FACTORS AND PRACTICES RELATED TO THE OCCURRENCE OF BLOTCHY RIPENING IN TOMATO

By

James W. Berry, Jr.

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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DOCTOR OF PHILOSOPHY

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ABSTRACT

FACTORS AND PRACTICES RELATED TO THE OCCURRENCE OF BLOTCHY RIPENING IN TOMATO

By James W. Berry, Jr.

Blotchy ripening, characterized by greenish-yellow areas on otherwise ripe tomato fruit, has been a serious problem during certain growing seasons. A lack of balance in soil nutrient levels, adverse weather conditions, viral infections or a combination of one or more of these factors have been suspected causes of blotchy ripening. The primary objective of this study was to evaluate the role of different moisture stresses upon the incidence of blotchy ripening.

The influence of different soil moisture levels in combination with several transpiration influencing practices upon the incidence of blotchy ripening were evaluated at the Horticulture farm in East Lansing during 1962 through 1964. Treatments used to influence transpiration were phenylmercuric acetate, glycerol, copper sulfate, octa-hexadecanol, misting with water, reducing air movement with various enclosures, and infra-red heat lamps. Phenylmercuric acetate, a chemical reported to close stomates, was the only chemical used to influence transpiration in both greenhouse and field studies. The other chemicals were used only in a greenhouse study. Fireball and Glamour were the principal tomato varieties used.

The over-all moisture stress to which tomato plants are subjected appears to influence the quality of fruit as measured by percent dry matter, soluble solids, and color uniformity. Data collected in these studies suggest that blotchy ripening and blossom end rot are caused by opposite moisture stress conditions, blotchy ripening appearing more frequently under conditions of low moisture stress and blossom end rot being more prevalent under high moisture stress conditions.

Seed density beneath blotchy and normal tissue was determined. Low locular seed incidence within a fruit was associated with blotchy tissue; a reduced source of auxin was postulated as possibly contributing to the disorder.

The placement of pollen on one side of the stigma, or the removal of a section of stigma and style at the time of pollination influenced the incidence of blotchy ripening. Poor pollination may play a role in the incidence of blotchy ripening by reducing the number of seed in some locules.

An interplay of both poor pollination and the occurence of adverse weather conditions to produce blotchy ripening is suggested.

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INTRODUCTION

Blotchy ripening of tomato fruit is characterized by outer wall tissue that usually remains greenish-yellow in color after the fruit has turned red (Fig. 1).

This ripening disorder of tomato fruits occurs sporadically in field and greenhouse grown tomatoes and affects a considerable percentage of the fruits during some growing seasons, but is almost nonexistant in others. The blotchy areas have been reported to occur anywhere on the fruit, but generally appear on the shoulders or midsection rather than on the blossom-end.

Numerous suggestions concerning the cause and control of blotchy ripening have been proposed. Hypotheses as to causation are generally related to a lack of balance in soil nutrient levels, weather conditions, viral infections, or a combination of one or more of these factors.

Because of the unevenly scattered outbreaks of blotchy ripening, and from a survey of the literature, it was suspected that climatic factors affecting the water balance of tomato plants play a dominant role in development of the disorder.

The primary objective of this study was to evaluate the role of different moisture stresses imposed upon tomato plants and their influence upon the incidence of blotchy ripening.

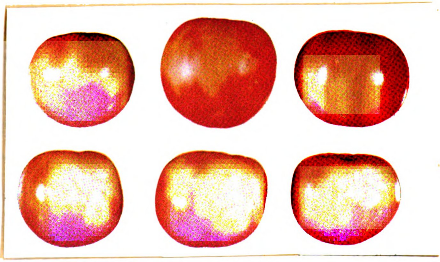

Fig. 1. Tomato fruit showing outer wall tissue affected with localized blotchy ripening.

REVIEW OF LITERATURE

Terminology

The first description of blotchy ripening occurred in a grading system introduced at the Experimental and Research Station, Chesthunt, England, in 1921, and was merely noted as grade E - blotchy fruit which ripen unevenly (20).

Bewley and White (5, 6) modified the definition by excluding fruits infected with virus, mosaic, and those having a hard green area, "greenback", around the stem-end. They defined blotchy ripening as a disorder in which fruits developed hard yellowish-green or clear glassy appearing areas when the remainder of the fruit's surface appeared normally colored. Brownish vascular tissue was usually associated with the affected areas.

In 1933, Bewley, Read, and Orchard (7) again listed the previously defined types of non-uniform colored fruit, and defined an additional class distinct from true blotchy ripening, which they termed "yellow mottle".

Later Seaton and Gray (98), in the United States, defined blotchy ripening as a disorder in which areas of the fruit remained hard and green. The position of the green areas was not included in the definition as it had been by Bewley and White. Seaton and Gray were of the opinion that the clear glassy areas were merely a later stage in the ripening of the green areas rather than a more severe case of blotchy ripening.

In New Zealand blotchy ripening was referred to by the name "cloud" by Kidson and Stanton (59). It was defined as a disorder in which ripe fruit showed green or brownish-green areas with underlying brown veins appearing anywhere on the fruit. They stated that the areas may eventually become yellowish-red or even red. They did not include fruits showing unpigmented glassy areas. Kidson and Stanton (59) noted that the disorder "cloud" was similar in appearance to "vascular browning" observed by Conover (19) in Florida. Conover described "vascular browning" as a grayish brown discoloration seen through the somewhat translucent outer wall and is similar to that outlined by Bewley and White (6) for severe cases of blotchy ripening. Conover stated that placental and septa tissues were not affected.

Haenseler (43) described a disorder similar to "vascular browning" in New Jersey. He noted that the affected fruits were usually somewhat abnormal in color, generally being yellowish. Affected fruits also showed dark translucent areas with indistinct limits near the stem end. The disorder Haenseler described differed from that of Conover's in that the septa and fleshy inner partitions of the fruit were severely browned in advance cases. Haenseler termed the disorder "internal browning".

Stoner and Hogan (107) used the term "graywall" to describe a disorder resembling blotchy ripening. For the most part their description of "graywall" agrees with Conover's description of "vascular browning". Lorenz and Knott (72) noted that affected fruit often show a relatively thin wall or pericarp on the side most exposed to the sun and suggested that the term "thin-wall" might be used to replace the term "graywall".

Cooper (21, 24) concluded that there are four color disorders included under the term blotchy ripening, each possibly with a different cause: 1. greenback, in which an area of the fruit around the calyx remains green when the rest of the fruit is red, with rarely any brown discoloration of the internal tissue; 2. green-blotch in which any area of the fruit may remain green when the fruit is red, vascular browning is usually, but not always, present; 3. yellow or unpigmented-blotch in which vascular browning may or may not occur, and which may or may not be visible as a bronzed discoloration in the immature green fruit; 4. bronzing in which ripe fruit show symptoms similar to yellow-blotch in the presence of tobacco mosaic virus.

Nutritional Aspects

Bewley and White (6) indicated that nutritional factors controlled blotchy ripening. They found an inverse relationship between the percentage of blotchy tomatoes and the increments of nitrogen and potash, particularly potash, added to the soil of plots deficient in these nutrients. They also implied that climatic factors could be involved because some fruits became blotchy even when plots were well fertilized.

Work on "cloud" in New Zealand by Kidson and Stanton (59) showed that the application of glucose to the soil and frequent watering increased the incidence of the disorder while applications of nitrogen and potassium tended to counteract it, and applications of calcium chloride almost completely prevented it. Kidson and Stanton concluded that a virus was not likely to be involved because of the frequency with which "cloud" was induced by greenhouse management. Temperature and rainy weather were also indicated as possible factors influencing the incidence of the disorder.

Winsor, et al. (120), found that the proportion of irregularly colored fruit could be reduced by adjusting the potash/nitrogen ratio to between 2.0 and 2.5. With applications of 1600-1800 lbs. potash (K_2O) per acre they obtained the smallest percentage of irregularly ripened fruit. Winsor and others (121) working with different concentrations of nutrients found that fruit quality improved up to a concentration of 394 ppm K_2O (potassium nitrate) and 225 ppm nitrogen (potassium nitrate and ammonium sulfate).

Stanton (106) found that, in general, fruit quality improved with higher levels of nitrogen and potassium. Owen

(90), Lamm (71), and Stromme (108) also reported a marked reduction in the proportion of blotchy fruit by increasing levels of potash.

Kidson and Stanton (68) found that heavy applications of superphosphate or lime increased the incidence of cloud; however, these harmful effects were offset by liberal applications of nitrogen and potassium. Analyses of plant material suggested a relation between cloud susceptibility and the P/K ratio in the soil, but this relationship was not apparent when plants were grown in water culture.

Clay and Hudson (17) found that blotchy ripening could be reduced by relatively heavy applications of a mixture of potassium and magnesium sulfates. They attributed the reduction in blotchy ripening to increased soil salinity, and also noted that blossom-end rot increased as soil salinity increased. Fruit of best quality were produced on soil with moderate levels of salinity.

In Florida it was found that the incidence and severity of blotchy ripening was higher when plants were grown in nutrient cultures associated with low nutrient concentrations and/or low nitrate/chloride ratios (39). Reports from the Cawthron Institute (15, 16) also indicated that nutrient levels markedly affected the incidence of cloud and observed twelve times as much cloud at a low as at a high level of N and K.

Working with tomatoes in water-cultures, Kidson (65,

66) found that an increased osmotic pressure of the nutrient solution reduced the incidence of cloud. This was accompanied by a reduction of Ca and K in the leaves and more than a 10-fold rise in Na. No relationship between blotchy ripening and various levels of B and Ca were found. The application of Fe, N, or K did not affect the incidence of cloud (62) whereas applications of zinc were associated with an increase in the severity of cloud symptoms (63). It appears that the quality of fruit color was not associated with any one nutrient but to a general increase in soluble salt concentration.

Butters (12, 13) used sodium sulphate in conjunction with an adequate level of major nutrients to increase the concentration of the soil solution. During the first year, the treatment gave an improvement in uniformity of pigmentation, but was less effective during the following growing season.

Environmental Factors

With reference to Bewley and White's work (6), Seaton (97), and Seaton and Gray (98) indicated that nutrient deficiency was not the primary cause of blotchy ripening. They advanced the hypothesis that the disorder is caused by a sudden withdrawal of water from the fruit three to five days before ripening, resulting in mechanical disruption of the vascular system and prevention of translocation of elaborated food materials. They based this conclusion on the morphological appearance of the vascular system in sections of affected fruit; but did not present any experimental evidence to support their view. They suggested that deficiencies of potassium and nitrogen are probably secondary factors with respect to the incidence of blotchy ripening.

Gignate (40) also found that vascular bundles of affected fruit appeared to be mechanically disrupted, and that the epidermis of a ripened fruit was often underlain with white spongy tissues. Gignate agreed with Seaton and Gray in that the vascular disruption could occur under moisture stress, and went further by outlining the environmental conditions under which this could occur; if a dry spell immediately follows a wet spell the fruit would experience a rapid uptake of water followed by a rapid loss of water through transpiration which would result in a stress on the vascular system of the fruits.

White (114) noted that an increase in daylength was associated with a decrease in the percentage of blotchy fruit despite an increase in over-all crop weight. Since these conditions would result in a greater depletion of nutrients, White suggested that blotchy ripening was not directly due to potassium or nitrogen deficiency, but to metabolic changes counteracted by increased light. He attributed the beneficial effect of increased light to increased carbohydrate levels in the plant.

Lorenz and Knott (72) attribute the disorder they called "graywall" or "thin-wall" to uneven heating of fruits, particularly those exposed to the sun. As the unshaded side of the fruit warmed, the water was distilled from the warm side to the shaded side of the fruit, thus, the young cells on the unshaded side of the fruit would not be able to maintain a turgor satisfactory for normal cell functioning. The uneven coloring disappeared as the fruit ripened.

