

To the Graduate Council:

I am submitting herewith a dissertation written by Noble S. Kearney, Jr., entitled "Effects of Plastic Mulch and Fumigation on Yield and Influence of Postharvest Handling on Quality of Tomato (*Lycopersicon esculentum* Mill.)." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

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EFFECTS OF PLASTIC MULCH AND FUMIGATION ON YIELD AND INFLUENCE
OF POSTHARVEST HANDLING ON QUALITY OF TOMATO
(LYCOPERSICON ESCULENTUM MILL.)

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To Vernice,
with love. Many thanks.

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ABSTRACT

The effects of black plastic mulch and methyl bromide-chloropicrin fumigation on yield of 'Flora-Dade' tomatoes (Lycopersicon esculentum Mill.) under Tennessee growing conditions were studied. Total marketable yield was increased by 15-18 percent with mulch or mulch plus fumigation, over no mulch or fumigation only. Combining mulch and fumigation appeared to delay early marketable yield by promoting vegetative growth. Improved soil moisture and nutrient regimes under plastic mulch seemed to be the primary factor in improving total yields. Mulch or mulch plus fumigation may be of questionable economic advantage in areas of Tennessee where soil pathogens and nematodes are not a serious problem.

The influence of plastic mulch, fruit size, ethylene gas and storage time on fruit color, firmness, pH and soluble solids of 'Flora-Dade' tomato were also studied. Although significant differences due to the treatment inputs were found for firmness, pH and soluble solids, the magnitude of the differences may be too small to be of practical importance. Exterior and interior red color development of the fruit showed the most pronounced response to the treatment inputs. Red color development was significantly enhanced by the treatment inputs of no mulch, ethylene, and storage times of 8 and 11 days, respectively. Fruit of greater than 7.3 cm diameter had more color development than fruit of smaller diameter. Mulch appeared to exert its influence by generally optimizing growing conditions. Storage times of 8 and 11 days

had the most profound effect on the quality attributes studied, while ethylene influenced mainly red color development.

Sensory evaluation panelists could detect no differences in flavor (acidity) or color and appearance between vine ripe tomatoes or tomatoes picked mature green and ripened in storage with ethylene. They rated the vine ripe fruit as having significantly better texture and overall acceptability than the ethylene treated fruit.

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CHAPTER I

INTRODUCTION

The tomato (Lycopersicon esculentum Mill.) is a member of the nightshade or Solanaceae family and as such is closely related to the potato, eggplant and pimento pepper. Tomatoes are highly regarded for their food value, both fresh and processed, and are second only to potatoes in dollar value in the United States (74). Tomatoes probably originated in tropical America, possibly Mexico or Peru. They are a warm season plant, requiring three to four months from seeding to production of ripe fruit. Climatologically, tomatoes grow best under clear, dry weather conditions at temperatures of 18 to 30°C. Tomatoes will tolerate a wide variety of soil types and may be grown as far north as Canada. Deep, loamy well-drained soils with a good supply of lime, organic matter and fertilizer, in the pH range of 6.0 to 6.5, are ideal for tomato production (74,24).

Across the United States, some 25 states, led by California, Florida, and Ohio, have enough tomato production to report in USDA's Agricultural Statistics (71). The total values for fresh market and processing tomatoes for 1979 were \$517.8 million and \$495.6 million, respectively. Acreage for fresh market tomatoes has decreased from 147,500 in 1969 to 128,310 in 1979. However, the acreage for processing increased from 266,590 to 311,730 acres, during the same period of time. Yield per acre for both categories increased as did the value per unit (71).

In Tennessee, the majority of tomato production is concentrated in the Eastern portion of the state. The tomatoes are grown primarily for the fresh market and are sold locally or shipped out of state (62). Production for 1981 was from 4300 acres at a value of \$12.1 million to the producers. This represents an increase of about 50 percent in acreage and 70 percent in value to the producers over the 1979 figures.

Cultural practices for tomato production and postharvest handling of the fruit vary considerably in Tennessee according to grower preference and market considerations (61). Determinate as well as indeterminant cultivars are used in commercial tomato production in Tennessee. Growers either buy their transplants or grow their own. Some grow with plastic mulch while others do not. Fumigation of the soil with methyl bromide-chloropicrin to control disease, nematodes and weeds is becoming a standard practice. Producers who ship to distant markets are now harvesting mature green tomatoes and "degreening" them with ethylene to control firmness at shipping and color development (61).

In response to grower interest, studies were initiated to evaluate, under Tennessee growing conditions, the effects of plastic mulch and fumigation on tomato yield, and the influence of postharvest treatment with ethylene on certain quality attributes of tomatoes picked at the mature green stage of maturity. The results of this two-year study at the Knoxville Plant Science Field Laboratory are presented here as two journal articles, which follow a more comprehensive review of literature than is included in the articles. The literature review is divided into three sections. The first section deals with the cultural practices of soil fumigation and mulching as they affect

tomato yield. The second section reviews the biology and physiology of ethylene action. The third section reviews the effect of postharvest handling on certain quality attributes of tomato fruit.



CHAPTER II

LITERATURE REVIEW

I. Cultural Considerations

Cultural practices for tomato production vary considerably from state to state and within states; however, certain common considerations apply to all practices. Comprehensive treatment of cultural practices such as cultivar usage, land selection and preparation, transplanting, staking, irrigation, pest control, fertilization and harvesting may be found in books by Ware and McCollum (74) and Gould (24), or in extension service publications of most states (44,61).

Soil Fumigation

The soil is host to many forms of plant and animal life. Many of the organisms are beneficial; others are not. Soil treatment with herbicides, nematocides, insecticides and fungicides help to eliminate or control harmful weeds, nematodes, insects and disease pathogens (33). Soil fumigation, as a control measure on a large scale, has been practiced since the 1940's (23,33) and is used primarily on high value crops such as vegetables (22,38,67), especially where crop rotation is not practiced. Due to the volatility of most soil fumigants, incorporation into a well-prepared seed bed usually necessitates a sealant: polyethylene or paper mulches or other sealants (22,33,36). Hough and Mason (33) recommend that the soil temperature at the time of

application be between 7 and 20°C and the soil moisture be between 5 and 15 percent, on a dry weight basis.

Good and Rankin (23) evaluated eleven soil fumigants for control of nematodes, weeds and soil fungi on Georgia Coastal Plain, Tifton sandy loam. They found that Vapan 4-S, Mylone 50D and Vorlex were the only three of the eleven fumigants that controlled all three pest problems. However, methyl bromide-chloropicrin (MB-C) was not included in their study. Chloropicrin has been used successfully as a soil fumigant since 1919. The organismal toxicity of methyl bromide (MBr), a general soil toxicant, was first discovered by Le Goupil in 1932 (47). They are formulated together now as a general soil fumigant.

In another report, Good (22) compared MBr, Vapam and Mylone, under three methods of sealing with Vorlex and Nemagon for control of nematodes, weeds and fusarium wilt, using okra as the test crop. He found that MBr, when injected in beds covered with plastic mulch gave excellent control of nematodes and fusarium wilt, as well as weeds. Okra yields were significantly increased under these conditions. The other fumigants tested did not give such broad spectrum pest control as did the methyl bromide. The MB-C mix, chiseled in and sealed with plastic, is the recommended soil fumigation practice for Tennessee tomato producers (61).

For large scale operations, MBr is applied and incorporated into the soil with a chisel applicator with one or more chisels for each bed, depending on the bed width (37,67). Recent work was reported by Jaworski et al. (37) with MBr on tomatoes; they used chisels spaced 23 cm apart on mulched bed widths of 28, 56, 84, and 112 cm. They

obtained better control of nematodes and soil fungi and increased yield of tomatoes at the wider row widths. Any fumigation rate of 70 kg/ha MBr or above gave significant control of pests.

