soil samples should be taken and appropriate fertilizers added as recommended by University of Hawaii soil scientists for the particular soil type. Excessive fertilizer application beyond crop needs may result in salt buildup, phytotoxic effects on plant growth, groundwater contamination, and capital losses due to purchase of unneeded fertilizer. Recommended rates for Hawaii are 1500–2000 lb/acre of 10–20–20 or similar fertilizer, with half applied at planting and the remainder four to five weeks later. Supplemental 100 lb/acre urea or 200 lb/acre sulfate of ammonia can be applied every three to four weeks after harvest begins. Phosphorus is an important nutrient for root development, flower development, fruit set, and fruit maturation.

On soils that test low for phosphorus, apply 1000 lb/acre treble superphosphate. This is applied preplant in 12-inch (30 cm) bands in the plant row and worked to a depth of 6–12 in (15–30 cm). Soil magnesium deficiencies are corrected with 150–200 lb/acre magnesium sulfate. Minor crop magnesium deficiencies may be corrected as needed with magnesium sulfate (epsom salt) sprays of 10 lb/100 gal water per acre.

An adequate calcium supply is necessary to prevent blossom-end rot in tomatoes. Calcium deficiencies are corrected with weekly foliar calcium nitrate or calcium chloride applications at rates of 10 lb/100 gal and 5 lb/100 gal, respectively.

Fertilizer Placement

In nonmulched crops, apply all P and up to half the N and K before planting, incorporating with disks or rototilling. Supplemental fertilization during the growing season should be banded on both sides of the row.

For drip-irrigated crops, apply all phosphorus, micronutrients, and 20 to 40 percent of total N and K before laying the plastic mulch. The remaining N and K are applied at levels corresponding with the crop developmental stage. At the seedling stage, apply weekly 2–5 percent of the total N and K requirements. At the early fruiting stage, begin weekly applications of 10 percent of the total N and K requirements.

Nutrient Tissue Analysis

Periodic nutrient analysis of foliage tissue may be used to provide an estimate of a crop's nutritional status and serve as a record of crop performance. The tissue analysis should be calibrated with soil fertility levels, according to soil samples taken before planting. For tissue analysis, collect a young mature whole leaf (petiole and leaflets) located below the last open flower cluster. A representative tissue sample from a field will consist of 25 to 100 collected leaves free of insects or disease. The critical growth stage of phosphorus uptake is when the first flower cluster develops, and tissue levels should thus be maintained above 0.4 percent to avoid flower abortion. With rapidly growing plants the calcium level must be maintained above 2.5 percent from the first flower set and preferably throughout the plant life cycle. Excessive nitrogen applications resulting in tissue levels >5 percent will inhibit calcium and potassium uptake, reduce internode length, and promote excessive vegetative growth. Recommended optimum ranges for tomato are found in Table 2.

Table 2. Recommended nutrient ranges for tomato

Nutrient	Range	Target level
N	3.0–4.5%	3.0%
P	0.4–1%	0.5%
K	3.0–7.0%	3.5%
Ca	2.0–5.0%	3%
Mg	0.4–1.5%	0.4%
Fe	100–250 ppm	120 ppm
Zn	25–150 ppm	25 ppm
Mn	40–300 ppm	75 ppm
Cu	5–25 ppm	10 ppm
B	25–100 ppm	25 ppm
Mo	0.15–5.0 ppm	0.16 ppm

CULTURE AND MANAGEMENT PRACTICES

In typical commercial operations, tomatoes are grown in polyethylene-mulched beds with drip irrigation. Irrigation and fertilization can be monitored closely with drip irrigation. The plastic mulch helps to maintain efficient use of water and fertilizer. Tomatoes are susceptible to

damage from wind, and growers in windy areas should consider the use of suitable windbreaks. Protect your crop in wind-prone areas with wiliwili (*Erythrina*), yuba cane, or other shrubs suitable to your area. An in-field rotation may be conducted for the following crop by rototilling the row where the windbreak was grown, planting in the row, and preparing the bed in that area.

Time to Plant

In Hawaii, tomatoes are grown year-round at 1000–3000 ft (300–1000 m) elevation, from March through August at 3000–4500 ft (1000–1500 m), and from September through May from sea level to 1500 ft (500 m).