Conover (19) found that "vascular browning" was most severe in fruit from heavily shaded plants. He isolated no causual organisms. Stoner and Hogan (107) working with what appeared to be the same disorder as reported by Conover, concluded that the disorder was some physiological factor, neither nutritional nor viral.

Haenseler (43) was unable to find a correlation between internal browning, major nutrient levels, minor element deficiencies or toxic materials in the soil. He observed that fruits from only the second and third harvest were seriously affected in that particular growing season and that the trouble diminished as the season progressed.

Kidson and Stanton (59) observed that cloud is most pronounced in the early pickings, and that it decreases and often disappears during mid-season, and then reappears late in the season. Ells (35) also found blotchy ripening to be most severe on fruit from lower clusters, and that it seldom occurred on fruits from upper clusters later in the season.

Steam sterilization, heavy watering, raw organic manures, heavy defoliation, and excess leaf and vine growth have been shown to increase the incidence of cloud (59).

Season to season variations occur in the incidence of blotchy ripening, and it has been suggested by Kidson and Stanton (59) that rainy weather during the early part of the season may affect the incidence of the disorder.

Experiments were conducted to observe the effects of shade, moisture, soil texture, and cool temperatures on the incidence of vascular browning by Hall and Dennison (44, 45). The results indicated that all the above influence vascular browning. Low night temperature was more effective when combined with mist, or shade and mist in the production of vascular browning. Stanton (105) indicated that light, water supply, major, and minor elements also contribute to the incidence of vascular browning. Ells (35) observed that heavy watering increased blotchy ripening, and it has been observed that the weight of rough and unmarketable fruit was generally higher on shaded plants (2).

Shade and high humidity, separately and in combination, have been suggested as cloud inducing factors. Kidson (63) thought that high humidity may not be harmful in the presence of high light intensity. Frequent watering increased the effect of high humidity, and partial shading for three weeks resulted in a lower dry matter content of tomato fruit (Kidson 62, 63, 87).

Cooper (24, 25), Jones (56), and Jones and Alexander (57) concluded that blotchy ripening was increased by shade, high day temperatures preceded by low day temperatures, high moisture, and high nitrogen levels.

In another investigation Cooper (23) showed that wide spacing (6' x 6') of tomato plants and the retention of auxillary shoots resulted in an increase in the percentage of uniformly colored fruit. The number of fruit and yield per plant was increased, but resulted in a decreased mean fruit weight.

These results do not agree with work done by Ells (35) and by Kidson and Stanton (59) who found that high yielding plants tended to produce more blotchy tomatoes; Ells observed that as the ratio between fruit weight and green plant weight increased, blotchy ripening increased.

Low temperature (65°F. Day) was reported by Cooper (22, 26) to reduce the proportion of "greenback", but increase the proportion of "yellow-blotch". The low temperature was also associated with a 20 percent increase in yield due to an increase in mean fruit size and not to an increase in fruit number.

Woods (125) and Winsor and Massey (118) indicated that greenback and blotchy ripening should be classified separately. These workers found that shade reduced the incidence of greenback, but increased the percentage of blotchy fruit.

Dennison (33) observed that at temperatures above 86°F. tomato fruit developed a yellow color because the red pigment lycopene was not produced. Minges, et al. (80), found blotchy ripening and graywall associated with periods of low temperatures in the field and the greenhouse (60°-70°F.) as compared to warm temperatures (70°-80°F.). It was observed by Gardner (37) that abundant light resulted in relatively high sugar levels, especially combined with a cool night-warm day regime (63°-65°F. night, 67°-75°F. day). A high level of soil moisture depressed dry matter, especially when fruits and plants were shaded. In general, he found the smallest fruits to be of highest quality.

Controlled environment experiments showed that low light intensities one or two weeks prior to ripening caused blotchy ripening, and that the condition was associated with reduced sugar content (18, 92, 87).

Gilbert (41) observed in Hawaii that vascular browning ceased to appear as soon as the trade winds started to blow day and night. This happened despite the occurrence of cloudy, wet, cold spells during the windy period. It was suggested that the disorder might result from sub-oxidation injury in affected tissue during periods of little air movement.

Tobacco Mosaic Infection

Holmes (52, 53) working in the same area of New Jersey as Haenseler (43) found a close association between tobacco-mosaic virus infected plantains (Plantago species) growing near tomato fields or cold frames and the incidence of blotchy ripening. Both plantains and tomatoes were found to contain a series of similar but unusual strains of tobacco mosaic virus (TMV).

Raychaudhuri (93) found, and Boyle (10) confirmed, that the TMV strain that was associated with internal browning was not the same as the ordinary strain of TMV.

Boyle (8) and Boyle and Wharton (9) consistently isolated strains of tobacco mosaic virus from internally browned fruit and from foliage of plants that had produced internally browned fruit. They observed a negative correlation between the early appearance of mosaic symptoms and the ultimate production of internally browned fruit. They showed that internal browning could be reproduced in large healthy tomato plants by mechanical inoculation with an isolate just as the first fruit were beginning to ripen, but that inoculation of young plants did not result in internal browning. These authors concluded that internal browning was a "shock reaction" resulting from virus invasion of the fruit, followed by a hypersensitive response of the host, and they found no correlation between incidence of the disorder and the rate of fertilizer application, disease spray program or variety.

Although Boyle and Wharton (9) found no relationship between internal browning and rate of fertilizer application, Selman (99) found that blotchy ripening appears to respond differently to potash levels in control and mosaic infected plants. High potash tended to reduce the incidence of blotchy ripening in mosaic infected plants, but similar quantities of potash applied to control plants increased the percentage of blotchy fruit. In the latter case, Selman suggested that the hardening or growth check, associated with potash application tended to increase the susceptibility of the control plants to accidental infection. Rich (94) also found that the incidence of internal browning could be influenced by fertilizing. High potassium alleviated internal browning in virus-inoculated plants, and high phosphorous tends to obscure the beneficial effect of high potassium. Rich's results indicated that virus alone would not result in severe internal browning.

Cotter (28, 29) suggested that when all lack of normal red color disorders are grouped together, there seemed to be a difference in fertility effect on fruit color as compared to browning of vascular bundles, thus suggesting that fruit color and bundle necrosis could be different in nature. He distinguished them by referring to them as blotchy ripening and internal browning respectively. The incidence of internal browning was not affected by N, K, B, and various infective conditions of TMV. This report contradicts that of Rich (94) as well as the report of Taylor (109) who found that the incidence of internal browning in virus infected plants to be greatly influenced by nitrogen and boron nutrition. Taylor (109) believed that internal browning was the result of interference with the movement of reducing sugars to the developing fruits. Cotter (28, 29) did find that high nitrogen levels significantly increased the incidence and severity of blotchy ripening, and a high potassium level improved fruit color.

A distinction between graywall, internal browning, and blotchy ripening was made by Murakishi (84). Internal browning appeared to be induced by late infection with strains of tobacco mosaic virus, and could be seen in either mature green or ripe fruit. Graywall, on the other hand appeared to be induced by low light intensities on TMV-free plants, but was restricted to green or mature green fruits. Blotchy ripening was the same as graywall except that the former appeared on unevenly colored ripe fruit (113). Murakishi (83, 85, 86) noted that during the investigations he could not distinguish graywall from internal browning by outward symptoms with any degree of certainty. Therefore, differentiation was based not on symptoms but on whether the affected fruit was produced on TMV-infected plants or TMV-free plants. Low light intensities were reported to aggrevate both disorders.

Jones and Alexander (55, 56, 57) found that under a low temperature regime followed by high temperature, the number of diseased fruits increased as the potassium level decreased. The correlation was not as good under normal temperatures. The percentage of blotched fruit was also increased by subjecting greenhouse plants to high soil moisture, high nitrogen levels, shade, and injection of plants with TMV. Tobacco mosaic virus increased the incidence and severity of blotchy ripening in both field and greenhouse crops, but blotchy ripening occurred with high incidence and severity in the greenhouse on plants that tested free from tobacco mosaic virus.

Composition

Internal as well as external factors have frequently been associated with blotchy ripening. The composition of the tomato fruit and plant has been studied and fairly definite differences between blotchy and non-blotchy fruit have been found. White (114) found that juice expressed from blotchy areas had diminished capacity for starch hydrolysis. It has also been indicated that blotchy ripening susceptibility is related to low starch content in immature fruit (66).

Brewer (11) found that mosaic infected plants were characterized by a reduction in total weight and a reduction in total carbohydrate content. The reduction occurred mainly in the polysaccharides. Generally, there was no reduction in the nitrogen content and the carbon-nitrogen ratio was usually lower in diseased plants.

Davies (31) found that the citric acid concentration was much lower in both the red and green wall areas of blotchy fruit than usually occurs in normal fruit. This was accompanied by fairly high concentrations of malic acid, which was found to be as high in blotchy areas as in unripe fruit. The red areas of blotchy fruit also had a higher malic acid concentration than normal fruit.

Hall and Dennison (44) found the Ca, K, Mg, and P, content to be higher in blotchy fruit than in normal fruit.

Hobson (48, 49, 50, 51) observed that the pectic substances of both the red and non-red areas were much higher in blotchy fruit than in uniformly ripened fruit, while pectin methylesterase activity was lower than normal. Blotchy tomatoes also showed highly significant differences in polygalacturonase activity between the green and red areas. The activity in the green area was only 16 percent of that in the corresponding red areas. Whether these enzymatic changes caused blotchy ripening or whether blotchy ripening caused the enzymatic changes was not determined.

It has been suggested by Kidson and Stanton (60, 61) that cloud is associated with low dry-matter content of fruit and leaves, and that this condition might be due to excessive water uptake or to reduced photosynthesis. In most cases the total solids content of small tomato fruit was higher than that of larger fruits from the same plant. Analyses of normal and blotchy tomato fruits showed the content of dry matter, soluble solids, reducing sugars, acidity and nitrogenous compounds to be lower in blotchy fruit than in normal fruit (77, 78, 116, 117, 118).

It was observed by Kidson (64) that high polyphenol oxidase activity normally decreases as fruit ripen, and that cloud affected fruit show an abnormal retention of polyphenol oxidase activity in the blotchy areas. Walker (110) found that cloud tissue had a lower phenolic acid content than healthy tissue the same age.

Observations made by Kidson (67) indicated that the use of sodium or potassium sulphate to increase the osmotic concentration of a nutrient solution decreased the incidence of cloud and also resulted in highly significant changes in the level of Ca in the plant (67).

Environmental and cultural factors play a role in fruit and plant composition as shown by Krobonits (69). In his experiment the dry matter content of tomato fruits was higher from plants grown on drier, heavier loams than those grown on wetter soils. A high plant density also increased dry matter content of fruit.

It has been found that low light intensities decrease reducing ability of tomato leaves as measured iodometrically (70). It has also been found that starch, amino acids, and protein content of leaves of shaded plants were lower than plants grown under normal light (96, 118).

Siegel (100) found that the presence of chloride in the nutrient solution generally reduced the dry matter content of the tomato plants. Chloride ions reduced the content of glucose, fructose, and sucrose. At high potassium levels the sugar concentrations were not reduced as much as they were in solutions with low potassium.

Winsor and Davies (119), Winsor (122), and Winsor et al. (123) found that reducing sugars and total solids in the expressed sap of fruit were significantly increased by virus infection. Numerous explanations for this may be available, but the fact that total yield and the proportion of high grade fruit were reduced may account for the small but significant increase in sugars and solids. It was also observed by these workers that total solids, sugars, refractive index and dry matter content of the fruit was markedly reduced by partial defoliation, while limiting the number of fruit per truss resulted in an increase in these values.