Mulching

Mulching or artificially modifying the soil surface is an old established practice with vegetable growers. Early materials used for mulching included crop residues, straw, sawdust, peat, stones and the soil itself (15). More recently, paper, petroleum, asphalt, black and clear polyethylene films and aluminum mulches have been researched (15,18,36,68,69). Mulching, regardless of the material used, produces similar effects. It improves crop performance by conserving moisture and nutrients, stabilizing soil temperature, reducing some disease, reducing or eliminating weeds and by increasing early harvest yields. Film mulches may also act as sealants for soil fumigation as part of a system approach with trickle irrigation and soil fumigation for producing high value vegetable crops (22,36,67). Reflective film mulches may also act as repellants of certain insect pests (64).

In 1931, Thompson and Platenius (69) found that paper mulch increased marketable yield of tomatoes by 17 percent and early yield by 30 percent. Further, soils from mulched plots averaged 2 percent more moisture and had significantly higher nitrification rates than those from unmulched plots. Emmert (18), a pioneer researcher with black polyethylene, in 1956, also reported higher moisture levels under black polyethylene, less leaching of nutrients, 15 to 20 percent increase in tomato yields and good weed control than from conventional culture. Jaworski et al. (36), however, observed that plastic mulch

somewhat restricted infiltration of sprinkler irrigation water under the mulch even when extra slits were cut. They recommended drip/trickle irrigation to overcome this problem. Possibly due to a more favorable moisture, nutrient and temperature regime, roots under mulch become concentrated in the top six inches of the soil (36,37).

Jones et al. (39) found that plastic mulch reduced percolation and leaching of applied nitrates in a loamy sand soil over that from unmulched soil, resulting in a 16 percent increase in tomato yield. They also found that calcium and magnesium levels were significantly higher in the covered plots. Knavel and Mohr (45) observed that mulching, especially with black plastic, promoted more lateral or horizontal development of roots in tomato, muskmelon and squash. They concluded that mulching improved the surface soil microclimate by creating a more favorable temperature-moisture-nutrient regime. *Step*

Plastic mulch alone may give good control of tomato pathogens, according to Jones et al. (38). The efficacy of soil fumigants is enhanced by using mulch as a sealant, particularly with the more volatile compounds such as MBr (22,37,38,67). As referenced earlier, Good (22) found that applications of MBr under polyethylene mulch gave excellent control of root-knot nematodes and fusarium wilt of okra, as well as controlling weeds. Pod yields were significantly increased. Covering a fumigated or treated seed bed with plastic also prevents recontamination and may permit the use of lower rates of soil fumigants (38).

Jaworski et al. (36,37) and Sumner et al. (67) advocated a "system" approach for production of high value vegetables on soils

where root-knot nematodes, fusarium wilt and weeds combine to create a serious problem. They achieved significant reductions in root-knot larvae, Fusarium spp, Pythium spp. and Rhizoctonia solani and root-gall indices while increasing tomato yield (37). The system approach involves the use of polyethylene mulch, soil fumigation (with MBr), drip irrigation and optimum fertilizer application methods and rates. This system is more costly and more labor intensive than conventional practices, but it might be well worth the extra expense particularly where the above pests are known to be present in the soil. Additional experiments with this integrated system are being conducted.

Despite the many benefits, mulches are expensive to put down and take up, especially as petroleum and labor costs continue to rise (36). For Tennessee tomato production, mulches are a part of the recommended practices, but are not widely used (61,62). However, producer interest in this cultural practice is increasing.

II. Biology of Ethylene Action

History

Ethylene, a simple hydrocarbon gas (C_2H_4), is now generally recognized as a plant hormone (53). Abeles (1), in his frequently quoted book, stated that the first report of the effects of ethylene can be traced back to Girardin, who, in 1864, reported that leaking illuminating gas defoliated shade trees in several German cities.

The Russian physiologist, Neljubov, in 1901, determined that ethylene was the active component in illuminating gas which caused pea seedlings

to grow horizontally. In 1910 H. H. Cousins advised the Jamaican government that oranges produced a gas that promoted the ripening of bananas. According to Abeles (1), by the middle 1930's most of the physiological effects of ethylene had been described, primarily by investigators at the Boyce Thompson Institute. Research in ethylene physiology waned somewhat during the 1940's and 50's due to increased interest in auxins, gibberellins, cytokinins, and abscisic acid. The advent of better analytical equipment, notably paper, gas and thin layer chromatography and advanced radiological techniques, increased the researchers' ability to quantify ethylene production very precisely. Thus, by use of these precise analytical techniques researchers began to elucidate its physiological pathway. Some of the diverse physiological effects of ethylene on plants include stimulation of ripening of fleshy fruits, stimulation of leaf abscission, inhibition of root growth, increase in membrane permeability, stimulation of flowering in pineapple, and epinasty of leaves (53). Although unique in its chemical properties and site of synthesis, ethylene is now generally accepted as a plant hormone, along with auxins, gibberellins, cytokinins and abscisic acid (2,53).

Biosynthesis

Since analyses of various fruit tissue show that ethylene is not always in high enough concentration to promote ripening, researchers were led to identify precursors and intermediates in the production of ethylene (12). S. F. Yang and co-workers at the University of California, Davis, have defined the biosynthetic pathway of ethylene in

plant tissue (2,3,10,32,79). Starting with the work by Burg and Clagett (13), which showed that methionine is the main precursor in ethylene production, Adams and Yang determined that s-adenosylmethionine (SAM) is an intermediate in the pathway (2). Radiochromatographic techniques were employed to determine that methionine combined with adenosine triphosphate (ATP) to produce SAM. Subsequently, by using radiolabeled and inhibitory compounds, they further identified the most immediate precursor of ethylene as 1-aminocyclo-propane-1-carboxylic acid (ACC) (3). Yu et al. (79) determined that the conversion of SAM to ACC, promoted by auxins and inhibited by the same compounds that inhibit pyridoxal phosphate-mediated reactions, was the rate-limiting step in ethylene production. Endogenous ACC may be transported in the xylem sap from roots to the leaves (10). The complete pathway is as follows: methionine to SAM to ACC to ethylene, with methylthioadenosine being recycled. Carbon dioxide, formic acid and ammonia are formed from ACC along with ethylene. Further, ethylene production and action are promoted by oxygen and inhibited by carbon dioxide, under conditions encountered in "controlled atmosphere" storage (53).

The actual site of synthesis is still under investigation, although evidence suggests that some part of the ethylene-forming system is associated with the cell membrane (32). Also, the mechanism of action of ethylene is still unresolved and may not be the same under all physiological situations (48,52,53). Several recent reviewers discuss the various physiological roles ethylene plays in plant physiology (48,52,57).

Ethylene in Ripening

Physiologically, the ripening of fleshy fruits involves the collective changes resulting in softening, hydrolysis of storage materials, changes in flavor and pigmentation and changes in respiration rates (53,57,58). Fruit ripening is complex; it is a special case of organ senescence, and not all of the changes which occur represent deterioration. As stated by Moore (53), the respiratory climacteric of some fleshy fruits is characterized by a decrease in respiration rate in mature fruit, followed by a large increase during the time of ripening and a final decrease in respiration after the fruits reach final size. Tomatoes, avocados, bananas, apples and pears are climacteric fruits. Those which show a steady or declining respiration rate during ripening are classed as nonclimacteric fruit; e.g., oranges and peppers (53). Besides ethylene production, other changes that occur during the climacteric phase of fruit metabolism are increased RNA and protein synthesis and breakdown and reorganization of certain cellular structures (58).

That ethylene induces ripening, a rise in the respiratory climacteric and senescent changes in many kinds of fruit, has been well documented (50,53,57); however, the exact role in fruit metabolism and the respiratory climacteric has been hotly debated, and is still unclear. Several hypotheses have been put forth that attempt to explain the mechanism of action in terms of the effects on enzyme activities, interaction with nucleic acids, effects on lipoprotein membranes, and the formation of complexes with metallo-enzymes (52,57).