Field Preparation

Plow the soil if a hard pan is present. Liming, when necessary, is broadcast and disked along with any crop residue or weeds. Bedding, fertilizing, and fumigating may also be conducted at preplant.

Propagation

Tomatoes are normally transplanted in Hawaii to assure proper stand establishment. Seedlings are transplanted three to five weeks after sowing. About 1 oz of seed/acre is needed if transplanted and 2 lb/acre if direct-seeded.

Spacing

Bush tomatoes are spaced 3–4 ft apart in rows spaced 5–7 ft apart. Trellised plants are spaced 14–24 in apart on 5-ft-tall trellises with rows spaced 5–6 ft apart.

Transplanting

Seedlings are grown in containerized plastic or styrofoam multicell packs or similar systems in which the cell surface area is 2 sq in (5 sq cm). These seedlings can then be transplanted with minimal disturbance to the root system. Early root development is enhanced with soluble 10–52–17 or similar fertilizer when applied at 3–4 lb/50 gal water. The transplants are kept in a greenhouse or shadehouse. Follow proper sanitary conditions by using sterile trays and soilless growing media. The seedlings should be carefully monitored to maintain proper watering, nutrition, and disease-free material.

Training

Staked tomatoes provide ease of harvest and higher fruit quality by keeping fruits off the ground and minimizing rot. Staked tomatoes are normally pruned to one or two main stems. Staking is done two to three weeks after transplanting. Wooden stakes 50–60 in long are driven into the ground halfway between each pair of plants or between alternating pairs of plants. Plants are trained by tying them with plastic twine or construction wire onto the trellis beginning three to four weeks after transplanting; this is repeated three or four times during the growing season. The twine is tied around each stake and on both sides of the plant to provide vertical support. Before being reused, stakes should be sterilized by steaming one to two hours at 200°F under a plastic tarp, or with methyl bromide fumigation. Height of the stakes and training technique vary depending on wind conditions during the growth cycle or on traditional practices followed in the different tomato production areas of the state.

Irrigation

Drip irrigation for tomatoes has gained popularity because of its increased efficiency of water use and because it allows application of fertilizers and pesticides with the irrigation water (Fig. 1). With drip irrigation it is possible to closely synchronize weekly water and nutrient application rates with the corresponding stage of crop development.

PESTS

Tomato yields may be reduced by myriad insect and disease pests. Integrated pest management (IPM) is a systems approach to reduce pest damage to tolerable levels using a variety of techniques such as natural enemies, genetically resistant plants, sound cultural practices, and, when appropriate, chemical pesticides. The IPM approach is based on proper pest identification, periodic scouting, and the application of pest management practices during the precise stage of the crop's development when no control action would result in significant economic losses. Two additional strategies of an integrated management approach are (1) taking pest control actions during the most vulnerable stage in the pest's life cycle to maximize results with the least possible effort, and (2) using synthetic pesticide spray applications for pest suppression only after all other pest control alternatives have been considered and exhausted. The main objectives of using alternative pest controls are to reduce the high capital costs incurred with frequent pesticide applications and to maximize the abundance of beneficial organisms.

Insects

Important insect pests of tomato include aphids, armyworms, cutworms, tomato fruitworm, leafminers, melon fly, mites, root-knot

nematodes, tomato pinworm, thrips, and whiteflies. Outbreaks of the sweetpotato whitefly and the greenhouse whitefly are currently a major problem for tomato production in Hawaii. Apply insecticides only when necessary and, when possible, rotate pesticide families to delay development of insect resistance. Insects with exploding population growth rates such as thrips, whiteflies, mites, leafminers, and aphids are especially prone to develop pesticide resistance when exposed to frequent applications of the same insecticide.

Aphids. Aphids feed on plant sap, which may reduce plant vigor. Aphids may also act as vectors of plant viruses and may introduce toxins into the plant, resulting in growth deformations. Growers should use timely insecticide applications as needed based on close monitoring of aphids and their natural enemies.