It is thus apparent, from the numerous workers cited that the term blotchy ripening and terms derived from it have been used with several meanings. Many suggestions have been offered as to its cause, which have resulted in confusion, and, therefore, blotchy ripening has come to mean little more than non-uniformly colored fruit. Whether or not these disorders are different manifestations of the same trouble or actually different disorders with different causal agents has not yet been clearly demonstrated.

FIELD EXPERIMENTATION

Effect of Soil Moisture Level and Shade on Blotchy Ripening (1962)

It has been suggested by various workers (59, 44, 45, 105, 35 and 41) that frequent watering, defoliation, carbohydrate stress in the fruit at some critical period during fruit development, and cloudy, rainy weather may increase the incidence of blotchy ripening.

Most investigators that have indicated adverse environmental factors as possibly being associated with the incidence of blotchy ripening indicated that the critical period for induction of the disorder is just prior to fruit ripening (18, 92, 87). Because the factors resulting in adverse weather vary from year to year the time of outbreaks of blotchy ripening would differ from season to season.

An initial study was undertaken to correlate the occurrence of blotchy ripening with periods of adverse weather, but it was found that data available on dates of flower anthesis, flower set, harvest dates, and severity of blotchy ripening in Michigan were not complete enough to be correlated with available weather data. Because of this, the most susceptible size or stage of development at which tomato fruit develop blotchy ripening could not be determined by correlation comparisons.

For these reasons an attempt was made to partially simulate environmental conditions in the field that had been indicated in the literature as being associated with the incidence of blotchy ripening and evaluate their infflluence on the disorder.

Because many different factors have been indicated as being associated with the occurrence of blotchy ripening, it was decided to use treatments including more than one factor, and if a particular treatment resulted in significantly more blotchy fruit, the separate factors could be identified in further work.

Procedure:

Seed of the tomato varieties Bird's Nest and Fireball were sown on April 4, seedlings were maintained in a greenhouse, and transplanted into the field on May 26. Eight-hundred pounds of 5-20-20 fertilizer and 40 tons of manure per acre were applied and worked into the soil before transplanting. On July 2, a side dressing of 100 pounds per acre of ammonium nitrate was applied.

A randomized complete block design was used. It included a comparison of the varieties and of shaded and unshaded plots, with two replications. There were nine plants per plot on two foot centers in the row and three feet between the rows.

The material used to shade the plots was Lumite saran shade fabric (Chicopee Manufacturing Corporation, Cornelia, Georgia). It covered the whole plot and reduced light intensity by 72 percent as measured in foot candles by a model 756 Weston Illumination meter. The shade fabric was suspended approximately six-inches above the tomato plants. The shaded plots received 4 inches of water over a 4 day period starting at the time they were covered, and in addition were also sprayed three times daily with approximately 3 quarts of water. The addition of the 4 inches of water and the spray insured a high level of available soil moisture and humidity. Shades were placed over the variety Bird's Nest and Fireball on July 9, and July 19 respectively, and remained over the plots 14 days.

At harvest the fruit were classified blotchy when 10 percent of their surface area was affected. The number and weight of blotchy and nonblotchy fruit was recorded for each harvest, and percent soluble solids were determined with a hand refractometer.

A preliminary investigation of sampling technique for percent soluble solids was conducted. Soluble solids from the following portions of Fireball and Bird's Nest fruit were sampled to determine if significance differences existed among them: 1. the upper one-quarter of the fruit or calyx-end, 2. the walls of the middle half of the fruit, 3. the internal placental tissue, and 4. the bottom one-quarter or blossom-end of the fruit.

Soluble solids were determined from blotchy and from normal fruit from both shaded and control plots. The averages used for the analyses of variance represented 20 fruit.

The analyses of variance were performed on the resulting data as indicated by Snedecor (103) and mean comparisons made by the method described by Duncan (34).

Results and Discussion:

Neither yield nor the incidence of blotchy ripening were influenced by the shade plus the initial four-inch application of water, and there was no difference in the incidence of blotchy ripening between the variety Fireball and Bird's Nest (Table 1).

From the preliminary investigation of percent soluble solids, it was found that there were differences in soluble solids among the various portions of the fruit that were sampled (Table 2A). Wall tissue from the middle one-half of the tomato fruit were used for all subsequent soluble solids determinations.

Only a 4 percent difference in percent soluble solids was found between blotchy and normal fruit (Table 2C). Although there was no significant difference in percent soluble solids between fruit from shaded and control plots, fruits from control plots averaged 13 percent higher in soluble solids than fruit from shaded plots (Table 2B).

Ells (35) suggested that blotchy ripening might be caused by insufficient photosynthate for fruit development

TABLE 1.--The Influence of Shade and High Soil Moisture on Blotchy Ripening.

Treatment:	Control				Shade Plus High Soil Moisture			
	Blotchy1/		Non-Blotchy		Blotchy		Non-Blotchy	
Bird's Nest:		%		%		%		%
Frt. Wt./Plant	6.2	42	8.5	58	5.6	50	5.5	50
Frt. No./Plant	40	52	37	48	55	58	40	42
Avg. Fruit Weight (lbs)	.15		.22		.10		.13	
Fireball:								
Frt. Wt./Plant	9.0	56	7.0	44	13.8	67	6.8	33
Frt. No./Plant	39	53	34	46	50	66	26	34
Avg. Fruit Weight (lbs)	.23		.20		.28		.26	

1/ Blotchy fruit were those with yellow discolored areas on more than 10 percent of their surface area.

TABLE 2.--Variation in Percent Soluble Solids of Tomato Fruit.

A: Average soluble solids of indicated portions of tomato fruits.

Area of Fruit Sampled	Soluble Solids(%)	Statistical Significance*
Calyx-end tissue	3.96	a
Mid-outside wall tissue	4.25	b
Placential tissue	4.63	c
Blossom-end tissue	4.80	d

B. Average soluble solids of tomatoes grown on shaded and control plots.

Shaded plots	4.13 1/	a
Control plots	4.69	a

C: Average soluble solids of blotchy and normal tomato fruits.

Blotchy fruit	4.32 1/	a
Normal fruit	4.49	a

1/ Averages include both Fireball and Bird's Nest fruit; samples from the calyx-end, the mid-outside wall tissue, placental tissue and the blossom-end tissue of tomato fruits.

* Means with uncommon letters are significantly different at 5% level.

when small plants were heavily laden with a crop of tomato fruit. Others (59, 44, 45) have indicated that heavy watering, and cloudy weather are associated with the incidence of blotchy ripening.

While the plants were not particularly small, and did not carry an unusually large load of fruit, the shade material might have reduced carbohydrate levels by reducing photosynthetic activity. If a shortage of carbohydrates is a factor in the development of blotchy ripening, the low light intensities associated with cloudy, rainy, weather would help explain results of other workers that have associated blotchy ripening with periods of inclement weather.

Another possibility is that under high humidity, low evaporation, low light intensities, cloudy atmospheric conditions and rainy weather the water balance of the tomato plant and fruit might become upset and lead to the development of blotchy ripening.

Results indicate that the treatment employed was not effective in inducing more blotchy ripening than occurred on the control plots. However, 42 and 56 percent of the fruit on a weight basis, and 52 and 53 percent on a fruit number basis, from the respective control plots of Bird's Nest and Fireball were classed as blotchy (Table 1).

Because a large percentage of fruit from the control plots were affected with blotchy ripening there were environmental conditions during 1962 that contributed to the

development of blotchy ripening. The season was not favorable for measuring the effectiveness of the treatment in inducing blotchy ripening.

Effect of Various Treatments on the Incidence of Blotchy Ripening

Procedure:

The following treatments were a continuation of the previous study: 1. 90 percent shade with an initial application of 4 inches of water over a period of 4 days, 2. pruning 1/3 to 1/2 of the mature leaves from the plants, 3. removal of 1/2 of the fruit over 2 inches in diameter, 4. misting the plants by an automatic misting apparatus and 5. a control.

A split plot arrangement with main plots in 3 randomized complete blocks was used. The main plots consisted of three varieties: Fireball, Moreton Hybrid, and Burpee Hybrid. Each treatment consisted of 6 plants set with 2½ by 5 foot spacing. Only data from the 4 middle plants in each treatment were recorded.

The shade cloth was placed over the plots 7-10 days before the first harvest, and remained over the plots for 14 days.

An automatic misting apparatus was set up and moved when the shades were moved. The length of the misting period was regulated by a Mist-A-Matic-Model B control system (E. C. Geiger, North Wales, Pennsylvania). The interval between mistings varied with water accumulation and evaporation rate from a counterbalanced metal screen, which controlled a solenoid valve. The counterbalance of the screen was adjusted so that the misting cycle was synchronized with evaporation from the plant foliage. Misting did not add any appreciable amount of water to the soil.

One-third to one-half of the mature leaves were removed on July 16, July 27, and August 23, for the varieties Fireball, Moreton Hybrid, and Burpee Hybrid, respectively.

One-half of the fruit over 2 inches in diameter were removed from Fireball, Moreton Hybrid, and Burpee Hybrid plants on replicated plots on July 20, July 31, and August 25, 1962.

At harvest, fruit were graded into three classes: non-blotchy (less than 10 percent of the fruit's surface area affected), slightly blotchy (10-25 percent), and severely blotchy (over 25 percent of surface showing defect).

Results and Discussion:

None of the treatments affected the incidence of blotchy ripening or yield. However, yield and the percentage of blotchy fruit were influenced by variety. The variety Fireball and Moreton Hybrid produced a significantly larger percentage of fruit classes as severely blotchy than Burpee Hybrid (Table 3).

The yields recorded in Table 3 include only ripened

TABLE 3.--The Influence of Various Treatments on Fruit Size, Yield, and the Percentage of Blotchy Ripening.

Treatment	Yield Ripe Fruit Per Plant No.	Yield Ripe Fruit Per Plant lbs.	Average Weight Per Frt (lbs.)	Percent by Weight and Number[1/] Normal Wt.	Normal No.	Slightly Blotchy Wt.	Slightly Blotchy No.	Severely Blotchy Wt.	Severely Blotchy No.
Variety: FIREBALL									
90% shade	64	10.9	.17	37	38	37	34	25	28
Defoliation	68	16.6	.24	47	47	29	31	24	22
Auto-misting	65	15.3	.23	39	41	33	35	27	23
Defruiting	56	13.3	.23	48	51	29	27	23	21
Control	69	15.2	.22	44	45	47	35	21	20
Variety: BURPEE HYBRID									
90% shade	17	7.1	.41	65	70	34	29	0.1	0.2
Defoliation	21	8.6	.41	60	63	39	36	1.1	0.2
Auto-misting	18	6.9	.38	73	72	25	26	2.7	2.2
Defruiting	13	5.5	.42	57	60	42	39	0.3	0.6
Control	13	5.8	.44	65	69	35	31	0.0	0.0
Variety: MORETON HYBRID									
90% shade	36	24.6	.68	39	60	43	28	17	11
Defoliation	47	21.8	.46	51	53	34	33	15	14
Auto-misting	37	15.0	.40	59	51	32	40	8.	8
Defruiting	33	14.5	.43	44	45	45	45	11	10
Control	39	17.6	.45	44	46	50	45	6	8

1/ Normal, less than 10% of fruit's surface area affected with blotchy tissue

Slightly Blotchy, 10-25% of fruit's surface area affected with blotchy tissue

Severely Blotchy, more than 25% of fruit's surface: area affected with blotchy tissue fruit. A large percentage of the fruit of Burpee Hybrid were green at the time of the first killing frost in the fall and was not included.