In tomatoes, as in some other fruit, ethylene production, ripening, and senescence are not fully achieved until the fruit reaches a critical, minimum level of maturity (12,50,53,56). Ethylene and ACC may be present in sufficient quantities at a preclimacteric stage to initiate ripening but prevented from doing so by some inhibitory mechanisms until a certain level of physiological maturity is reached (12,32,50). Lyons and Pratt (50) found that internal concentrations of ethylene in tomatoes ranged from 0.08 to 0.8 ppm at 10 to 42 days after pollination. This corresponded to 20 to 93 percent, respectively, of the total growth period of the fruit. Other metabolic changes associated with tomato ripening include a climacteric rise in respiration, a decrease in chlorophyll content, an increase in carotene, a conversion of starch into reducing sugars, and a softening of the tissues (1). Hobson and Davies (31), quoting Basham, state that whereas ethylene production and respiration rates were closely correlated up to the onset of the climacteric rise, once this had begun there was no longer a consistent association. Further, they state that the relation between ethylene production and red color formation is a continuing one and both processes have similar temperature coefficients.

Two general methods of ripening or "degreening" of tomatoes are used commercially: treatment with ethephon (2-chloroethyl phosphonic acid) and ethylene gas. Ripening of processing tomatoes on the vine, for once-over mechanical harvest is accomplished by spraying with ethephon at about 0.5 lb/a (14,35,78). Ethephon is thought to accelerate ripening by releasing ethylene in the plant tissue (14).

Late season fresh market tomatoes may be sprayed on the vine for a final clean-up of the crop (14).

Fresh market tomatoes, picked at the mature green or "breaker" stage of maturity, may be degreened with ethylene gas before, during or after shipment from the packinghouse to the wholesaler (62). Ethylene is supplied as the chemically pure gas, as fumes from the incomplete combustion of kerosene, or by a catalytic generator (4). In the "shot" method, pure ethylene is introduced into an air-conditioned storage room at about 200 to 250 ppm every 6 to 8 hours. The room is kept well ventilated between gassing to keep CO_2 levels below 1.0 percent and O_2 levels high (4,65). In the "trickle method" pure ethylene is metered into air circulating in the storage unit, at a level of 20 to 30 ppm (4). In a third older method, ethylene from the combustion fumes of kerosene is added to circulating air.

Ethylene may also be supplied by the catalytic conversion of a compound called ETHY-GEN[®] (85 percent ethanol), produced by Catalytic Generators, Inc., Norfolk, Virginia (49). In this method, the generator is placed inside the storage room; ethylene is produced at a level of 20 to 150 ppm depending on the size of the room and length of time the unit is operated. Usual practice in Tennessee is to gas for 12 hours with the catalytic generator, air out the storage rooms for 12 hours, then gas for 12 additional hours (62). The catalytic generator may also be used to gas tomatoes while in shipment.

Sherman and Gull (65) describe a flow-through system for ripening tomatoes. This method provides a constant, ripening-effective, low-level blend of ethylene (150 ppm) and air; the mixture passes over the

tomatoes and out the exhaust port of the storage room, thereby preventing a build-up of an inhibitory level of CO_2 . Though still in the developmental stage for tomato ripening, this system has been used successfully on citrus fruits.

Conditions for optimum ripening of mature green tomatoes are:

- (1) a concentration of 20 to 200 ppm ethylene for 12-24 hours;
- (2) temperature at 68-77°F; (3) relative humidity at 85-95 percent; and
- (4) good internal air circulation to replenish the O_2 and diminish the CO_2 levels (4,65). Also, it has been noted that the riper the tomatoes, the less the effect of added ethylene (63). Coffey et al. (14) determined that cultivars, as well as stage of fruit maturity, influenced the effect of ethylene (from ethephon) on the ripening of tomatoes.

III. Postharvest Handling Effects on Tomato Quality

As stated by Kramer and Twigg (46), quality in foods is the composite of those characteristics that differentiate individual units of a product and have significance in determining the degree of acceptability of that unit by the buyer. Quality may be thought of as the degree of excellence of a product. Quality also may be considered a function of physiological ripeness. However, the terms quality and ripeness are not interchangeable; a fruit or vegetable may be ripe, but not of acceptable quality. In a recent symposium, Watada (75) emphasized that horticultural researchers should relate such post-harvest quality measurements as subjective sensory evaluation, and objective color and texture evaluation to measurements of consumer satisfaction. The quality of fresh market tomatoes is determined by

appearance, firmness, flavor, and nutritive value. In the eyes of the consumer, appearance and flavor are most important (41).

Objective evaluations of quality include pH, titratable acidity, ascorbic acid content, lycopene and carotene content, color (Hunter L, a,b), sugar content, sugar/acid ratios, firmness (pressure to puncture or deform) and solids (soluble and total) content (41,46). Subjective measurements include sensory evaluation for flavor, texture, appearance, firmness, and overall acceptability of the product (46).

Effects of Ethylene

Ethylene, whether from the gas or ethephon, promoted red color development of detached tomato fruit (25,41,55,56,59). Ethylene shortened the time required for full color development, as reflected by Hunter a/b values or ripeness scores (25,56,59). Further, ethylene had no effect on the final level of beta-carotene and lycopene concentration or Hunter L or a/b color values (55,77). Fruit at a more mature stage of development ("breaker" or later) showed less response to ethylene than less mature fruit (25,56).

Several workers reported that ethylene treatment had no significant effect on pH or soluble solids content, total solids, or titratable acidity, when the treated and nontreated fruit are compared at the same stage of ripeness (41,55,77). Most differences in these measurements were due to cultivar characteristics.

Some decrease in fruit firmness due to ethylene was noted by Paynter and Jen (55). However, Gonzalez et al. (21) and Hicks et al. (30) found no difference in firmness between table ripe treated and

nontreated fruit. Gonzalez et al. (21) speculate that endogenous ethylene may activate the enzyme polygalacturonase which is involved in the softening of normal fruits.

Researchers reported no difference in flavor or taste between ethylene treated and nontreated fruit, when both are picked at the mature green stage and allowed to ripen to the table ripe stage (25,41, 60). However, Kader et al. (41) observed that fruit harvested green and ripened at 20°C with or without added ethylene were perceived to be less sweet, more sour and have more "off-flavor" than fruits harvested table ripe. Watada et al. (76) and Kader et al. (41) reported that the ascorbic acid content was slightly higher in mature green tomatoes ripened with ethylene than in those ripened without added ethylene. However, ethylene ripened tomatoes may have lower ascorbic acid contents than vine ripened tomatoes (41).

Effects of Storage

Mature green tomatoes, with or without added ethylene, increase in red color development during storage, as evidenced by an increase in the Hunter a/b ratio (55,59) or in lycopene content (55). Beta-carotene also increases with storage (5). The storage temperature for optimum color development seemed to be in the range of 18-20°C. A relative humidity of 80 percent or greater is recommended also (65).

Firmness decreases with increased storage time (42,66) with a more rapid decrease occurring in the first five days than during longer storage time (27,55). Stage of maturity at picking affects subsequent decreases in firmness; more mature fruits are firmer at table ripe than

are mature green or "breaker" stage. This may be explained by the greater length of storage time required for the less mature fruit to reach table ripe.

The effects of storage on pH are inconsistent and are, generally, not significant (5,9,11,16). Craft and Heinze (16) found that temperature and duration of storage had no appreciable effect on pH. The inconsistencies may be due to complicated experiments with several widely different cultivars and different postharvest handling procedures.

Storage duration also appeared to have little or no effect on soluble solids content or total acidity (9,11,16). Pantos and Markakis (54) reported a decline in ascorbic acid content over time at several storage temperatures. In another study, Betancourt et al. (8) found a decline in soluble solids, total solids and an increase in ascorbic acid content between breaker stage and full ripe fruits when they were ripened at 20°C or under field conditions.

Results of sensory evaluation studies comparing stored with vine ripe tomatoes gave the vine ripe tomatoes higher marks (9,41). Stored tomatoes tend to develop "off-flavors" and lose the characteristic tomato aroma (41). In the above cited research, field ripened fruit were judged to be significantly sweeter, compared to room ripened fruit (9).

Effects of Size

Little research has been conducted relating fruit size to fruit quality. In one study, Ibarbia and Lambeth (34) found a low correlation between fruit weight and the quality traits of Brix (soluble solids), pH and citric acid equivalent. Emery and Munger (17) reported that

dwarf plants produced smaller fruit than nondwarf plants but with no difference in the soluble solids content.