Armyworms. Beet armyworm (*Spodoptera exigua*) and nutgrass armyworm (*S. exempta*) infestations on tomato may cause fruit losses of up to 25 percent. Armyworms can be distinguished by the inverted "Y" on the front of the head. Adult moths are active at night and can lay eggs on the leaves in groups of 100 or more. Feeding by young caterpillars can reduce leaves to veins, leaving only webs behind. Caterpillars normally begin feeding on the fruit after molting three or four times, and they later pupate in the soil. Damage to the fruit consists of superficial feeding wounds that dry out as the fruit matures. Small caterpillars, however, may penetrate the fruit and cause damage similar to the feeding damage caused by the tomato fruitworm. A caterpillar normally feeds on more than one fruit. Armyworms should be controlled before they reach a length of ½ in. Monitor the crop weekly, beginning at fruit set, and apply pesticides when more than 0.25 larva per plant (i.e., one larva per four plants) are detected

Cutworms. These caterpillar pests, which include the variegated cutworm (*Peridroma saucia*) and the black cutworm (*Agrotis ipsilon*), can devastate young tomato plants by chewing through the stems at the soil line. Cutworms are active at night. Control is warranted when high populations are present in the field before planting. Baits containing *Bacillus thuringiensis* are available for cutworm control. Control is normally not recommended when the plants are ≥1 ft tall.

Tomato fruitworm. The tomato fruitworm (*Helioverpa zea*) damages green fruit. It is also an important pest of corn, lettuce, beans, and other crops. Eggs are laid singly on leaflets close to the small fruits. The larva feeds on green fruit and later burrows into the soil to pupate. The pupa is formed in a tiny cell 2 in below the soil surface. Adults are active at dusk and during the night. Female moths begin laying eggs 48 hours after emergence. Important natural enemies of the fruitworm include the parasitic wasps *Trichograma* spp. and *Hyposoter exiguae*, as well as some general predators. The critical period for monitoring begins at flowering and lasts until the green fruit stage. Egg counts are made from leaves below the inflorescence. Pesticide applications may be needed when more than four viable eggs are found in a sample of 30 leaves. Pesticide treatments are also recommended when a large percentage of young caterpillars are feeding on the foliage before fruit damage has occurred.

Leafminers. Leafminers are normally a secondary pest that is kept in check by natural enemies. Both the vegetable leafminer (*Liriomyza sativae*) and the celery leafminer (*L. trifolii*) may become primary pests, however, in tomato fields where intensive pesticide use has destroyed their natural enemies. Leafminers are small yellow maggots that form trails beneath the leaf epidermis as they feed. When fully grown, the larvae drop to the soil to pupate. A monitoring program consists of placing white styrofoam or plastic pans at the soil level below the plants throughout the field to collect larvae as they drop and pupate. Insecticides are recommended when average counts rise above 20 pupae/pan/day. Because contact insecticides won't reach the larvae inside the leaf, systemics are recommended.

Melon fly. The melon fly (*Bactrocera cucurbitae*) has long been a major pest of tomatoes in Hawaii. The pest has traditionally been controlled in problem areas with protein baits and an insecticide such as malathion applied to corn border rows. Infested fruits should be removed from the field to reduce insect numbers. Do not dispose of culled fruit with live melon fly larvae in areas close to the production field.

Mites. Outbreaks of carmine spider mites (*Tetranychus cinnabarinus*) and the tomato russet mite (*Aculops lycopersici*) may occur during hot, dry weather. Tomato russet mites are tiny spiderlike animals that feed preferentially on the lower stem, and then move on to feed on the upper section of the plant and on leaves. Their life cycle—egg hatching and two nymphal stages until maturity—takes one week in hot weather. The presence of the mites is indicated by the bronze, greasy appearance of stem and leaves. Similarly, the carmine spider mite completes its life cycle in about one week. Its feeding causes leaves to become stripped with

light-colored dots. Leaves may later turn yellow and drop. Silk webbing may be present when infestation is heavy. Wettable sulfur and other miticides are effective against mites.

Root-knot nematodes. Root-knot nematodes are microscopic roundworms that feed on the roots of plants. Symptoms on the foliage caused by the affected root system include stunting, wilting, and leaf yellowing. Infested roots develop gall-like swellings. Adult stages of the nematode live inside these swellings in the roots. Before planting, tomato fields are normally fumigated for nematode control. Many commercial cultivars, including the UH-bred lines, are resistant to root-knot nematodes. Several grasses that are nonhosts to the root-knot nematode, such as oats, barley, wheat, and rhodes grass, may also be grown before tomatoes. Other nematodes that infest tomatoes include sting, stunt, reniform, and dagger nematodes. The soil may be tested to estimate the population of parasitic nematodes.