The treatments had no affect on average fruit weight of fruit classed as normal, slightly blotchy or severely blotchy (Table 4). Generally, fruit from the two blotchy classes were slightly larger than normal fruit.

There were no significant differences in percent soluble solids of fruit among treatments or between normal and blotchy fruit. However, fruit classed as normal did average slightly higher in percent soluble solids than fruit from the two blotchy classes (Table 5).

Again as in the case of the previous study, a large percentage of the fruit produced by plants growing on the control plots was affected with blotchy ripening, making it difficult to determine if the treatments were effective in inducing blotchy ripening.

Environmental Influences on Blotchy Ripening (1963)

Again as in 1962 experiments were conducted to simulate environmental conditions that might be associated with blotchy ripening. Emphasis was placed on evaluating factors affecting the water balance of the plant.

Procedure:

Seed of Fireball and Glamour were sown on April 15,

TABLE 4.--The Effect of Variety and Treatment on Average Fruit Size.

Variety and Treatment	Normal Fruit (lbs.)	Slightly Blotchy Fruit (lbs.)	Severely Blotchy Fruit (lbs.)	Mean Fruit Weight (lbs.)
FIREBALL				
90% shade	.16	.19	.15	.17
Defoliation	.24	.23	.26	.24
Auto-misting	.22	.22	.27	.23
Defruiting	.22	.25	.25	.23
Control	.21	.22	.22	.22
BURPEE HYBRID				
90% shade	.39	.47	.35	.41
Defoliation	.39	.43	.40	.41
Auto-misting	.38	.36	.44	.38
Defruiting	.39	.43	--	.42
Control	.42	.51	--	.44
MORETON HYBRID				
90% shade	.44	1.03	1.04	.68
Defoliation	.45	.46	.50	.46
Auto-misting	.46	.32	.39	.40
Defruiting	.43	.44	.45	.43
Control	.42	.48	.35	.45

Normal, less than 10% of fruit's surface area affected with blotchy tissue

Slightly Blotchy, 10-25% of fruit's surface area affected with blotchy tissue

Severely Blotchy, more than 25% of fruit's surface area affected with blotchy tissue

TABLE 5.--The Effect of Treatments on the Percent Soluble Solids of Normal and Blotchy Fruit of Fireball Tomatoes.

Fruit Classes	90%-Shade	Defoliation	Auto-misting	Defruiting	Control	Average
			Soluble Solids			
Normal	4.8	4.1	4.0	4.2	4.3	4.2
Slightly-Blotchy	4.1	4.2	4.0	4.0	4.2	4.1
Severely-Blotchy	4.0	4.3	4.0	4.3	4.1	4.1

Each value represents the average of approximately 20 determinations.

A composite sample of both blotchy and normal tomato fruit tissue from the walls of the middle half of the fruits were used for these determinations.

1963, transplanted into 3 inch veneer bands on May 1, and planted in the field on May 30, 1963. Five-hundred pounds of 10-20-20 fertilizer per acre was applied to the field before the tomatoes were transplanted, and 1/2-pint of 10-52-17 starter solution (3 lbs./50 gal. water) was applied to each plant at transplanting.

The field plot design was a split-split plot with two replications. The first split was between moisture levels, the second between varieties, and the third among treatments. Each plot consisted of four plants spaced at 3 x 6 feet. Records were taken from the two center plants in each plot.

An attempt was made to maintain two moisture levels in the field during the growing season of 1963: 1. a minimum of 80 percent available soil moisture, and 2. a minimum of 40 percent available soil moisture. Delmhorst soil blocks were placed in the soil at depths of 6 and 15 inches in 12 locations. An average of readings from the two different depths was used to determine the time of irrigations.

The following treatments were employed: 1. application of calcium chloride at a rate of 1500 lbs. per acre, 2. foliage applications of phenylmercuric acetate, 3. misting plots with water, 4. shading, 5. a combination of plastic windbreaks and misting, and 6. plastic windbreaks alone.

A solution of calcium chloride was applied on July 29 to increase the osmotic concentration of the soil solution.

Phenylmercuric acetate (PMA), a chemical reported to influence transpiration (126, 127) was initially applied on July 29 to the tomato plant foliage as a spray at a concentration of 3.3×10^{-4}M. Repeated applications were made at 10 day intervals throughout the season. A preliminary experiment was conducted with PMA before field application. The procedure described in the following study on influence of chemicals on transpiration was used, except the variety used was Fireball.

Two types of shade material were used, a coarse nylon material that reduced light intensity, as measured by a foot candle meter, by 20 percent, and a finer textured material that reduced light intensity by 70 percent. The 20 percent shade material was placed approximately 6-inches above the tomato varieties Fireball and Glamour on July 22, well in advance of fruit ripening. The 70 percent shade material was placed over the light shade material, resulting in an approximate 90 percent reduction in light intensity, at the time the fruits in the first cluster were in the white-star stage of ripening. The 70 percent shade material was placed over the tomato variety Fireball on July 30 and over the tomato variety Glamour on August 9, 1963, and remained over the plants for 20 days.

Misting of plants was performed by the same equipment described previously, and the influence of misting upon relative humidity was determined with a battery powered psychrometer.

Windbreaks of 4-mil clear plastic 2½ feet high were placed on both sides of the plant rows on July 23, 1963. In a supplemental study, clear and green plastic windbreaks were placed in an open area to determine their effect on temperature and humidity. Thermocouples, connected to a Minneapolis Honeywell temperature recorder, were placed between the windbreaks at three different heights above the ground surface (4, 12, and 24 inches) and in an adjacent open area at the same heights to serve as a control.

Humidity determinations were measured between the windbreaks at ground level and at 12 inches above the ground surface with a battery powered psychrometer.

Soluble solids determinations of Fireball and Glamour fruits were taken throughout the season with a hand refractometer.

Fruits were graded into the following three classes: 1. uniformly colored including those with less than 10 percent of their surface blotchy, 2. those with 10-25 percent of their surface area blotchy, and 3. fruits with more than 25 percent of their surface area blotchy.

The growth rates of fruits from the different treatments were compared to determine if rate of fruit growth and swelling was associated with the incidence of blotchy ripening, and to determine if the different treatments induced changes in rate of fruit growth.

The diameters of two fruits on each of two plants from each plot were measured with direct reading calipers from July 26 to September 6. To insure that fruit diameter measurements taken on different dates would be taken at the same points on the fruit, a small dot was applied on each side with a marking pencil, and the caliper's tips were placed on these dots at each measurement.

Because fruits selected for measurement were of slightly different diameters and because some fell off of the vine or ripened early and had to be substituted by other fruits, increase in growth was expressed as percentage increase in fruit diameter.

The analyses of variance were performed on the resulting data as indicated by Snedecor (103) and mean comparisons made by the method described by Duncan (34).

Results and Discussion:

Results from a preliminary experiment utilizing PMA showed that the chemical reduced water loss by 15 percent. The relative humidity in the peripheral foliage of misted plants was 10 to 40 percent higher than that recorded in corresponding non-misted plants. The supplementary windbreak studies showed that temperatures recorded within the green plastic windbreaks were lower than those recorded within the clear plastic windbreaks, or in the adjacent open area (Table 6). Temperatures recorded between the clear plastic windbreaks and adjacent open area were approximately the same

(Table 6). Relative humidity between the clear plastic windbreak was found to be 3.7 percent higher at ground level than in the open control area. However, at a height of one foot above the ground the relative humidity between the clear plastic windbreaks was 38.2 percent higher than that recorded in the open area at the same height (Table 7).

There was no differences in weight of Glamour fruit per plant or in number of fruit per plant among the different treatments (Table 8).

There was no differences in number of fruits produced by plants of the variety Fireball grown on the calcium chloride treated plots, the shaded plots, or the plots sprayed with phenylmercuric acetate. Plants subjected to the calcium chloride treatment produced more fruit, on a number basis, than was produced by plants grown on the control plots, the misted plots, the plots protected by windbreaks or the plots that were protected by windbreaks and misted (Table 8).

With respect to the weight of fruit produced by plants of the variety Fireball, those plants grown on calcium chloride treated plots produced more fruit than were produced by plants subjected to the combination treatment of misting and windbreak protection. There were no differences in the weight of fruit produced per plant among the remaining treatments (Table 8).

With respect to severeness of blotchy ripening it was

TABLE 6.--The Influence of Windbreaks Upon Temperature.

Height of Temp. Measurement Above Ground	Clear Plastic Windbreak	Green Plastic Windbreak	No-Windbreak
4"	92.6a*	89.9b	92.1a
12"	91.6a	87.1b	90.5a
21"	91.8a	87.4b	91.1a

* a, b, are for values in the same horizontal column.

Means with uncommon letters are significantly different at 5% level.

TABLE 7.--The Influence of Windbreaks Upon Relative Humidity.

Height	Between Clear Windbreak	Adjacent Open Area	Percentage Difference
Ground-level	75.0	72.2	3.7
1-Foot Above Ground	70.8	43.7	38.2

TABLE 8.--The Effects of Treatments Designed to Modify Moisture and Carbohydrate Stresses on the Number and Weight of Fruit Produced Per Plant.

Variety and Treatment	No. of Frt./Plt.	Variety and Treatment	Wt. of Frt./Plt.	Avg. Frt. Wt. (lbs.)
Fireball		Fireball		
Calcium Chloride1/	87.3 a	Calcium Chloride1/	16.3 a	.19
PMA2/	60.1 ab	Control	15.0 ab	.21
Shade	60.0 ab	Windbreak	12.6 ab	.19
Control	58.5 b	PMA2/	12.5 ab	.25
Windbreak	56.9 b	Misting	12.2 ab	.22
Misting	56.4 b	Shade	11.6 ab	.22
Windbreak + Misting	42.0 b	Windbreak + Misting	8.3 b	.20
Glamour		Glamour		
Control	27.4 a	Control	10.4 a	.38
Calcium Chloride1/	32.0 a	Calcium Chloride1/	11.4 a	.36
PMA2/	29.2 a	PMA2/	11.2 a	.38
Misting	27.8 a	Misting	11.1 a	.40
Shade	26.9 a	Shade	9.7 a	.36
Windbreak	24.6 a	Windbreak	8.7 a	.35
Windbreak + Misting	19.5 a	Windbreak + Misting	7.4 a	.38

1/ Calcium chloride applied to soil at rate of 1500 lbs./acre
2/ PMA = phenylmercuric acetate
* Means with uncommon letters are significantly different at 5% level.

found that the relatively larger fruit tended to be most severely affected with blotchy ripening. In the case of fruit from the variety Fireball there was no differences in average fruit weight for the different classes of fruit. The average weight of Glamour fruits with more than 25 percent blotchy tissue were found to be significantly heavier than fruits classed as normal (Table 9).

A significant difference in percent soluble solids of 4.7 percent between Fireball fruits classed as normal and fruits affected with blotchy tissue on more than 25 percent of their surface area was found (Table 10). There were no differences in percent soluble solids among classes of Glamour fruit (Table 10).

Relatively larger tomato fruits have been shown by MacGillivray and Clements (75) and by Gardner (37) to be lower in total solids and sugars than smaller fruits. These findings may partially explain why the larger fruit in this study tended to be affected with blotchy ripening.

Normal tomato fruit tissue was found to be significantly higher in soluble solids (9 percent higher in Fireball fruits, and 7 percent higher in Glamour fruits) than blotchy tissue from the same tomato fruits (Table 11).

There was a significant interaction between treatments and moisture levels with respect to percent soluble solids for the variety Fireball, but not for the variety Glamour (Table 12). Percent soluble solids of Fireball

TABLE 9.--Relationship of Fruit Size to Blotchy Ripening.