Hicks et al. (30) reported that within any treatment combination, large (6 x 6 pack) fruit showed more color development than medium (6 x 7 pack) and small (7 x 7 pack) fruit. Kader et al. (40) stated that tomatoes picked at stages of maturity earlier than mature green and ripened at 20°C were less sweet, more sour and had less "tomato-like" and more "off-flavor" characteristics than those picked at the table ripe stage.

Effects of Mulch

There is little research reported on the effects of plastic film on the quality of tomatoes. As referenced earlier, mulch has been shown to affect the moisture and nutrient balance of the soil and as such may affect fruit quality (36,39,45). Kattan et al. (43), however, found that the quality of processed tomato products did not seem to be related to any soil fertility factors. In their study climatic conditions and inherited varietal characteristics were found to be the main factors affecting quality.

CHAPTER III

THE EFFECT OF PLASTIC MULCH AND FUMIGATION ON TOMATO YIELD

I. Introduction and Review of Literature

The intensive cultural practices of mulching and soil fumigation have been proven to increase the yield of many high value vegetable crops (15,22,36,37,38,67). Mulching improved crop performance by conserving moisture and nutrients (18,36,37,39,69); in addition, it reduced the effects of soil pathogens and weeds (22,38). Soil fumigation, especially with methyl bromide-chloropicrin (MB-C), improved yield by reducing or eliminating the detrimental effects of soil pathogens and weeds (36,37,38,67). The effect of soil fumigation was further enhanced by the use of plastic mulches as sealants to contain the gas in the seedbed (67). Jaworski et al. (36,37) advocated a "system" approach or production of high value vegetable crops on soils where root-knot nematodes, fusarium wilt and weeds may be a serious problem. The system involved the use of polyethylene mulch, soil fumigation (with MB-C), drip irrigation, and optimum fertilizer application methods and rates.

Fresh market tomato production in Tennessee is gaining in economic importance (62). Both mulching and soil fumigation are part of the recommended practices for Tennessee tomato producers (61). However, only soil fumigation is widely practiced by Tennessee producers

at this time, probably due to the expense involved. In response to interest expressed by Tennessee producers, an exploratory study was initiated during the Spring of 1980 to determine the effects of black plastic mulch and soil fumigation on tomato yield under Tennessee growing conditions.

II. Methods and Materials

The experiment was conducted on an Etowah silt loam (fine-loamy, siliceous, thermic Typic Paleudult) at The University of Tennessee, Knoxville, Plant Science Field Laboratory, during the 1980 and 1981 growing seasons. Fertilizer application for both years consisted of 1120 kg/ha of 6-12-12, applied (broadcast) preplant. An additional two side-dress applications of 33.6 kg/ha $\text{Ca}(\text{NO}_3)_2$ were made during each growing season. Weed control was with Metribuzin (1.12 kg/ha a.i.) and diphenamid (5.6 kg/ha a.i.) applied posttransplant. Plant diseases and insects were controlled by applying recommended pesticides at weekly intervals (61). Irrigation from an overhead sprinkler system was applied as needed to supplement rainfall. Experimental plots consisted of two rows, 1.7 by 6.4 m each, with 14 plants per row; untreated guard rows separated each experimental plot.

The four treatments consisted of the following: (1) conventional planting (no mulch or fumigation); (2) black plastic mulch only (1.2 m wide, 1.5 mil polyethylene); (3) fumigation only (methyl bromide-2% chloropicrin, 500 kg/ha); and (4) fumigation (as #3) plus mulch (as #2). The treatments were replicated six times in a randomized complete block design.

The plastic mulch and fumigation treatments were applied on April 18, 1980, and April 8, 1981. The black plastic mulch was applied with a tractor-driven sheet mulch laying machine manufactured by ENPARCO. Plastic was removed from treatment #3 on April 21, 1980, and April 13, 1981. Six-week old tomato transplants of 'Flora-Dade' were planted on April 26, 1980, and April 16, 1981. The plants were staked, two plants between stakes, and supported using the Florida weave system. Harvesting and data collection began on July 3, 1980, and June 25, 1981. Eight individual harvests were made, at weekly intervals, in 1980; nine harvests were made in 1981. The first three harvests in 1980 and the first four harvests in 1981 were designated as early yield. At each harvest, the fruits were graded according to U.S. standards for fresh tomatoes (70) and the number and weight of U.S. No. 1, No. 2 and culls were recorded. The data were subjected to an analyses of variance followed by mean separation by Duncan's multiple range test at the 5 percent level. All data analyses were performed utilizing Statistical Analysis System (SAS) programming (7).

III. Results and Discussion

Rainfall for the 1980 and 1981 growing seasons (April through August) was 14.95 ins. and 18.90 ins., respectively (72). The 1980 season had 3.5 ins. less rainfall than normal, while the 1981 season had about 0.5 ins. more than normal. Average maximum and minimum temperatures for the months of April through August were 84 and 62°F for 1980 and 82 and 63°F for 1981, respectively. The 1980 season had an average of 19 percent more sunshine than the 1981 season.

Excellent weed control throughout both growing seasons was obtained from the applied herbicides.

As an index of growth plant height was measured in 1980 only, on June 5, six weeks after transplanting. Although not significantly so, plants in the fumigated plus mulched plots were the shortest, with a mean height of 48.2 cm; plants in the other three treatments ranged from 51.5 to 51.8 cm in height.

Effect on Early Marketable Yield

Early yields are important to fresh market producers in terms of higher prices for the first fresh tomatoes of the season. In this study, the early yields included the first three harvests in 1980 and the first four harvests in 1981.

In 1980 the early marketable yield (EMY) ranged from 16.9 to 21.3 MT/ha with no significant differences in yield among the treatments (Table 1). In 1981 significant differences in early yields were noted, with the mulched only plots having the highest yields. In the combined analysis, the mulched only plots were significantly higher in yield than the control or fumigated plus mulched plots. Over both years the fumigated plus mulched plots (treatment 4) had the lowest early yield. This reduction or delay in early yield for treatment 4 may be due to reduced stress on the plants, allowing them to remain in the vegetative state longer than stressed plants, thereby delaying anthesis and maturation of the fruit (26).

Table 1. The effects of black plastic mulch and soil fumigation on early marketable yield of tomatoes.

Treatment	Early Marketable Yield MT/ha ^w		
	1980	1981	Combined
1. Control	18.0a ^x	16.9ab	17.5b
2. Mulched only	21.1a	19.8a	20.4a
3. Fumigated only	21.3a	15.1b	18.2ab
4. Fumigated + mulched	16.9a	16.0b	16.5b

^wEarly marketable yield includes the U.S. No. 1 and 2 fruit from the first three or four harvests of the season.

^xMeans within a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

Effect on Total Marketable Yield

Total marketable yield included all U.S. No. 1 and 2 fruit from all harvests throughout the season. In 1980, there was no significant difference in total marketable yield (TMY) among the four treatments (Table 2). In 1981, the mulched only plots and fumigated plus mulched plots were significantly higher in TMY than the control or fumigated only plots. The combined analysis over the two years indicates that the plots receiving mulch (Treatments 2 and 4) were significantly higher in yield than the control. Mulched only plots did not differ significantly in TMY from the fumigated only plots, however. As the growing season progressed, the effects of mulch on the conservation of moisture and nutrients became more pronounced. Any delay in early yield as a result of more vigorous vegetative growth that may have been caused by MB-C under the plastic was overcome by the end of the season. Nematodes and soil pathogens were apparently not a serious problem since the results indicate only a slight improvement in TMY due to fumigation.

There was no difference in percentage marketable yield (total marketable yield/total yield) among treatments, within each year or over the two years. All treatments averaged about 82 percent marketable yield. Most of the culls were of small size, but fruit cracking and blossom end rot were also a problem.

Effect on Total Yield

Total yields included both U.S. grade No. 1 and 2 fruit as well as the culls, for the entire growing season. The effects of the

Table 2. The effects of black plastic mulch and soil fumigation on total marketable yield of tomatoes.