Tomato pinworm. The tomato pinworm (*Keiferia lycopersicella*) is a small caterpillar that can severely damage tomato. Crop losses can reach 80 percent, despite the application of insecticides. The yellowish green larva is 1/4 in long. Activity of the adult moth peaks between 4:00 and 9:00 p.m., at which time eggs are laid preferably in leaves just above or below the inflorescence. Young larvae tend to live in the leaves. The leaf tips are tied together by the pinworm as it feeds, making it difficult to target with insecticide applications. While some pinworms complete their life cycle in the leaf, in most cases third instar larvae perforate the fruit near the calyx. The pinworm normally pupates in the soil, but in some cases it may pupate in the fruit itself. Alternative controls include the enhancement of parasitoids, clearing of weedy areas close to the production field, quick disposal of the crop after harvest, and establishment of crop-free periods. A monitoring program for the tomato pinworm consists of weekly egg and larval counts, assessment of fruit damage, and adult counts with pheromone traps. Insecticide treatments are recommended when larval counts are above 0.25 per plant.

Thrips. The western flower thrips (*Frankliniella occidentalis*) is a vector for TSWV. This disease has caused a dramatic decrease in tomato acreage on Maui over the past few years. Thrips may also reduce plant vigor when feeding on tomatoes in large numbers. Their direct damage to fruit may cause bronzing.

Whiteflies. Recent sweetpotato whitefly (*Bemisia tabaci*) outbreaks have caused considerable losses in tomato fields statewide. The main symptom is an irregular ripening of the fruit, which is difficult to distinguish on green-mature tomatoes. The irregular ripening symptom, which is probably caused by a toxin injected by the whitefly, is visible only after ripening, when the tomatoes have normally reached the wholesaler (Fig. 2). Additional sorting operations and an in-house ripening step may be required to reduce the numbers of poorly ripened fruit. Full canopy coverage with insecticide sprays is necessary to reach the eggs and adults on the underside of the leaves. Areawide control strategies may be necessary in places where whitefly numbers are abnormally high. The sweetpotato whitefly–transmitted gemini virus, which has resulted in stunting and reduced fruit size in Florida and California, has not yet been detected in Hawaii.

The greenhouse whitefly (*Trialeurodes vaporariorum*) is also common in Hawaii tomato production areas. Parasitic wasps and predators such as the tomato bug help to keep the greenhouse whitefly below damaging levels. In contrast to the case of the sweetpotato whitefly, tomatoes can sustain greater population levels of the greenhouse whitefly without yield reductions. Control strategies will therefore vary depending on the specific whitefly species in the field. Before conducting any pest control measures, identify the whitefly species that is actually present in your field.

Diseases

Bacterial canker. Corynebacterium michiganense can be a serious disease in tomato because it can persist in the soil for many years and because it is seed-transmitted. Symptoms include wilting and cankers on stem and fruits. Drip irrigation has reduced the incidence of this disease. For control, use disease-free or certified seed. Contaminated open-pollinated seed may be treated with the following treatments:

1. Fermentation: Ferment crushed pulp for 96 hours before extracting seed at temperatures near 70°F. Stir it at least twice a day.

2. Acid: Soak freshly extracted seed in an 0.8 percent acetic acid solution. This is done by adding 1 fl oz acetic acid to 1 gal water. Place seed in loosely woven cloth and immerse in solution for 24 hours at 70°F.

Bacterial spot. Xanthomonas campestris pv. *vesicatoria* may become a problem during wet weather. Both foliage and fruits are affected. Infection occurs through natural leaf openings or through wounds in the fruit. Fruits show numerous 1/8-inch spots. Leaves show irregularly shaped brown spot lesions. Destroy tomato plants after harvest to reduce inocolum levels.

Bacterial wilt. Pseudomonas solanacearum is the most serious disease of tomatoes in the tropics and subtropics. Symptoms include rapid wilt and death of the entire plant without any yellowing of the leaves. If the stem is cut and placed in a glass of water, a gray bacterial ooze is visible. The disease is difficult to control because it remains in the soil for many years. Contaminated fields should be rotated with non-solanaceous crops. Prevent machinery and field personnel from moving from contaminated to noncontaminated soils. The disease penetrates the plant through wound openings in the roots. Old cultivars 'Kewalo' and 'BWN-21', developed by the University of Hawaii, are highly tolerant to bacterial wilt.