FIREBALL		GLAMOUR	
Class	Average Weight (g.)	Class	Average Weight (g.)
25% Blotchy	93.42 a	25% Blotchy	184.35 a
10-25% Blotchy	93.10 a	10-25% Blotchy	169.75 b
Normal	91.28 a	Normal	162.17 b

* Means with uncommon lètters are significantly different at 5% level.

TABLE 10.--Mean Percent Soluble Solids of Fireball and Glamour Tomatoes Classed as Normal and Blotchy.

FIREBALL		GLAMOUR	
Class	% Soluble Solids	Class	% Soluble Solids
Normal	3.74 a	Normal	4.38 a
10-25% Blotchy	3.63 ab	10-25% Blotchy	4.34 a
25% Blotchy	3.57 b	25% Blotchy	4.31 a

* Means with uncommon letters are significantly different at 5% level.

TABLE 11.--Average Percent Soluble Solids of Normal and Blotchy Tissue from Tomato Fruit of the Varieties Fireball and Glamour.

FIREBALL		GLAMOUR	
Normal	Blotchy	Normal	Blotchy
3.7 a	3.4 b	4.4 a	4.1 b

* Means with uncommon letters are significantly different at 5% level.

TABLE 12.--Influence of Various Practices, Treatments, and Soil Moisture Levels on Percent Soluble Solids of Tomato Fruit.

FIREBALL				GLAMOUR			
Treatment	High Moist.	Low Moist.	Avg.	Treatment	High Moist.	Low Moist.	Avg.
PMA[1/]	3.82	4.12	3.97 a	CaC12	4.44	4.70	4.57 a
Control	3.58	4.17	3.88 a	Control	4.51	4.50	4.51 ab
CaCl2	3.49	4.06	3.77 ab	Windbreak	4.32	4.46	4.39 ab
Windbreak	3.21	4.04	3.63 bc	PMA[1/]	4.20	4.42	4.31 bc
Misting	3.52	3.49	3.50 cd	Misting	4.18	4.44	4.31 bc
Shade	3.31	3.57	3.44 cd	Shade	4.16	4.23	4.19 c
Windbreak + Misting	3.11	3.59	3.33 d	Windbreak + Misting	4.11	4.16	4.13 c
	3.43 a	3.86 b			4.27 a	4.41 a	

1/ PMA = Phenylmercuric acetate.

* Means with uncommon letters are significantly different at 5% level.

fruit from the low moisture plots averaged 12 percent higher than fruit from the high moisture plots. Glamour fruit from the low moisture plots were also slightly higher in percent soluble solids than fruit from the high moisture plots (Table 12).

Other workers (60, 61, 69, 96, 117) have also indicated that high moisture levels or environmental factors that reduce transpiration losses often resulted in fruits with low percent soluble solids, reduced amounts of sugars, and lower dry matter.

Generally, fruits from treatments designed to reduce moisture stress or carbohydrate levels were lower in soluble solids than the control. Shaded plants and plants that were both protected by windbreaks and misted produced fruit with the lowest soluble solids in both Fireball and Glamour (Table 12). The calcium chloride treatment, which was used to increase the moisture stress, had no affect on soluble solids (Table 12).

Growth rates of fruits from both Fireball and Glamour tomato varieties were influenced by the various treatments employed in this study. However, no significant differences in fruit growth rates between high and low moisture levels were recorded for fruits of either Fireball (Table 13) or Glamour varieties (Table 14).

Fireball plants treated with PMA, which was shown to reduce transpiration, produced fruits that increased in

TABLE 13.--The Influence of Various Practices, Treatments, and Soil Moisture Levels Upon the Average Rate of Increase of Fireball Tomato Fruit Diameter.

Treatment	Low Moisture	High Moisture	Treatment Means
	Moisture x treatment means		
	%	%	
Phenylmercuric acetate	3.70	2.75	3.22 a
Windbreak	2.50	3.00	2.75 b
Control	2.65	2.50	2.57 bc
Misting	2.40	2.45	2.42 cd
Shade	1.60	2.85	2.22 de
Windbreak + Misting	2.20	1.85	2.02 e
Calcium Chloride	1.60	2.40	2.00 e
Moisture Level Means:	2.37	2.51	

* Means with uncommon letters are significantly different at 5% level.

L.S.D. to compare means of treatments at the same moisture level-$L.S.D._{.05} = .92$

L.S.D. to compare means of the two moisture levels within the same treatment-$L.S.D._{.05} = .52$

Values are the average percent increase in fruit diameter, measured at 4 day intervals, from July 26 to September 6, 1963.

TABLE 14.--The Influence of Various Treatments and Soil Moisture Levels Upon the Average Rate of Increase of Glamour Tomato Fruit Diameter.

Treatment	Treatment Means1/
Windbreak + Misting	4.97 a
Misting	4.47 b
Windbreak	4.45 b
Control	4.42 b
Calcium Chloride	4.30 b
Phenylmercuric Acetate	4.30 b
Shade	3.75 c

1/ Values are the average percent increase in fruit diameter, measured at 4 day intervals from July 26 to September 6, 1963.

* Means with uncommon letters are significantly different at 5% level.

diameter at a more rapid rate than fruit from plants subjected to the other treatments (Table 13). The phenylmercuric acetate treatment appeared to be more effective in inducing a more rapid rate of fruit growth with a low soil moisture level than with a higher soil moisture level (Table 13).

On the other hand, plants subjected to the calcium chloride treatment, which was applied to induce a higher moisture stress, produced fruit with the slowest growth rate. This supports the views expressed by Bartholmew (4), Hendrickson and Veihmeyer (47), Magness et al. (76), Anderson and Kerr (1), and MacDougal (74) that when an internal water stress develops because of low soil moisture and high transpiration, water usually moves from fruits to leaves with a resultant decrease in rate of fruit growth.

It appears that the significantly greater rate of fruit diameter increase induced by PMA may indicate that an excess amount of water might be incorporated into fruits under climatic conditions conducive to low transpiration in combination with high levels of available soil moisture. A trend for larger fruit to be more severely affected with blotchy ripening has already been mentioned. Thus, the amount of water retained in the fruit tissue could be an important factor in determining if tomato fruit develop blotchy ripening.

Cooper (22) presents data supporting the idea that conditions conducive to low transpiration are associated with blotchy ripening. He reported low day temperatures increased the incidence of yellow-blotch and that a 20 percent increase in yield was also associated with cool day temperatures. Increased yield was due to increased mean fruit size and not increased fruit number. This would imply that the increased yield was a result of more water being incorporated into the fruits because of less water loss from the plant's leaves. Minges et al. (80) reported similar findings. Observations reported by Kidson and Stanton (59) and Gilbert (41) imply that low transpiration may also be involved in the production of blotchy ripening. These results also suggest that fruits with higher water contents tend to have a higher incidence of blotchy fruit.

As already mentioned, the growth rate of fruit of the variety Fireball grown on calcium chloride treated plots was slowest of any treatment. The fact that plants grown on calcium chloride treated plots did produce a larger number of fruit per plant suggests that there may not have been as much photosynthate per fruit as was available to fruit grown on plants from the other treatments. If this were true, it would probably result in smaller fruits. There is, however, data that suggest that lack of water contributed to the slow rate of fruit growth and smaller fruit size, especially under a low moisture regime (Table 13). Growth rates of tomato fruit from calcium chloride treated plots in combinations with the higher soil moisture level were not significantly different from growth rates of tomato fruit from the high moisture control plant, but growth rates of fruit from calcium chloride treated plots in combination with low moisture were significantly lower than the low moisture control and the growth rate of fruits from plants subjected to the calcium chloride-high moisture regime. It thus appears that the calcium chloride treatment was effective in reducing rate of fruit growth under the low moisture condition.

It had been anticipated when the experiments were set up that the calcium chloride would increase the osmotic concentration of the soil solution, and thereby reduce the amount of available water that could be taken up by the plant and incorporated into the fruit, and this in turn would tend to reduce the incidence of blotchy ripening. A partial explanation as to why calcium chloride was not effective in reducing blotchy ripening may be in the paper presented by Siegel and Bjarsh (100). They found that the presence of chloride in nutrient solutions generally reduced the dry matter content of plants and also reduced the glucose, fructose, and sucrose content of tomato plant. Geraldson (39) found that nutrient solutions with a low nitrate/chloride ratio were associated with more severe blotchy ripening. Consequently, it would appear from the results of Siegel and Bjarsh and Geraldson that the influence of chloride in reducing the amount of dry matter, glucose, fructose, and sucrose may have offset any beneficial affects a soil solution of high osmotic concentration might have had on reducing blotchy ripening.

Growth rates of tomato fruit of the variety Glamour do not appear to be as easily influenced by manipulating moisture levels surrounding the plants as are growth rates of fruit of the variety Fireball (Table 14). This is illustrated by the fact that the growth rates of Glamour fruits produced on misted plots, plots protected by windbreaks, calcium chloride treated plots and phenylmercuric acetate treated plots are not different from the growth rate of fruit from control plants, whereas, there were significant differences in rate of fruit growth induced by these same treatments on fruit of the variety Fireball (Table 13).

Not only are fruit growth rates of the variety Glamour not as easily influenced by different moisture levels, the treatments do not affect the growth rate of fruits in the same way as they affected growth rates of Fireball fruits. It can be seen in Table 14 that Glamour plants grown on the plots that were both misted and protected by windbreaks produced fruit that increased in diameter at a significantly more rapid rate than did fruits from the other treatments, while plants grown on the shaded plots produced fruit that grew at a slower rate than did fruits from the other treatments.

Glamour tomato plants had a larger root system and leaves that were more pubescent than did the variety Fireball.

This may explain why Glamour plants were not as easily influenced by the different moisture levels as were Fireball plants.

Winsor and Davies (119) have found a close relationship between the refractive index from expressed sap of tomato fruits and the total soluble solids of tomato fruits, which in turn are closely correlated with their sugar content. Thus, percent soluble solids are an indication of quality of the tomato fruit. It was suspected that treatments which tended to reduce transpiration and/or reduce photosynthetic activity would reduce percent soluble solids of tomato fruit. Such a response was indirectly implied in the data of various workers (60, 61, 69, 96, 118, 14) who found that such factors as high soil moisture levels, overcast, cool, rainy weather often resulted in fruit with low soluble solids, reduced amounts of sugars, and lower dry matter.

In general, plants grown under treatments that tended to reduce transpiration and/or photosynthetic activity tended to have fruits that averaged lower in soluble solids than plants growing on the control plot (Table 12).

Although none of the treatments employed in the field during 1963 significantly increased or decreased the amount of blotchy ripening, some general trends were noted. Fruit with more than 25 percent of their surface area affected with blotchy tissue tended to be larger (Table 9), and fruit affected with blotchy ripening tended to have lower percent soluble solids (Table 10). It was also noted that blotchy tissue was lower in soluble solids than the normal tissue of the same fruit (Table 11).

The Influence of Locular Seed Density on the Localization of Blotchy Ripening

Field observations in 1963 indicated that there was an apparent relationship between localization of blotchy ripening and tomato fruit locules of low seed density. This idea was pursued in the following investigation.

Procedure:

Tomato fruits with varying amounts of their surface area affected with blotchy ripening were obtained from both the local market and the Horticulture farm at East Lansing. This sampling procedure insured that diverse growing areas and culture practices were represented as well as different varieties.

The number of seed underlying normal and abnormal portions of outer wall tissue was determined by either counting the seeds in an entire locule or by counting seeds obtained in a core sample taken through the locule. When a core sample was used, it was taken transversely through the center of the locule with a cork bore. Seed counts, except where all seeds in a locule were counted, are expressed as the number of seeds found under a square centimeter of surface area. Seed counts, which in all cases were obtained from normal and affected locules within the same fruit, were summarized and compared by appropriate statistical methods.