Treatment	Total Marketable Yield, MT/ha		
	1980	1981	Combined
1. Control	44.8a ^x	58.0b	51.4c
2. Mulched only	45.5a	71.0a	58.2ab
3. Fumigated only	49.1a	58.3b	53.7bc
4. Fumigated + mulched	50.1a	70.7a	60.4a

^xMeans within a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

treatments on total yield followed a pattern similar to that of TMY (Table 3). This was expected since the percent marketable yield was similar for all treatments. In the combined analyses the plots receiving mulch as a treatments (Treatments 2 and 4) had significantly higher total yields than those not receiving mulch. The differences may be due to higher rainfall, in spite of irrigation, and somewhat lower temperatures favoring better fruit set in the 1981 growing season.

Effect on Early Fruit Weight

There were no significant differences in the weights of early fruits that fell in U.S. grade No. 1 among the treatments between years (Table 4). It is interesting to note that early fruit from plots receiving no fumigation (Treatments 1 and 2) were about 10 gms/fruit heavier than fruit from the fumigated plots (Treatments 3 and 4). During each growing season, early fruit from the fumigated plus mulched plots (Treatment 4) had the lowest weights. This is consistent with the results of EMY (Table 1, p. 23) for Treatment 4. Early fruit growth may have been delayed by the effect of MB-C under the plastic on promoting vegetative growth (26), resulting in fruits that were generally smaller.

IV. Conclusions

Under the conditions of this experiment, mulching with black plastic increased early and total marketable yields, over no mulch or fumigation only. Increases of 15-18 percent in total marketable yield

Table 3. The effects of black plastic mulch and soil fumigation on total yield of tomatoes.

Treatment	Total yield, MT/ha		
	1980	1981	Combined
1. Control	55.1b ^x	69.2b	62.2b
2. Mulched only	56.8b	85.5a	71.1a
3. Fumigated only	61.1ab	69.7b	65.4b
4. Fumigated + mulched	64.6a	83.1a	73.8a

^xMeans within a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

Table 4. The effects of black plastic mulch and soil fumigation on early fruit weight of tomatoes.

Treatment	Average Fruit Weight, ^w gms/fruit		
	1980	1981	Combined
1. Control	171.4 ^x	187.3	179.3
2. Mulched only	178.9	181.4	180.2
3. Fumigated only	165.5	179.4	172.4
4. Fumigated + mulched	162.2	178.0	170.1

^wFruit weight = weight of early No. 1 fruit/number of early No. 1 fruit.

^xNone of the means in columns differed significantly at the 5% level.

were observed and are in accord with the result reported by other researchers such as Jones et al. (39) and Jaworski et al. (37). The effects of combining fumigation and mulch seems to be a delay in early yield, and an improvement in total marketable yield. Jaworski et al. (37) also found no significant differences in fruit yield with increasing levels (0 to 280 kg/ha) of MB-C fumigation on 'Walter' tomatoes. In fact, they noted slight decreases in yield at higher concentrations of MB-C, under plastic. In addition, they observed significant increases in yield due to increasing the width of the mulched beds.

Improved soil moisture and nutrient regimes under plastic mulch seem to be a primary factor in improving yields of tomatoes regardless of the populations of nematodes and soil pathogens (22,36,37,38). In areas of tomato production where soil pathogens and nematodes are not a serious problem, fumigation plus mulch may be of questionable benefit, over mulching alone, especially if early marketable yield is important to the producer. Additional studies that would employ a system approach, as proposed by Jaworski et al. (36), using film mulch, fumigation, fertilization and drip irrigation would provide additional answers for Tennessee tomato producers. However, before any recommendations are made on the use of mulch and soil fumigation to improve yield, related economic studies should be conducted to determine if the increase in yield justifies the additional expense involved, under Tennessee conditions.

CHAPTER IV

THE INFLUENCE OF POSTHARVEST HANDLING ON TOMATO QUALITY

I. Introduction and Review of Literature

According to Kader et al. (40), most fresh market tomatoes sold in U.S. supermarkets are harvested at the mature green or breaker stage rather than table ripe stage of maturity. Consumers are becoming increasingly dissatisfied with the quality of fresh market tomatoes, blaming both new cultivars and postharvest handling procedures for the lower quality. Increased emphasis is being placed on research on the effects of harvesting techniques and postharvest handling procedures as they affect quality of fresh tomatoes (40,41). Consumers buy fresh tomatoes mainly because of flavor and appearance. Quality of fresh market tomatoes is determined by appearance, firmness, flavor and nutritive value (41). Determinations of quality may involve both subjective and objective evaluations. Objective evaluations include pH, titratable acidity, ascorbic acid content, lycopene and carotene content, color (Hunter L,a,b), sugar content, sugar/acid ratios, firmness and soluble and total solids content (41,46). Subjective evaluations include sensory evaluation for flavor (acidity), texture, firmness, appearance and overall acceptability of the product (46).

Postharvest handling procedures may have variable effects on the final quality of fresh tomatoes. Ethylene gas or ethylene from ethephon

(2-chloroethyl phosphonic acid) has been shown to shorten the time required for full color development and to increase ascorbic acid levels (25,41,55,56,59,76). Several researchers have compared the quality of tomatoes picked mature green and ripened to the table ripe stage with and without ethylene (30,41,55,77). They reported that treatment with ethylene has no appreciable effect on firmness, pH, soluble and total solids, titratable acidity or flavor.

As time in storage increased, tomatoes showed an increase in red color development (Hunter a/b), and lycopene (red pigment) and Beta-carotene (yellow pigment) content (5,55,59). Firmness decreased during storage, especially in the first five days (27,42,55,66). Some researchers reported that the effects of storage on pH is inconsistent (9,11,16). Others reported that riper fruit increased in pH (and decreased in titratable acidity) over less ripe fruit (5,31,51,55). Storage duration appeared to have little or no effect on soluble solids content or total acidity. Kader et al. (41) compared stored tomatoes to vine ripe tomatoes using a trained taste panel to evaluate flavor quality. Their results indicate that stored tomatoes lose the characteristic tomato aroma and develop more "off-flavor" than vine ripe tomatoes.

A paucity of experiments are reported which relate fruit size to fruit quality. Ibarbia and Lambeth (34) found a low correlation between fruit weight and Brix (soluble solids), pH or citric acid content. Research by Hicks et al. (30) indicates that large (size) fruit may show more red color development than small (size) fruit.

Tennessee tomato producers are beginning to use ethylene treatment as a postharvest practice. They are concerned about the effects of ethylene and storage conditions on tomato quality (62). The following questions are of concern:

1. Does treatment with ethylene alter the composition or flavor?
2. How long can tomatoes be stored before they become too soft to ship?
3. Does fruit size influence ripening or storability?

In July 1980 a two-year study was initiated to evaluate the effects of ethylene treatment, storage duration, fruit size, and plastic mulch on such quality measurements as pH, firmness, color development and soluble solids. A sensory evaluation (consumer preference) test was conducted in 1981, to compare vine ripe tomatoes with tomatoes picked mature green and ripened in storage with and without ethylene.

II. Methods and Materials

This study was conducted during the growing seasons of 1980 and 1981, at the Knoxville Plant Science Field Laboratory. Tomatoes of 'Flora Dade' were used, and were U.S. No. 1 grade, harvested at the mature green stage of development (green skin color, no pink color showing) (19). Four harvests were made, at weekly intervals, during each growing season; 192 fruit from each harvest were used. Half the fruits were from plants grown on black plastic mulch, the other half were from plants grown conventionally. The fruits were then sized into large (7.3-10.0 cm or 5 x 5 to 4 x 4 pack) and small (5.0-7.3 cm, or

7 x 7 to 5 x 5 pack) sizes using size templates. Half of these received treatment with ethylene gas, half did not. Ethylene, at 50-150 ppm for 24 hours, was generated from ETHY-GEN[®] compound (85 percent ethanol) in a catalytic generator (44). All fruit were stored at 20°C and 85 percent relative humidity in an air conditioned room of about 20.0 cubic meters volume. At the end of 5, 8, and 11 days from picking, an eight-fruit sample of each treatment combination was analyzed for quality.

The experimental design consisted of two levels each of mulch, size, and gas, and three levels of storage time, replicated eight times, over four harvests and two years. This gave a randomized complete block design in a 2 x 2 x 2 x 3 factorial arrangement. Mean separations by analysis of variance (ANOVA) and Duncan's multiple range test were performed on selected responses and effects, using the Statistical Analysis System (SAS) programming (7).