Blossom-end rot. This physiological disease may cause severe yield reductions in tomato. The initial symptom will be a slight, water-soaked discoloration on the blossom end of fruits. The lesions enlarge and turn dark brown or black. An irregular water supply compounded with a fast growing crop may promote blossom-end rot. The disease results from a localized calcium deficiency in the fruit. Calcium is translocated in the plant through the transpiration flow. Being the major vascular system sink, the leaves obtain the primary supply of calcium; when calcium deficiencies occur, the fruits are the first organs to show deficiency symptoms. Factors that have an effect on the plant's calcium supply should be monitored: cultivar, plant nitrogen status, soil fertility, pH, and an even moisture supply in the root zone. Nitrogen overfertilization may accentuate blossom-end rot by promoting excessive shoot growth.

Blotchy ripening, or gray wall. This physiological disease, also called internal browning, is characterized by irregular browning on the side walls of the fruit. The fruits develop a normal red color except in the affected areas. A cross section of affected fruits shows brown veins with yellow to gray cells in the blotched areas. The incidence of blotchy ripening is increased with tobacco mosaic virus (TMV) infection, succulent growth, low potassium, and sudden temperature changes. Commercial cultivars have good resistance to this disease.

Catface. In this physiological disorder, fruits show extreme malformation and scarring at the blossom ends. Catface results from any growth factor that affects normal pistil development in the flower. Prolonged heat during blossoming and other stress factors may result in catfacing. Most commercial varieties are not affected by catface. Remove affected fruits as soon as possible so that remaining fruits are allowed to develop.

Double streak virus. This disease is normally a combination of TMV and potato virus X or Y. A combination of TSWV and potato virus Y can also cause the disease. The initial symptom is light green mottling of leaves followed by development of small grayish brown spots on leaves. Later, brown spots appear on stem and leaf petioles. Infected plants are stunted and fruits, if produced, are covered with dark spots. The virus complex is transmitted mechanically. Controls include growing TMV-resistant cultivars and determinate cultivars that do not require pruning (Fig. 3).

Early blight. Symptoms of the fungus *Alternaria solani* are concentric lesions of dead tissue on leaves and stems, as well as spotting on leaves and fruits. The disease can result in crop defoliation during warm, wet weather any time during the crop cycle. Controls include a three-year rotation; planting on wide, high beds; and fungicide treatments.

Fruit cracks. Three common types of physiological cracks make fruits unsalable and permit the entrance of secondary disease organisms: (1) radial, in which cracks radiate from the stem; (2) concentric, in which cracks extend in a more or less circular fashion around the stem-end portion of the fruit, and (3) splitting or bursting, which occurs in nearly ripe fruit after rain or irrigation. Cracking can be partially controlled by providing an even moisture supply, thus preventing alternating stages of fast and slow fruit growth.

Fusarium wilt. Fusarium oxysporum f. *lycopersici* is a soilborne fungus that enters the plant through the root and interferes with the plant's vascular system by stopping the transpirational flow. As a consequence, the lower leaves are the first to turn yellow and wither. The symptoms progress and eventually the entire plant is affected, with a dark brown discoloration in the bark of affected areas and with live leaves limited to the branch tips. Commercial cultivars are available with resistance to races 1 and 2. In addition, sanitation, rotation with grass crops, soil fumigation, and soil pH near 6.5 should be used for control of races 1, 2, and 3.

Gray leaf spot. Stemphylium solani begins as small, circular, sunken brownish lesions with spots surrounded by a yellow halo. The fungus is favored by hot weather, and it can cause severe defoliation in susceptible cultivars. Best control is achieved with resistant cultivars. Destroy the tomato crop promptly after harvest.

Late blight. Phytophthora infestans causes severe defoliation, stem girdling, and severe

fruit rot. Cool nights and warm days with abundant moisture favor development of this fungus. Fruit symptoms include irregular water-soaked spots that turn brown and wrinkle at the surface. Control includes careful monitoring and use of fungicide applications.