The number of seeds underlying normal and blotchy tissue was also determined for a 65 fruit sample from tomato varieties Fireball and Glamour which were grown in the greenhouse in the early spring of 1964.

Results and Discussion:

Locular areas under normally colored outer wall tissue based on 12 to 47 fruit per sample, average 13 to 93 percent higher in seeds per unit area than those observed under affected outer wall tissue (Table 15). When the seven samples of fruit obtained at the local market were combined involving 93 fruits, 50 percent more seeds were found under normal than under blotchy wall tissues of the same fruits. And when all 14 samples were combined, involving 236 fruits, 40 percent more seeds were observed under the normal tissue than under blotchy tissue (Table 15).

Figure 2 illustrates the relationship of seed density to blotchy ripening in a large fruit. The locules below normally colored tissue contained from 22 to 62 seeds, while those under blotchy tissue contained from 0 to 17 seeds. Only a small percentage of the fruit examined showed such a clear relationship between low seed density and the incidence of blotchy tissue. In most fruits where locules were of more uniform size, actual seed counts were generally required to distinguish differences in seed number underneath blotchy and

TABLE 15.--Relation of Seed Per Unit Area in Blotchy and Non-Blotchy Areas of the Same Fruit, Field 1963

Source	Variety	Number of Fruits	Average Number of seed/cm^2 Blotchy	Non-Blotchy	% Increase in seed in Non-Blotchy
Farmers' Markets					
Benton Harbor	Fireball	12	2.9	5.6	93**
Bay City	Unknown	15	1.1	1.5	36
Essexville	Unknown	14	1.8	1.5	67
Circle	Unknown	13	2.4	3.9	62*
Unknown	Unknown	12	2.1	3.9	86**
Unknown	Unknown	14	4.5	5.1	13
Unknown	Unknown	13	1.7	2.6	53
Combined Market Total	-	93	3.4	5.1	50**
Horticulture Farm					
East Lansing	Cardinal	18	5.1	7.6	49**
East Lansing	Fireball	14	7.9	10.5	33
East Lansing	Glamour	23	4.3	6.8	58**
East Lansing	Fireball	47	4.8	7.1	48**
East Lansing	Glamour	8	34.2[a]	43.8[a]	28
East Lansing	Cardinal	9	44.6[a]	57.0[a]	28
East Lansing	Fireball	24	19.4[a]	28.6[a]	47**
Combined Total	-	236	8.2	11.5	40*

* 5 percent level of significance, ** 1 percent level of significance.

a. Indicates average seed number for entire locule.

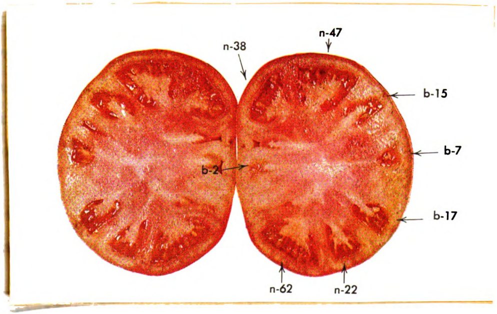

Fig. 2 Cross section of tomato fruit indicating relationship between low seed density and incidence of blotchy tissue. Areas designated (n) normal contained from 22-62 seed per locule, those designated (b) blotchy, contained less than 22 seeds per locule.

non-blotchy tissues.

These results were verified by a 65 fruit sample including fruits from varieties Fireball and Glamour that were grown in the greenhouse in the early spring of 1964. It was found that there was 40 percent more seed underneath normal tissue than under blotchy tissue. From a sample of 75 fruit, there was an average of 38 seed per locule underlying normal tissue and only 27 underneath blotchy tissue.

Ells (35) mentioned that blotchy areas were more prevalent between the fruit's septa, but offered no explanation as to why blotchy ripening in outer wall tissue should occur more commonly between the septa than over them. Observations made during this study confirm Ells' findings that blotchy tissue was found predominantly between the fruit's septa. However, it should be pointed out that some tomato fruit display blotchy areas that extend into outer wall tissue that is over septa tissue. Data collected in this study indicate that localization of blotchy areas in the wall tissue is associated with underlying locules of low seed density.

An explanation of the association of localized blotchy ripening in outer wall tissue areas above locules containing a low seed number was deduced from the reports of previous investigators.

Auxin production in the early stages of fruit growth moves to the ovary tissue surrounding the young embryo (42).

In later stages the major source of auxin is the young developing embryo (124, 73, 81). The very important role that auxins play in development of fruit has been demonstrated by Nitsch (88) working with strawberry fruits. His experiments indicate that auxin produced in the developing achene was the major factor contributing to fruit growth. Thus, it has definitely been shown that the seeds of fruits play a key role in the fruit's development.

On the basis of these findings one might further postulate how seed number might influence the development of blotchy ripening. White (114) demonstrated that juice from blotchy tissue had a lower amylase activity than from non-blotchy tissue and postulated that blotchy ripening is associated with decreased starch hydrolysis and sugar content. Ells (35) furthered this hypothesis by demonstrating that soluble solids content of juices from blotchy tissues were lower than those from non-blotchy tissues. Skoog and Robinson (101), Audus (3), and Mitchell et al. (82) indicated that auxins are associated with the transition of polysaccharides to sugars. Because seeds are an important source of diffusible auxins in fruits, seed numbers may be linked to auxin imbalance and to lower sugar content found in blotchy as compared to non-blotchy areas of fruit. Seed number, through auxin imbalance and starch hydrolysis is thus linked to respiratory metabolism, which in turn would be linked to lycopene development through considerations of the energy requirements for its synthesis.

Influence of Uneven Pollination on the Incidence of Blotchy Ripening

Because low seed density per locule was found to be associated with blotchy ripening in a previous study, an experiment was conducted to determine whether poor pollination might influence low seed number per locule and the incidence of blotchy ripening.

Procedure:

Glamour tomato plants spaced 4 by 5 feet were transplanted on May 28, 1964, into a field fertilized with 300 lbs. of 5-20-20 fertilizer and 100 lbs. of ammonium nitrate per acre. On July 7, 1964, an additional 300 pounds per acre of 12-12-12 fertilizer was applied as a side dressing.

Attempts were made to induce uneven ovule fertilization by the following methods: 1. flowers were emasculated at the time of anthesis and the stigma was pollinated, then after an hour delay a section of the stigma and style was removed by making a vertical cut through the stigma and down the style of the pistil; 2. treatment two varied slightly from that of one in that a section of the stigma and style were cut away four hours after pollination rather than one hour after pollination; 3. the stigma was pollinated on only one side with pollen that had been collected on a very narrow spatula.

According to Cooper (27) dehiscence of tomato stamens begins 24 to 48 hours after the opening of the corolla, so only flowers that were in the first stages of opening were selected for treatment in order to prevent natural self-pollination. Gelatin caps were placed over treated flowers to keep them from being chance pollinated. The first pistils were cut and pollinated on July 10, 1964, and the last treatments were made on July 23, 1964.

Five tomato plants were used in each treatment, and each treatment was replicated twice. Twenty flowers per plant were treated and then tagged for further observation.

Two moisture levels were used. A small rotary sprinkler with a 1/16 inch orifice manufactured by the Rain Bird Company was put in operation on bright, hot days to increase the relative humidity and lower the plant's potential transpiration rate.

Results and Discussion:

The various pollination treatments definitely influenced the number of treated flowers that ultimately produced mature fruits. Sixty-five percent of the flowers that had only a portion of their stigmatic surface pollinated and had no section of the style or stigma removed produced mature fruits (Table 16). The stigmas and styles of flowers that were cut at one and four hour intervals after hand pollination

TABLE 16.--The Influence of Various Methods to Induce Uneven and/or Poor Pollination Upon the Incidence of Blotchy Ripening.

Treatment After Flower Emasculation	Sprinkled Percent Fruit Set	Sprinkled Percent Blotchy Fruit	Non-Sprinkled Percent Fruit Set	Non-Sprinkled Percent Blotchy Fruit	Average Percent Blotchy Fruit
Pollinated only ½ of stigma	64	48	65	42	45.2 a
Stigma Pollinated, then cut after 4 hours	46	44	44	38	41.2 a
Stigma Pollinated, then cut after 1 hour	35	33	37	30	31.5 b
Control	88	30	87	27	28.5 b

* Means with uncommon letters are significantly different at 5% level.

produced a fruit set of 35 and 45 percent respectively (Table 16). All treatments resulted in reduced fruit set when compared to the percentage of fruit set by control flowers which were allowed to pollinate naturally.

A possible reason for the low percentage of mature fruit produced by flowers that were hand pollinated may be that the removal of part of the stigma cone surrounding the pistil resulted in a less favorable environment for pollen germination. There was also a chance that the style was damaged more than intended and this could have kept the pollen tubes from fertilizing the ovules. Other factors that could be involved in reducing the number of fruit set are the quantity of pollen applied to the hand pollinated flowers was less than that reaching the stigma under conditions of natural self-pollination, and that an excess amount of pollen was applied at times and was not spread out over several applications (95).

The application of water to the treatments apparently did not affect fruit set or the incidence of blotchy ripening.

Flowers that had only a portion of their stigma pollinated and flowers that had sections of the stigmas and styles removed four hours after pollination produced a higher percentage of mature fruit affected with blotchy ripening than did flowers from the remaining treatment or flowers from the control plants (Table 16).

Seed density beneath normal and blotchy tissue was determined. From a sample of 77 fruit, there was an average of 40 seed/locule underlying normal tissue and only 28 underneath blotchy tissue.

A number of flowers that were unevenly pollinated produced fruit that were not symmetrical, and it was observed that the majority of the fruits that were not symmetrical were affected with blotchy ripening on the flattened side of the fruit. This relationship did not always occur and no actual data was collected to substantiate the observation. Nevertheless, it was found that blotchy surface areas were associated with underlying areas of low seed density.

Although not all flowers that had been manipulated produced non-symmetrical fruit or fruit affected with blotchy ripening, flowers that had been manipulated in an effort to induce poor and/or uneven pollination produced significantly more fruits affected with blotchy tissue than flowers from the control plants. Thus, these data suggest that areas of low seed density, could possibly be caused by poor and/or uneven pollination, and that such conditions could contribute to the incidence of blotchy ripening.

Kudrjavcev (70) reported that reducing light intensities by 20 percent of full daylight when pollen mother cells were at the tetrad stage caused a reduction in the fertility of the flowers. According to Smith and Cochran (102) the best range for tomato pollen germination is 70° to 85° F.

and the best temperature for maximum pollen tube growth is at 70°F. Germination and growth were reported to be very poor on either side of the optimum temperatures. From these studies it appears that adverse weather conditions could cause poor and/or uneven pollination early in the season, which could result in uneven seed distribution throughout the fruit's locules and possibly contribute to the incidence of blotchy ripening.

Kidson and Stanton (59) and Ells (35) have both reported blotchy ripening to be most severe in the early harvests. If adverse weather is a factor in the development of blotchy ripening, it may be that fruit produced early in the season are more likely to encounter periods of cloudy, rainy weather or cool temperatures and are, therefore, more likely to develop blotchy ripening. The possibility also exists that flowers producing the early mature fruit are more likely to be subjected to conditions that could adversely affect pollination than flowers opening later in the season, or a combination of both factors may produce blotchy ripening.

EFFECT OF CERTAIN CHEMICALS ON TRANSPIRATION

The influence of various chemicals that modify transpiration rates and might affect the rate of tomato fruit growth and the incidence of blotchy ripening were studied.

Procedure:

The effect of the following chemicals upon transpiration of the variety Moreton Hybrid were investigated: 1. copper sulfate as a foliage spray (rate: 5 lbs./100 gal.), 2. octa-hexadecanol as a soil application (rate: 5 grams/5 inch clay pot), 3. octa-hexadecanol as a foliage spray (rate: 10% solution by volume), 4. glycerol as a foliage spray (rate: 10 ppm), and 5. control.