The quality measurements on the fruits included exterior and interior color and luminance, subjective and objective firmness, pH and soluble solids. Fruit weight was taken after storage in 1980 and before and after storage in 1981.

A HunterLab Color Difference Meter (Model D25 D2M) was used and calibrated against a white tile (C2-136). A more detailed discussion of the Hunter tristimulus colorimetry may be found in Francis and Clydesdale (20). Exterior color and luminance were determined on a representative spot on the equatorial surface of the fruit that showed average color development for the individual fruit. Values for Hunter L (luminance), a (+red, -green), and b (+yellow, -blue) were taken. Interior values were taken on a cross-section, sliced through the

equatorial plane of the fruit. Values for red color development are reported as Hunter a (red/green). Values for Hunter L and b may be found in Appendix B, Tables 10 and 11.

Subjective firmness was determined by hand-squeezing each fruit and assigning a rating of 1 (very soft) to 5 (very firm). Objective firmness was measured with an Effegi Fruit Pressure penetrometer, using a 1.0 cm^2 probe. Values are expressed in kg of pressure required to penetrate the tomato at a spot on the shoulder of the fruit with the skin intact.

Whole tomatoes were blended into a puree with a food blender for measurements of pH and soluble solids. The pH readings were made with a Corning (Model 5) pH meter, standardized with pH 4.0 buffer. The electrodes were immersed in approximately 150 ml of puree and read after 15 seconds equilibration. Soluble solids, expressed in percent, were determined on three drops of filtrate from the puree, with a hand-held Atago refractometer.

During the 1981 season, a sensory evaluation experiment was conducted on a selected treatment combination. The sensory evaluation was performed at the Food Technology and Science Sensory Evaluation Laboratory. The evaluation was conducted in an air-conditioned room with partitioned booths for each panelist (72). The samples were viewed under cool white fluorescent lights. The samples were randomly assigned a three-digit code number. Ratings were made using hedonic scales and entered on a scoresheet (see Appendix A). The evaluation room was separate from the room used to prepare the samples. An untrained consumer-preference panel, consisting of 50 observers at each

of two sessions, was asked to evaluate three lots of tomatoes for flavor (acidity), texture, appearance and color and overall acceptability. Two of the lots consisted of large, mature green fruit: one lot was treated with ethylene (MG-T), the other lot was untreated (MG-U). Both of these lots were ripened in storage for eight days prior to evaluation. The third lot were vine ripe fruit (VR) of approximately the same size and degree of red color development as the stored fruit. The panelists rated quartersections of fruit for flavor (acidity) and texture; they rated whole fruit for appearance and color as viewed under a cool white fluorescent light. Overall acceptability was rated by the panelists based on impressions gained from the flavor, texture and appearance and color ratings. Flavor scale was from 1-very sweet to 6-very acid. The texture scale was from 1-very mealy to 6-very smooth. The appearance and color scale were from 1-very poor to 6-excellent. Overall acceptability scale ranged from 1-dislike very much to 6-like very much. Analyses of variance, with mean separation by Duncan's multiple range test were performed on the data using SAS programming (70).

III. Results and Discussion

In the discussion that follows, it should be noted that only the main effects for the treatments are reported and discussed. Most of the interactions were not different at the 5 percent level of significance (see Appendix B, Tables 12 and 13, for ANOVA on main effects and interactions). There were significant differences between the year means for most measurements, and for the most part they can be

explained by the differences in growing conditions from one year to the next. Also, in 1981, stricter grading criteria were utilized and a more uniform sample was obtained from the field plots.

Treatment Influence on Red Color

A tomato producer or consumer may judge tomato quality by the red color development of the skin (exterior) or of the flesh (interior). 'Flora-Dade' is considered to be a "red" cultivar, i.e., red exterior and interior. Red color development was measured by tristimulus colorimetry and expressed as Hunter *a* values (20). With the exception of interior color for 1980, tomatoes grown under conventional methods (no mulch) exhibited significantly more red color development than ones grown on black plastic mulch (Table 5). The trend was the same across years both for exterior and interior measurements. These differences may be due to less moisture and nutrient stress of plants grown on mulch; such plants may remain in a more vegetative state longer, thus delaying fruit maturity (26).

Large diameter fruit showed significantly more red color development than did small diameter fruit. These results agree with those of Hicks et al. (30), who found that large fruit exhibited more red color development than smaller fruit. The large fruit may have been slightly more physiologically mature than the smaller diameter fruit, although extreme care was taken to harvest all fruits at the same subjective stage of maturity.

As the results of other researchers had shown, tomatoes treated with ethylene had significantly more red color development than those

Table 5. Exterior and interior red color of tomato fruit as influenced by mulch, size, ethylene and storage time.

Treatment	Level	Exterior Color			Interior Color		
		1980	1981	Combined	1980	1981	Combined
Mulch ^x	yes	18.6b	16.9b	17.8b	15.5a	11.5b	13.5b
	no	20.6a	19.0a	19.8a	16.0a	13.1a	14.5a
Size ^x	large	21.0a	19.7a	20.3a	18.0a	14.3a	16.1a
	small	18.3b	16.2b	17.3b	13.5b	10.3b	11.9b
Ethylene ^x	yes	21.3a	19.4a	20.3a	16.9a	13.1a	15.0a
	no	18.0b	16.6b	17.3b	14.6b	11.5b	13.1b
Storage ^y time	5 days	8.6c	4.6c	6.6c	8.7c	4.5c	6.6c
	8 days	24.1b	22.3b	23.2b	18.3b	14.7b	16.5b
	11 days	26.3a	27.1a	26.7a	20.2a	17.7a	19.0a

^xMeans in a column, within treatments, followed by the same letter are not significantly different at 5% level, ANOVA.

^yMeans in a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

not treated with ethylene. This trend was the same across years for both exterior and interior measurements. These results are consistent with the findings of other researchers, which show that ethylene promotes or enhances red color development in stored tomatoes (25,41,55, 56,59).

As time in storage increased, physiologically mature tomatoes showed a decrease in chlorophyll and an increase in lycopene (red pigment) and Beta-carotene (yellow pigment) content (1). These results indicate that red color significantly increased with an increase in storage time; for this cultivar, the largest increase in red color, 16.6 units, occurred between 5 and 8 days of storage.

Treatment Influence on Fruit Firmness

Firmness is an important quality criterion since it determines how well fruit will withstand shipping and serves as an indicator of internal breakdown during ripening. Producers and consumers may use subjective firmness as a measure of tomato quality by simply squeezing the fruit. A tomato producer might also use an objective measurement to decide whether a fruit is too soft for shipment. Objective firmness, as measured in this study, was a destructive measurement and the readings indicated the amount of pressure required to penetrate the locular wall at the shoulder as well as to break the skin. The higher the pressure reading, the firmer the fruit. Other methods of pressure testing are available that are nondestructive (42,66). 'Flora-Dade' is extremely firm even at the ripe stage and because of this characteristic this cultivar is grown for the shipping market (73).

Tomatoes from plants grown on plastic mulch were significantly firmer and required more pressure to penetrate the skin than tomatoes grown conventionally (Table 6). This difference could be due to the improved moisture (and nutrient) regime that exists under plastic mulch, compared to no mulch (18,36,37,39,69). Fruits from the mulched plots may also have been physiologically less mature and had greater cell sap pressure (26).

For both years small diameter fruit were significantly firmer in the subjective rating than were large fruit, while size had no significant effect on the firmness from the objective measurement. Differences in the subjective rating may have been due to the fact that even though only one person rated the firmness throughout the study, fruit of different sizes fit the hand differently. They may have been perceived to have had a different firmness when, in reality, none existed, an idea which the subjective measurements tend to substantiate.

Treatment with ethylene had no significant effect on subjective firmness either year (Table 6). However, there was a significant difference in the pressure between the means in 1980 although the difference, 0.5 kg/cm^2 , is small in relation to a total pressure of about 7.0 kg/cm^2 . Other researchers found little or no reduction in firmness in fruit due to treatment with ethylene (21,30). That ethylene may only affect the red color formation and the initial rise in respiration rates is discussed by Hobson and Davies (31). No close association has been shown between ethylene and the other processes of ripening, especially the solubilization of protopectin and subsequent loss of firmness associated with the postclimacteric phase.