Puffiness. This physiological fruit disorder is common during the winter or early spring. Affected fruits are light and feel soft. Fruit shape is normal, but the surface is flattened or shrunken over the sections between the internal walls. Fruit cross sections show a normally developed outer wall and poorly developed seed locules, with existing cavities between the locules and the outer wall. Factors that may promote puffiness include poor pollination, excessive N applications under cloudy weather, excessive irrigation, and temperature extremes.

Sclerotinia. Sclerotinia sclerotiorum can cause serious losses in both tomato greenhouse and field operations. The fungus attacks the main stem at the soil line and is characterized by water-soaked areas that become light to dark brown. Further disease development results in wilting and plant death. Masses of white mold and black sclerotia are identifying characteristics. High moisture and temperatures promote disease development. Control the disease with proper sanitation, soil drainage, crop rotation with grass crops, and fungicide applications. This disease may build up in nearby bean fields.

Tomato spotted wilt virus. Growth ceases and the tomato plant ages quickly after infection with TSWV. In older plants, leaves near the growing tips show dark bronze or purplish circular, necrotic spots. Fruits also show circular concentric marks (Fig. 4). TSWV is the only virus known to be transmitted by thrips. The only effective means of control is resistant cultivars. 'Celebrity', the standard tomato cultivar in Hawaii, is highly susceptible to the new strain of spotted wilt. The PetoSeed hybrid 'PSR 55289' has shown resistance to TSWV and has comparable horticultural traits to 'Celebrity'.

Tobacco mosaic virus (TMV). Symptoms include mottling or mosaic effects on the leaves. Infections occurring when plants are young can significantly reduce yields. The virus is transmitted mechanically, through pruning and staking, and by field workers. Several commercial varieties are resistant to TMV.

Weeds

An integrated approach can be used to manage weed competition in tomato production. The IPM program for weed control uses weed identification, monitoring, sanitation, alternative cultural practices, and timely herbicide applications. A weed map for each field helps in the design of weed control measures and is a record of weed problems in the field. Cultural control practices for weed control include shallow cultivation, plowing, disking, hoeing, crop rotation, cover cropping, living mulches, organic or plastic mulching, and herbicides. The benefits of proper field preparation cannot be overemphasized to improve tomato growth and minimize weed problems during the crop growth cycle.

Useful crops for rotation with tomato include alfalfa, sugarbeets, and onions. Solanaceous crops such as potatoes and pepper are not recommended as rotation crops with tomato. Problem weeds in tomatoes include perennials, dodder, weeds of the nightshade family (solanaceous family), and grasses. The critical weed-free period for tomatoes (i.e., the number of days the field has to be kept weed-free after transplanting to prevent yield losses due to weed competition) is estimated to be between 30 and 35 days after transplanting.

HARVEST AND POSTHARVEST PRACTICES

Timing

Time from transplant to first harvest is generally 70–75 days for cherry types, 75–80 days for plum types, and 80–90 days for large-fruited tomatoes.

Production Yields

In Hawaii, bush tomato culture yields 20,000 lb/acre, while trellised tomato culture yields 30,000 lb/acre. The average Florida yield is 30,000 lb/acre, and the average Ohio yield is 13,500 lb/acre.

Maturity

Tomato fruits mature about 25–30 days after pollination. Maturity is correlated with increased fruit size, weight, specific gravity, total acidity, and hydrogen concentration. Grades for fresh tomatoes are U.S. No. 1, U.S. Combination, U.S. No. 2, and U.S. No. 3. Fruit category sizes for tomatoes are large, 7.2 oz (205 g); medium, 5.3 oz (150 g); and small, 4 oz (115 g). Harvesting stages for tomato include immature green, mature green, turning, half-ripe or pink, and ripe or red-ripe. Indices of maturity for green picked tomatoes include (1) size, which varies with cultivar; (2) a rounded shape, not angular; (3) a whitish green color development in the blossom end; (4) development of a brown corky tissue on the stem scar of some cultivars; and (5) a representative sample of the fruit's internal appearance (the preferred method but a destruc-

Fig. 1. Drip irrigation allows the grower to use water more efficiently and apply fertilizers and pesticides at the same time.

Fig. 3. The use of determinate cultivars eliminates the need for pruning.

Fig. 2. Irregular ripening is the main symptom in tomatoes damaged by the sweetpotato whitefly.