The plants were seeded on June 26 and transplanted into 5-inch pots on July 12. Five plants per treatment with two replications were used.

All plants were uniformly watered prior to application of chemicals on August 24, 1962. Just before the plants were treated and the pots sealed in polyethylene bags, enough water was added to the pots so that some water drained out. The amount of water transpired by the plants between weighings was expressed as a percent of the original weight, and the differences in amount of water lost among treatments was expressed as a percent of the control.

The temperature in the greenhouse during the first day attained 110°F., but on the second and third day the temperatures were 70-75°F., and the weather was overcast. When the last weighings were made the lower leaves of the plants had wilted. The glycerol concentration used in this investigation caused the leaves to yellow indicating that the concentration may have been too great.

Results and Discussion:

The glycerol application increased the rate of transpiration by approximately 3 percent, perhaps because of foliage injury. The copper sulfate solution initially inhibited transpiration, but after 29 hours slightly increased it (Fig. 3).

Both octa-hexadecanol treatments decreased the plant's transpiration rates. The transpiration rate of plants treated with the foliage application averaged less than 1 percent lower than the control, while the transpiration rate of plants treated with the soil application were 3 percent lower than that of the control plants (Fig. 3).

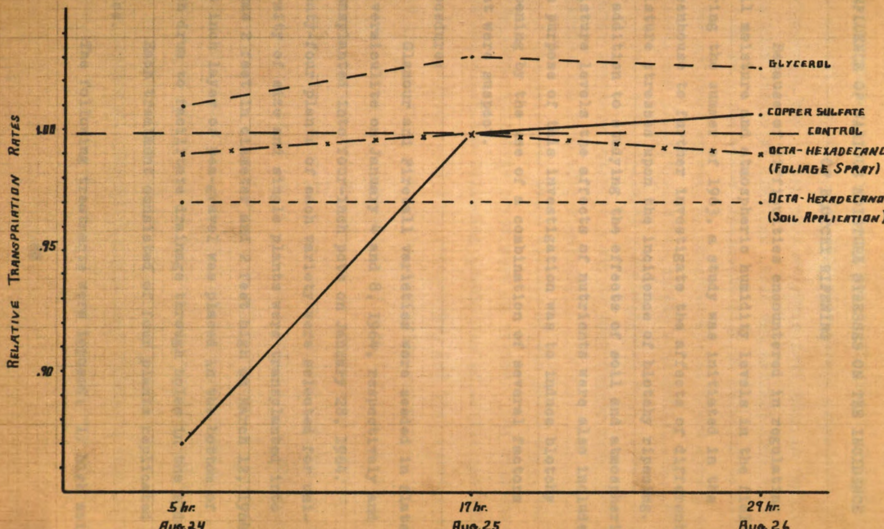

FIGURE 3 THE INFLUENCE OF GLYCEROL, COPPER SULFATE, AND OCTA-HEXADECANOL ON TRANSPIRATIO RATES OF TOMATO PLANTS

INFLUENCE OF VARIOUS MOISTURE STRESSES ON THE INCIDENCE OF BLOTCHY RIPENING

Because of difficulties encountered in regulating soil moisture and atmospheric humidity levels in the field during the summer of 1963, a study was initiated in the greenhouse to further investigate the affects of different moisture stresses upon the incidence of blotchy ripening. In addition to studying the effects of soil and atmospheric moisture levels the affects of nutrients were also included. The purpose of this investigation was to induce blotchy ripening by the use of a combination of several factors that were suspect.

Procedure:

Glamour and Fireball varieties were seeded in flats of vermiculite on January 4 and 8, 1964, respectively and transplanted into four-inch pots on January 28, 1964. Twenty-four plants of each variety were selected for uniformity of size and single plants were transplanted into drums 2 feet in diameter and 2 feet high on March 12, 1964. A 4 inch layer of pea-gravel was placed in the bottom of each drum to facilitate drainage through holes in the side.

Each treatment consisted of four plants replicated twice.

The following treatments were imposed: 1. high soil moisture (80% available soil moisture-ASM) plus high humidity surrounding the aerial portion of the plant, 2. intermediate soil moisture (50% ASM) with normal greenhouse environment, and 3. low soil moisture (20% ASM) in combination with infra-red heating. Heat was applied from 8:00 am to 6:00 pm. The above treatments will be referred to as: 1. low moisture stress, 2. intermediate moisture stress or control, and 3. high moisture stress treatments. Soil Moisture levels were evaluated with Delmhorst soil blocks, and average readings taken at 6 and 12 inch depths were used to determine the time of irrigations.

The soil used was a mixture of six parts soil, two parts sand, and three parts muck by volume. The soil mixture contained the following quantities of active material: 120 lbs. nitrogen, 10 lbs. phosphorus, 227 lbs. potassium, 1200 lbs. calcium, and 48 lbs. magnesium per acre. The low moisture stress plots were treated with 100 lbs. N from calcium nitrate, and 240 lbs. of Ca per acre as calcium chloride; the intermediate stress plots with 100 lbs. of N as ammonium nitrate and 60 lbs. of K split evenly between potassium chloride and potassium sulphate; and the high stress plots with 100 lbs. of N per acre as potassium nitrate, and 120 lbs. of K per acre as potassium sulphate. All treatments received 120 lbs. of P_2O_5 per acre as double super phosphate. The nitrogen in each treatment was applied March 16, March 30, and April 9, 1964 at the rate of 40, 30, and 30 lbs. per acre respectively.

Uniform watering was practiced until April 28 when the various treatments were imposed. Plants growing under low moisture stress received 78 liters, under intermediate stress 119 liters, and under high stress 77 liters of water per plant from April 30 to June 27 (Table 17).

High humidity was maintained in the low stress treatment by confining 4 plant plots in a six-foot high open polyethylene structure and misting from 8:00 am to 6:00 pm with an automatic mister described in a previous study. Water applied by misting compensated for only evaporational losses as was indicated by the fact that only a trace of water accumulated in collecting cans.

The yield of normal tomatoes, blotchy tomatoes, and tomatoes affected with blossom end rot were recorded from each treatment. Blotchy tomatoes were considered to be those with more than 10 percent of their surface area affected with blotchy tissue.

The percent dry weight of fruit and foliage tissue from the different treatments was determined. Fruit samples were dried at 135°F for 480 hours; plant tissue samples were first air dried and then dried at 150° for 48 hours in a forced air oven.

Chemical analyses were made on fruit and plant tissue from the different treatments for N, K, P, Na, Ca, Mg, Mn, Fe, Cu, B, Zn, and Al. Nitrogen was determined by the

TABLE 17.--Water Use by Tomatoes as Related to Irrigation and Treatment.

Treatment[1/]	Liters of water used/plant from April 30 to June 27
20% ASM, Infra-red Heat	77
50% ASM, Normal Greenhouse Environment	119
80% ASM, Misted Enclosure	78

1/ Soil recharged to field capacity when ASM (available soil moisture) fell to percent indicated.

Kjeldahl procedure, potassium with a flame photometer; and other elements by a direct reading photoelectric spectrometer (58).

The analyses of variance were performed on the resulting data as indicated by Snedecor (103) and mean comparisons made by the method described by Duncan (34).

Results and Discussion:

Enclosing the plants and misting increased the average relative humidity 15% and decreased light intensity, as measured in foot candles, a maximum of 7 percent.

There were no differences in the number of fruit per plant among the treatments, but fruit weight varied from 3.81 Kg. under high moisture stress to 5.44 Kg. per plant under the intermediate moisture stress treatment (Table 18). Fruit on plants grown under low moisture stress conditions were 40 percent larger than those grown under high stress. However, the percent soluble solids of fruit from the high moisture stress were 38 percent higher than were percent soluble solids of fruit from low moisture stress plots; and both the percentage dry weight of the fruit and the percentage dry weight of the foliage tissue produced under the high moisture stress treatment was higher than under low and intermediate moisture stress (Table 18).

Differences among the three classes of fruit (normal, blotchy, and blossom-end rot) were found. 83 percent of the

TABLE 18.--The Influence of Moisture Stress Upon Fruit Number, Fruit Weight, Average Fruit Weight, Soluble Solids, Dry Weight of Fruit and Foliage Tissues of Tomato Varieties Fireball and Glamour.

	Moisture Stress		
	Low	Intermediate	High
No. Fruit/Plant	52.5 a	62.9 a	56.0 a
Fruit Wt./Plant (Kg.)	5.0 a	5.4 a	3.8 b
Avg. Fruit Wt. (g.)	95.3 a	86.3 a	68.1 b
Soluble Solids %	4.5 b	5.1 a	6.2 a
% Dry Wt. of Fruit	6.2 b	6.8 b	8.6 a
% Dry Wt. of Foliage	11.8 b	12.7 b	15.4 a

* Means with uncommon letters are significantly different at the 5% level. Letters refer only to values in the same horizontal column.

fruits produced by plants subjected to the low moisture treatment were classed as normal, 16 percent as blotchy and 1 percent as being affected with blossom-end rot on a fruit weight basis (Table 19). Percentage values based on either number or weight of fruit from each class were similar. On a number basis it was found that 84 percent, 14 percent, and 1 percent of the fruit from low moisture stress plots were classed as normal, blotchy, and blossom-end rot respectively (Table 19).

Plants grown under the intermediate moisture stress produced significantly more fruit classed as normal than were produced by plants grown under the other two treatments. Percentage values, by weight, of the different grades of fruit from plants grown under intermediate stress conditions are as follows: 90 percent of the fruits were normal, 20 percent blotchy, and 8 percent were affected with blossom-end rot (Table 19). Percentages based on number gave nearly the same values for each class as fruit weight. There was no significant difference in weight of fruit classed as blotchy, and fruit classed as being affected with blossom-end rot within the intermediate moisture stress treatment (Table 19).

Within the high moisture stress treatment, fruit considered to be normal accounted for 77 percent, fruit with blossom-end rot 22 percent of the total, and blotchy fruit 1 percent of the total on a fruit weight basis. The percentage

TABLE 19.--The Influence of Moisture Stress Upon the Number and Weight Per Plant of Blotchy, Normal, and Fruit Affected with Blossom-End Rot.

	Moisture Stress					
	Low		Intermediate		High	
Fruit Class		%		%		%
Normal:						
Wt./Plt. (Kg.)	4.22	83	4.95	90	2.95	77
No./Plt.	44.3	84	57.8	92	45.4	81
Avg. Frt. Wt. (g.)	95.3		86.2		63.5	
Blotchy:						
Wt./Plt. (Kg.)	0.82	16	0.09	2	0.04	1
No./Plt.	7.5	14	0.8	1	0.5	1
Avg. Frt. Wt. (g.)	108.9		113.5		113.5	
Blossom-End Rot						
Wt./Plt. (Kg.)	0.04	1	0.41	8	0.82	22
No./Plt.	0.6	1	4.2	7	10.0	18
Avg. Frt. Wt. (g.)	77.1		95.3		81.7	

L.S.D. for differences among fruit class mean weight/plant for the same moisture stress treatment: $L.S.D._{.05} = .56$ Kg./plant.

L.S.D. for differences among moisture stress treatments for fruit weight/plant at the same fruit class level: $L.S.D._{.05} = .48$ Kg./plant.

values of each class of fruit on a number basis was 81 percent normal, 18 percent classed as having blossom-end rot, and 1 percent of the fruit were blotchy (Table 19).