Table 6. Subjective and objective measurements of tomato fruit firmness as influenced by mulch, size, ethylene and storage time.

Treatment	Level	Subjective Firmness, ^w 1-5			Pressure, Kg/cm ²		
		1980	1981	Combined	1980	1981	Combined
Mulch ^x	yes	3.9a	4.4a	4.2a	7.0a	7.2a	7.1a
	no	3.8b	4.3b	4.1b	6.9b	6.9b	6.8b
Size ^x	large	3.8b	4.3b	4.1b	6.7a	7.0a	6.9a
	small	4.0a	4.4a	4.2a	6.9a	7.1a	7.0a
Ethylene ^x	yes	3.9a	4.4a	4.1a	6.6b	7.0a	6.8b
	no	3.9a	4.4a	4.1a	7.1a	7.1a	7.1a
Storage ^y time	5 days	4.4a	4.8a	4.6a	8.3a	8.7a	8.5a
	8 days	3.8b	4.4b	4.1b	6.4b	6.7b	6.5b
	11 days	3.5c	4.0c	3.7c	5.8c	5.9c	5.8c

^wRating scale: 5 - very firm; 1 = very soft.

^xMeans in a column, within treatments, followed by the same letter are not significantly different at 5% level, ANOVA.

^yMeans in a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

As fruits ripen, there is a progressive increase in the breakdown of cell wall materials that contribute to firmness, e.g., proto-pectins and cellulose (31,58). Increasing time in storage significantly decreased firmness each year. Both the subjective ratings and objective measurements followed the same trend. These results are consistent with recent findings by Hall and Augustine (28) for 'Flora-Dade'. Other researchers report similar decreases in firmness with increased storage time (56,59).

Treatment Influence on Fruit pH

According to Hobson and Davies (31), the juices of the tomato constitute a weak acid/strong base buffer system in which the anions are mainly citrate and malate and the cations are mainly potassium. Matthews (51) and Ibarbia and Lambeth (34) found a significant negative correlation between titratable acidity and pH, which is expected since their numerical values are inverse.

Tomato fruit pH affects flavor determinations and canning considerations; the pH of fruit reportedly is affected more by differences among cultivars than by postharvest handling procedures (41,55,77).

Fruit from plants grown on plastic mulch had a significantly higher pH than fruit from conventionally grown plants, although the difference was .05 pH units (Table 7). From an organoleptic standpoint, this difference is probably not detectable. Matthews (51) found that tomatoes from plants grown under restricted moisture supply had lower pH and higher acid content than tomatoes from plants grown under optimum moisture levels.

Table 7. Tomato fruit pH as influenced by mulch, size, ethylene and storage time.

Treatment	Level	pH		
		1980	1981	Combined
Mulch ^x	yes	4.26a	4.22a	4.24a
	no	4.19b	4.17b	4.18b
Size ^x	large	4.25a	4.20a	4.22a
	small	4.20b	4.20a	4.20b
Ethylene ^x	yes	4.23a	4.20a	4.22a
	no	4.21b	4.19a	4.20b
Storage ^y time	5 days	4.20b	4.03c	4.11c
	8 days	4.21b	4.23b	4.22b
	11 days	4.25a	4.33a	4.29a

^xMeans in a column, within treatments, followed by the same letter are not significantly different at 5% level, ANOVA.

^yMeans in a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

In 1980, large diameter fruit had a significantly higher pH than smaller fruit, while in 1981 there was no difference between large and small size fruit. The difference between sizes was still only .05 of a pH unit. Ibarbia and Lambeth (34) found that large fruit weights were associated with higher pH values, but the correlation was low. Davies and Winsor, as reported in Hobson and Davies (31), report a highly significant negative correlation between fruit weight and titratable acidity for some English tomato varieties. This study (31) together with the observations of Matthews (51) would lend support to the premise that large fruit have higher pH values than do smaller ones.

Fruits treated with ethylene had a significantly higher pH than untreated fruit but only on the order of .02 pH units. Wells et al. (77) found that tomatoes treated with ethylene had a higher pH than untreated fruit. Although in their studies some significant differences were found among treatments, they were not consistent from year to year or from cultivar to cultivar. The authors (77) offered no explanation as to the effects of ethylene on pH.

Over both years there was a significant increase in pH as storage time increased. Hobson and Davies (31) indicate that changes in titratable acidity (and hence pH) are due mainly to changes in citric and malic acid. They report that during maturation and ripening acidity progressively decreases from the first appearance of the yellow pigment on through full ripe stage. Other researchers have reported slight increases in pH of stored tomatoes with increased storage time (5,16).

Treatment Influence on Fruit Soluble Solids

Soluble solids content is perhaps more important to the processing industry than the fresh market tomato producer but contributes significantly to flavor in the form of the sugar to acid ratio (51). Considered over all treatments and both years, there is little statistical and no practical effect on percent soluble solids content (Table 8). Rounding the results to the nearest tenth of a percent, a soluble solid content of 4.8 percent prevails. Other researchers report little or no significant effects on soluble solids content from ethylene, fruit size or storage duration (16,34,55,77).

Sensory Evaluation

Sensory evaluation ratings of the three lots (MG-T, MG-U, VR) are compared in Table 9. Reference to the scoresheet in Appendix A will help understand the results. Panelists could detect no difference in flavor (acidity) among the three lots of tomatoes (Table 9). All were rated as being between "slightly sweet" and "slightly acid" in flavor. The panelists rated the texture of the MG-T and MG-U as "slightly mealy" and the VR as "slightly smooth," with a significant difference between the two scores. The appearance and color of the MG-T and VR (whole tomatoes) were rated as being "very good" and were not significantly different. They were rated as significantly better than the MG-U, which received only a "good" score. The panelists rated the overall acceptability of the MG-T and MG-U as "liked slightly." The panelists rated the overall acceptability of the VR as "liked moderately," which was significantly higher than the MG-T and MG-U. These sensory evaluations

Table 8. Soluble solids content of tomato fruit as influenced by mulch, size, ethylene and storage time.

Treatment	Level	Soluble Solids (%)		
		1980	1981	Combined
Mulch ^x	yes	5.0a	4.8a	4.9a
	no	4.7b	4.8a	4.7b
Size ^x	large	4.8b	4.8a	4.8a
	small	4.9a	4.7b	4.8a
Ethylene ^x	yes	4.9a	4.8a	4.8a
	no	4.8b	4.7b	4.8a
Storage ^y time	5 days	4.9a	4.8a	4.8a
	8 days	4.8a	4.8a	4.8a
	11 days	4.8a	4.7a	4.8a

^xMeans in a column, within treatments, followed by the same letter are not significantly different at 5% level, ANOVA.

^yMeans in a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

Table 9. Sensory evaluation ratings of vine ripe compared to mature green tomatoes ripened in storage with and without ethylene.

Treatment	Flavor ^u	Texture ^v	Color and Appearance ^w	Overall Acceptability ^x
MG-T ^y	3.8a ^z	3.4b	4.9a	4.0b
MG-U	3.7a	3.4b	4.2b	4.0b
VR	3.6a	3.8a	4.8a	4.7a

^uRating scale 1-6, 1 = very sweet; 6 = very acid.

^vRating scale 1-6, 1 = very mealy; 6 = very smooth.

^wRating scale 1-6, 1 = very poor; 6 = excellent.

^xRating scale 1-6, 1 = dislike very much; 6 = like very much.

^yMG-T = mature green, ethylene treated, ripened in storage.

MG-U = mature green, untreated, ripened in storage.

VR = vine ripe.

^zMeans within a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

results agree with those reported by other researchers, who report no flavor or taste differences between tomatoes picked mature green and ripened to the table ripe stage with or without ethylene (25,41,60).

IV. Conclusions

Although significant differences due to treatment effects are reported for firmness, pH and soluble solids, the differences may be too small to be of any importance to a consumer. Generally, these results agree with those reported by other researchers. Mulch appears to exert its influence by generally optimizing the conditions for plant growth. Size may be more related to physiological maturity than was first assumed. Ethylene mainly influences color development and has little or no effect on the other quality measurements. Storage time has the most profound influence on the quality measurements studied, as the complex processes of ripening occur over a period of time.