Fig. 4. TSWV-infected tomato fruits exhibit the typical circular blemishes.

tive test). Both cherry and plum tomatoes are normally picked vine-ripe.

Harvesting Operation

In large field operations, fresh market tomatoes are hand-picked in 40- to 50-lb buckets and placed in bins, where a truck takes them to the packing shed. An alternative harvesting operation consists of a conveyor belt on ground tomatoes. Pickers travel a few feet to the conveyor belt, where the tomatoes are placed and conveyed into the loading truck. Bruising of tomatoes from excessive handling and unloading is significantly reduced with the conveyor belt. Tomatoes should be kept in the shade until taken to the packinghouse, where they are washed, presized, sorted, graded, sized, packed, unitized for shipment, and shipped to their destination market.

Washing Tomatoes

Water for washing tomatoes should be at or above the temperature of the tomatoes. Cooler water will be absorbed by the fruits. Wash water management practices should be an important consideration during the handling process to prevent the spread of postharvest diseases. Decayed fruit should be culled to eliminate potential sources of inoculum. Wash water is chlorinated at 150 ppm, and fruits are held in this water for no longer than two minutes in a single layer of floating tomatoes.

Presizing, Sorting, and Sizing

Tomatoes with a diameter of less than 2 in are culled. This operation is carried out through an automatic presizer in large commercial operations. Sorting and grading is conducted visually in the packinghouse by separating tomatoes based on USDA color stages. This operation takes on a double effort when sorting out tomatoes with irregular ripening symptoms brought about by sweetpotato whitefly feeding on the crop during the growing season. Larger commercial operations on the U.S. mainland are moving toward the use of automatic electronic color sorters such as the ones developed for apples. Tomatoes are then sized based on market classifications and conveyed to the packing line. They are normally packed in 25-lb cartons and unitized on 2000-lb pallets. See Table 3 for more information on sizing.

Ethylene Treatment

In Hawaii, some green-picked tomatoes are treated with ethylene to enhance and promote ripening uniformity. Some growers have moved to ethylene treatment to overcome the irregular ripening caused by the sweetpotato whitefly. Preliminary research conducted at the University of Hawaii, however, did not show improved ripening uniformity with ethylene treatment; instead, it indicated the need to improve harvesting techniques and training of the harvesting crew to pick fruit at the same stage of physiological maturity. Optimum ripening is obtained when the ripening rooms are maintained at 68°F and 90–95 percent relative humidity at ethylene concentrations of 150 ppm. Ethylene is normally applied with on-site catalytic generators or with flow-through systems.

Storage

Tomatoes should be stored at temperatures above 55°F (13°C). To delay ripening of tomatoes at a particular stage, they can be held in a room below 68°F (20°C). Chilling injury occurs below 50°F (10°C).

Packaging

Mature greens are sold in 25-lb bulk-packed cartons. Fruits are packed in each carton based on fruit number per row and column in a two-layered tomato package. Pink and vine-ripe tomatoes are packed in two-layer lug or tray packs. Cherry tomatoes are packed in flats holding 12 1-pint boxes. Plum tomatoes are preferably packed in quart boxes, eight per carton. To avoid bruising, cartons are not stacked more than two layers high. Fruit is packed stem up, to protect the shoulders.

Table 3. Sizing of tomatoes[1]

Name	Size	Inches min	Inches max
Maximum large	>4×5	$3^{15}/_{32}$	>
Extra large	5×5, 5×6	$2^{28}/_{32}$	$3^{15}/_{32}$
Large	6×6	$2^{17}/_{32}$	$2^{28}/_{32}$
Medium	6×7	$2^{9}/_{32}$	$2^{17}/_{32}$
Small	7×7	$2^{7}/_{32}$	$2^{9}/_{32}$
Extra small	7×8	$1^{28}/_{32}$	$2^{4}/_{32}$

[1]Hawaii growers should check with the Hawaii Department of Agriculture for current tomato grade standards.

Market Information

In 1990 the state imported about 14 million lb of tomatoes, or ≈70 percent of the volume consumed locally. The potential for the industry is to produce 100 percent of the local demand during the summer months and 40 percent

during the winter months. If the industry could produce 70 percent of local demand, the farm-gate value would be $8.46 million, based on production of 13 million lb and the 1990 average per pound price of 65 cents.

A solid tomato production program includes a sound and well planned marketing strategy. The prospective grower needs to have a good understanding of annual market trends (see Figs. 5, 6, and 7), market competitors, consumer needs, potential buyers, and market windows. To keep abreast of changing market situations and new business opportunities, producers need to be in close contact with fellow industry representatives and with other business, university, Cooperative Extension, and government organizations.

Essential to a producer's sound marketing program is also a clear understanding of the farm's financial situation at all times during the annual production cycle. Updated farm financial records and the input of financial information in budget generators will help the grower to cut overhead and improve efficiency of production. Updated financial information and well organized farm records are also helpful in the loan application process, in assessment of crop losses by unexpected pest outbreaks, and in making timely production and financial decisions to take advantage of potential investment opportunities or unexpected market windows.

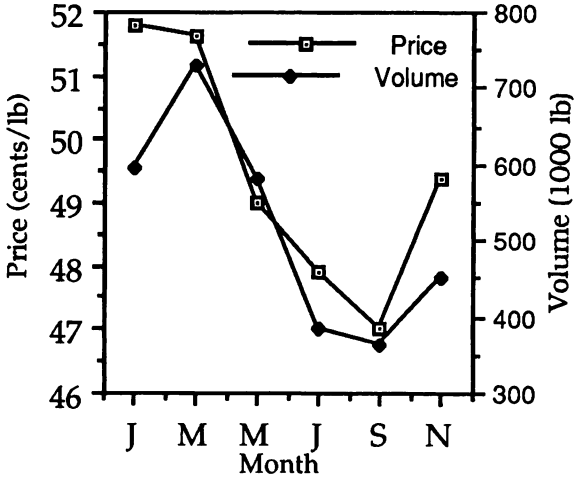

Figure 5. Average monthly price and volume for tomatoes in Hawaii, 1986–1990.

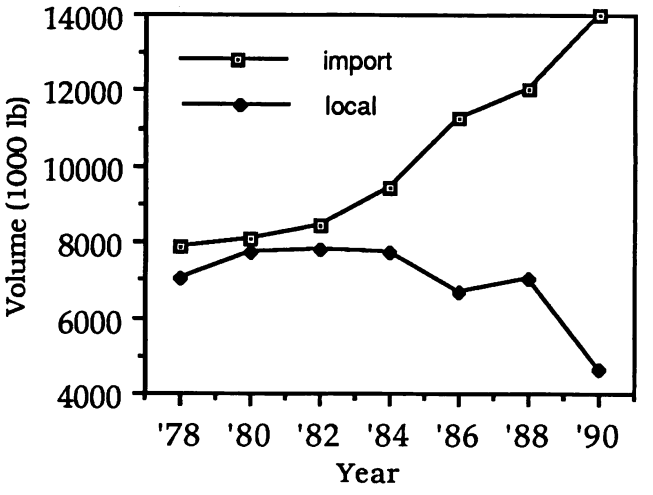

Figure 6. Hawaii tomato imports and local production, 1978–1990.

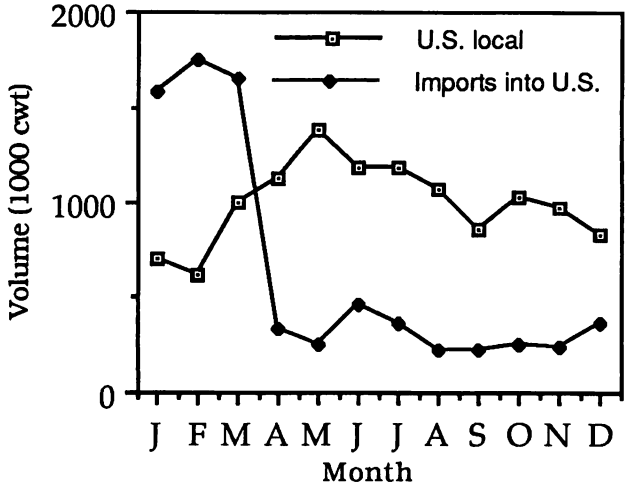

Figure 7. Monthly volume of tomato shipments in the United States and imports, 1990.

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RESEARCH EXTENSION SERIES 141—03/93 (4.5M)