In light of the objectives, we may conclude that Tennessee fresh market tomato producers, using 'Flora-Dade', can use mulch or ethylene with no adverse effects on quality. Producers can harvest at the mature green stage, treat with ethylene and store or ship for at least 11 days from picking and still have a firm tomato that is acceptable to the consumer. Smaller diameter fruit appear to hold their firmness for a longer period of time in storage and would maintain their quality in shipping better than larger fruit.

Additional research should concentrate on correlating fruit size (weight) with quality. Mulch as it affects quality and composition of fruit needs additional investigation. Extended storage times under

commercial conditions, as it affects fruit quality, should also be studied. Attempts should be made to monitor more closely the levels of ethylene present, during gassing and storage, both in experimental units and commercial operations. All quality measurements such as firmness and color should utilize the appropriate instruments, techniques and standards (i.e., color plates, pressure testers). The response on other commercial cultivars should also be evaluated.



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APPENDIXES



APPENDIX A

SCORESHEET USED FOR SENSORY EVALUATION OF TOMATO QUALITY

Scoresheet Used for Sensory Evaluation of Tomato Quality

Instruction: Please evaluate these samples of tomatoes for flavor, texture, appearance and color, and overall acceptability. You will be given three samples of tomatoes. Taste the tomatoes and indicate your preference by writing the number under each attribute for each code number. Then, evaluate the whole tomatoes on the table in the Testing Area where you are tasting for appearance and color. Your fair evaluation is requested; please try to be objective. If you have any questions, please ask.

Sample Code	Flavor	Texture	Appearance & Color	Overall Acceptability	Comments

Flavor	Mouthfeel	Appearance and Color	Overall Acceptability
6 - very acid	6 - very smooth	6 - excellent	6 - like very much
5 - moderately acid	5 - moderately smooth	5 - very good	5 - like moderately
4 - slightly acid	4 - slightly smooth	4 - good	4 - like slightly
3 - slightly sweet (mild)	3 - slightly mealy	3 - fair	3 - dislike slightly
2 - moderately sweet (mild)	2 - moderately mealy	2 - poor	2 - dislike moderately
1 - very sweet (mild)	1 - very mealy	1 - very poor	1 - dislike very much
(Fresh; not flat; acid-sweet, mild)	(Firm, smooth not mealy)	(Bright, attractive tomato, red not orange)	(Taking everything into consideration—flavor, texture, appearance)



APPENDIX B

TABLES

Table 10. Interior and exterior tomato fruit Hunter L values as influenced by mulch, size, ethylene and storage time.

Treatment Level		Hunter L					
		Exterior			Interior		
		1980	1981	Combined	1980	1981	Combined
Mulch ^x	yes	45.5a	46.9a	46.1a	48.0a	53.3a	50.7a
	no	44.4b	45.1b	44.8b	47.4a	51.7b	49.6b
Size ^x	large	44.7a	45.9a	45.4a	47.5a	52.8a	50.2a
	small	45.2a	46.0a	45.6a	47.9a	52.3a	50.1a
Ethylene ^x	yes	44.3a	45.5a	44.9b	46.8a	52.3a	49.6b
	no	45.6b	46.4a	46.0a	48.6b	52.8a	50.6a
Storage ^y time	5 days	52.2a	52.8a	52.5a	52.7a	57.2a	55.0a
	8 days	43.0b	44.9b	43.9b	46.8b	51.6b	49.2b
	11 days	39.7c	40.2c	39.9c	43.5c	48.7c	46.1c

^xMeans in a column, within treatments, followed by the same letter are not significantly different at 5% level, ANOVA.

^yMeans in a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

Table 11. Interior and exterior tomato fruit Hunter b values as influenced by mulch, size, ethylene and storage time.

Treatment	Level	Hunter b					
		Exterior			Interior		
		1980	1981	Combined	1980	1981	Combined
Mulch ^x	yes	21.9a	20.1a	21.0a	20.0a	17.6a	18.8a
	no	21.8a	19.4b	20.6b	19.6b	17.5a	18.5b
Size ^x	large	21.6a	19.7a	20.6a	19.5b	17.4a	18.4b
	small	22.0b	19.9a	20.9a	20.1a	17.8a	18.9a
Ethylene ^x	yes	21.3a	19.7a	21.0a	19.6a	17.5a	18.5b
	no	22.3b	19.9a	20.6b	20.0a	17.6a	18.8a
Storage ^y	5 days	24.4a	22.4a	23.4a	21.2a	19.1a	20.1a
	8 days	21.0b	19.6b	20.3b	19.3b	17.0b	18.1b
	11 days	20.0c	17.2c	18.6c	18.9b	16.6b	17.7c

^xMeans in a column, within treatments, followed by the same letter are not significantly different at 5% level, ANOVA.

^yMeans in a column followed by the same letter are not significantly different at 5% level, Duncan's multiple range test.

Table 12. Combined table of significance for Hunter L, a, and b for exterior and interior tomato fruit color; 1980 and 1981.

Source	df	Hunter Values					
		Exterior			Interior		
		L	a	b	L	a	b
Year	1	*	N.S.	*	*	*	*
Mulch (M)	1	*	*	*	*	*	*
Size (S)	1	N.S.	*	N.S.	N.S.	*	*
Ethylene (E)	1	*	*	*	*	*	*
Time (T)	2	*	*	*	*	*	*
MXS	1	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
MXE	1	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
MXT	2	*	*	N.S.	N.S.	*	N.S.
SXE	1	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
SXT	2	N.S.	N.S.	N.S.	*	N.S.	N.S.
EXT	2	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
MXSXE	1	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
MXSXT	2	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
MXEXT	2	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
SXEXT	2	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
MXSXEXT	2	N.S.	N.S.	N.S.	N.S.	N.S.	*

*Significant at 5% level.

N.S. - Not significant.

Table 13. Combined table of significance for certain quality measurements on tomato fruit; 1980 and 1981.

Source	df	Subjective Firmness	Wall Pressure	pH	Soluble Solids
Year	1	*	*	*	*
Mulch (M)	1	*	*	*	*
Size (S)	1	*	N.S.	*	N.S.
Ethylene (E)	1	N.S.	*	*	*
Time (T)	2	*	*	*	N.S.
MXS	1	N.S.	N.S.	*	*
MXE	1	N.S.	N.S.	N.S.	*
MXT	2	N.S.	N.S.	*	N.S.
SXE	1	N.S.	N.S.	N.S.	N.S.
SXT	2	N.S.	N.S.	N.S.	N.S.
EXT	2	N.S.	N.S.	N.S.	N.S.
MXSXE	1	N.S.	N.S.	N.S.	N.S.
MXSXT	2	N.S.	N.S.	N.S.	N.S.
MXEXT	2	N.S.	*	N.S.	N.S.
SXEXT	2	N.S.	N.S.	*	N.S.
MXSEXT	2	N.S.	N.S.	*	N.S.

*Significant at 5% level.

N.S. - Not significant.

VITA

Noble S. Kearney, Jr., was born in Greenville, Mississippi, on April 9, 1943. He was educated in the elementary schools in Leland, Mississippi, and graduated from Leland High School in May 1961. The following September, he entered Mississippi State University, College of Agriculture, and in June 1965, he received his Bachelor of Science degree in Agronomy-Soil Science. He began work toward his Master's degree in June 1965 at Mississippi State University in the Seed Technology section of the Department of Agronomy. His Master's degree was awarded in June 1967.

Following a two-year tour of duty with the United States Army, as an Intelligence Staff Officer, he and his family moved to Chattanooga, Tennessee. While in Chattanooga he worked at Baroness Erlanger Hospital, Ed Forstner Studio (as owner) and Collegedale Hydroponics. In July 1975, he moved to Woodbury, Tennessee, to take the position of 4-H Agent in Cannon County.

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He is married to the former Vernice Cavens of Millington, Tennessee, and is the father of two children: daughter, Katherine, and son, Brendan.