Blotchy fruit were found to be slightly, but consistantly heavier than normal fruit or fruit affected with blossom-end rot. The weight of blotchy fruit averaged 108.9, 113.5, and 113.5 grams per fruit for the low, the intermediate and the high stress treatments respectively, as compared to weight of fruit classed as being normal, which averaged 95.3, 86.2 and 63.5 grams per fruit, and those classed as having blossom-end rot which averaged 77.1, 95.3, and 81.7 grams per fruit for the three respective treatments low, intermediate and high moisture stress (Table 19).

A significant interaction between the three classes of fruits and the three treatments was found to exist. Plants subjected to conditions conducive to low moisture stress produced significantly more fruit, on a fruit weight basis, classed as blotchy than plants subjected to the intermediate and high moisture stress treatments. There was no significant difference in fruits classed as blotchy between intermediate and high moisture stress treatments. On the other hand, plants growing under conditions conducive to low moisture stress produced significantly less fruit affected with blossom-end rot than was produced by plants subjected to the conditions conducive to high plant moisture stresses (Table 19).

The correlation between soluble solids of tomato fruit and tomato fruit weight was determined for fruit from both varieties. A highly significant negative correlation coefficient ($r = -.740$) between fruit weight and percent soluble solids of tomato fruit from the variety Fireball was found. The amount of change in percent soluble solids associated with a change in fruit weight is shown in Figure 4. There was no significant correlation between fruit weight and percent soluble solids of fruit from the variety Glamour.

Mineral analyses showed that fruit taken from plants grown under low moisture stress removed significantly more phosphorus than fruits taken from intermediate or high moisture stress treatments (Table 20). The amount of calcium removed by fruits taken from plants grown under conditions conducive to high moisture stress was significantly less than the amount of calcium removed by fruits from plants subjected to the other treatments.

There were highly significant differences among all treatments in the amount or zinc removed by tomato fruits. Fruits grown under low moisture stress removed the most zinc, followed by fruits from plants subjected to intermediate moisture stress, which removed slightly less zinc. Very little zinc was removed by fruit from plants grown under conditions conducive to high moisture stress (Table 20 and 21).

Plants grown under low moisture stress removed

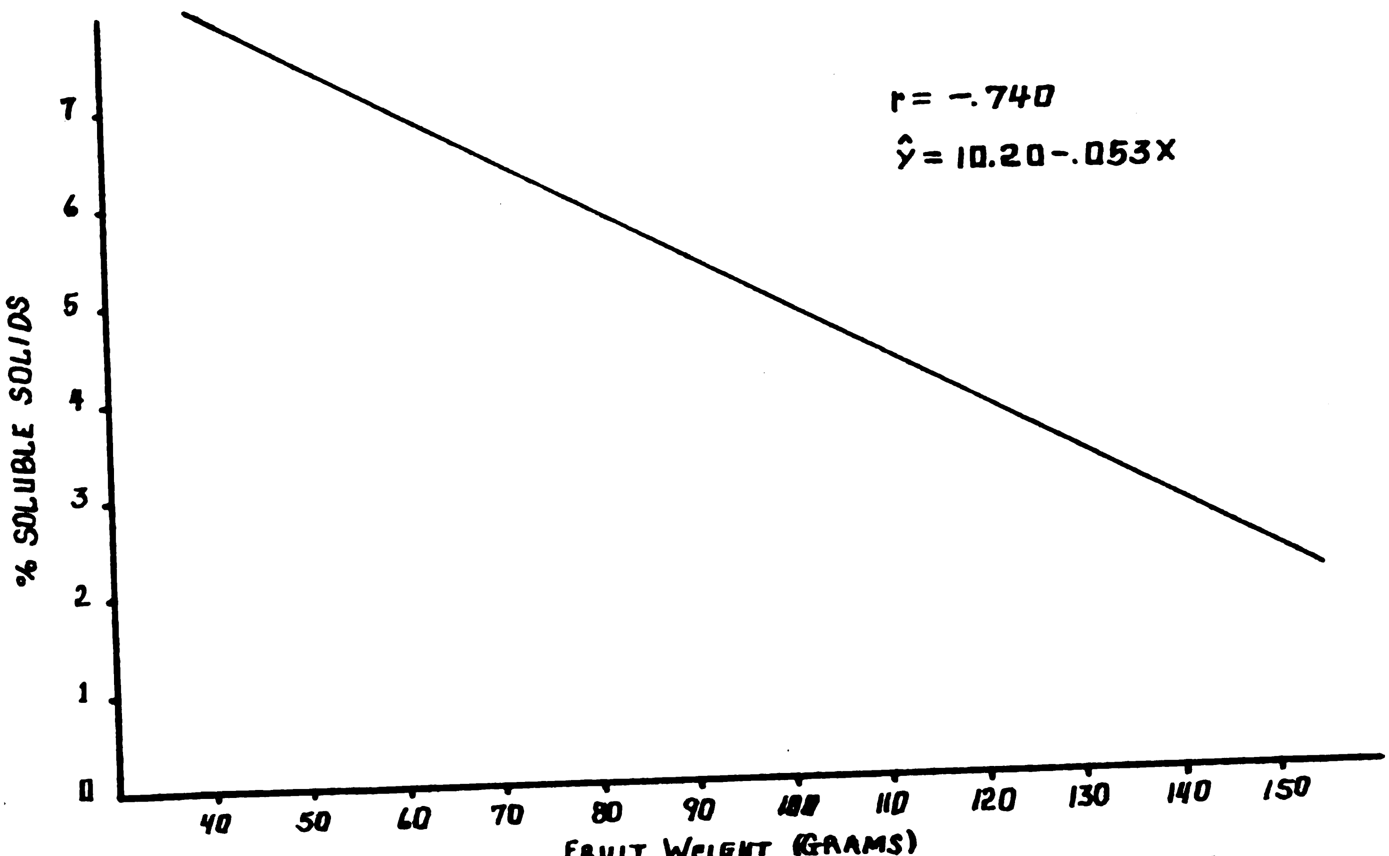

FIGURE 4 RELATIONSHIP BETWEEN FRUIT WEIGHT AND SOLUBLE SOLIDS FOR THE VARIETY FIREBALL

TABLE 20.--The Influence of Moisture Stress Upon the Average Amount of Minerals Accumulated in the Fruit and Foliage Tissue of Both Fireball and Glamour Tomato Plants.

Minerals	Moisture Stress: Low	Intermediate	High
	TOMATO FRUIT MINERAL COMPOSITION		
	(values expressed in grams/plant)		
N	11.3 a	13.3 a	10.7 a
K	19.6 a	19.9 a	17.6 a
P	1.3 a	1.0 b	0.8 b
Ca	0.5 a	0.5 a	0.2 b
Mg	0.8 a	0.6 a	0.5 a
	(values expressed in milligrams/plant)		
Na	225.0 a	133.0 a	178.0 a
Mn	7.0 a	7.0 a	5.0 a
Fe	25.0 a	18.0 a	15.0 a
Cu	2.5 a	1.2 a	1.5 a
B	5.2 a	4.0 a	3.7 a
Zn	1.2 a	0.5 b	Trace
Al	6.0 a	7.0 a	6.0 a
	TOMATO FOLIAGE MINERAL COMPOSITION		
	(values expressed in grams/plant)		
N	2.9 a	4.1 a	3.3 a
K	3.7 a	4.8 a	4.5 a
P	0.4 a	0.3 b	0.3 b
Ca	17.1 a	15.6 b	9.3 b
Mg	2.4 a	3.0 a	2.0 a
	(values expressed in milligrams/plant)		
Na	210.0 a	110.0 b	75.0 b
Mn	19.0 a	25.0 a	20.0 a
Fe	54.0 a	52.0 a	32.0 b
Cu	4.5 a	3.5 a	3.0 a
B	6.5 a	7.5 a	4.5 b
Zn	28.0 a	10.5 b	5.7 b
Al	34.0 a	51.0 b	30.0 b

* Means with uncommon letters are significantly different at the 5% level. Letters refer only to values in the same horizontal column.

TABLE 21.--The Influence of Moisture Stress Upon the Amount of Minerals Accumulated in the Fruit and Foliage Tissue of Fireball and Glamour Tomato Plants.

TOMATO FRUIT MINERAL COMPOSITION

Treatment	Avg. Fresh Wt./Plt. (g)	Avg. Percent Dry Wt.	Avg. Dry Wt./Plt. (g)	In Percent Dry Weight N	K	P	Ca	Mg
Low Moist. Stress	6740	6.1	411	2.80 a	4.78 a	.338 a	.13 a	.20 a
Inter. Moist. Stress	6631	6.8	450	2.96 a	4.24 a	.262 b	.13 a	.14 b
High Moist. Stress	5162	8.7	449	2.31 a	3.76 a	.184 b	.06 b	.11 c

Treatment	In ppm Dry Weight Na	Mn	Fe	Cu	B	Zn	Al
Low Moist. Stress	550 a	20 a	63 a	6.6 a	13.0 a	3.5 a	17.5 a
Inter. Moist. Stress	429 a	18 a	42 b	2.9 a	9.5 b	1.2 b	17.5 a
High Moist. Stress	455 b	12 b	34 b	3.1 a	8.9 b	Trace	16.5 a

TABLE 21 (continued)

TOMATO FOLIAGE MINERAL COMPOSITION

Treatment	Avg. Fresh Wt./Plt. (g)	Avg. Percent Dry Wt.	Avg. Dry Wt./Plt. (g)	In Percent Dry Weight N	K	P	Ca	Mg
Low Moist. Stress	1281	11.7	149	1.90 a	2.61 a	.271 a	12.0 a	1.59 a
Inter. Moist. Stress	1480	12.3	182	2.28 a	2.72 a	.191 b	9.0 ab	1.63 a
High Moist. Stress	1049	14.2	148	2.21 a	3.01 a	.175 b	6.0 b	1.38 a

	In ppm Dry Weight Na	Mn	Fe	Cu	B	Zn	Al
Low Moist. Stress	1433 a	118 a	351 a	28.7 a	44.3 a	188 a	224 a
Inter. Moist. Stress	579 b	138 a	292 ab	19.9 a	41.9 a	60 b	286 b
High Moist. Stress	509 b	138 a	221 b	20.7 a	31.4 b	41 b	207 a

* Means with uncommon letters are significantly different at the 5% level.

significantly more P, Na, Ca, Zn, and Al than plants grown under intermediate and high moisture stress treatments. Significantly more iron and boron were taken up by plants grown under the low and intermediate moisture stress treatments than plants subjected to the high moisture stress treatment (Table 20 and 21).

Transpiration as well as soil moisture appeared to influence the incidence of blotchy ripening and blossom-end rot. Although the amount of water required per plant from low and high moisture stress plots was nearly the same (Table 17). The ASM of low moisture stress plots did not go below 80 percent, while the ASM of high moisture stress plots dropped to 20 percent. The difference in ASM between low and high moisture stress plots was because of relatively different transpiration rates of plants from the respective plots. Significantly more blotchy fruit were produced on plants from the low moisture stress plots, associated with low rates of transpiration, and significantly more fruit with blossom-end rot came from high moisture plots, associated with higher rates of transpiration, than were found to be produced on the intermediate moisture stress plots (Table 19).

The accumulation of more water in the fruits of plants grown under low moisture stress conditions is indicated by their larger size, less dry weight, and lower soluble solids (Table 18). This could predispose the plants to blotchy ripening.

Thus, in this experiment where soil moisture and atmospheric conditions surrounding the aerial portion of the plants could be modified more easily than in the field, a higher percentage of fruits were affected with blotchy ripening under conditions of low moisture stress than under conditions of high moisture stress. As the soil moisture tension increased and transpiration increased, the percentage of fruit affected with blotchy ripening decreased, while the percentage of fruit affected with blossom-end rot increased.

Various workers have previously indirectly indicated that transpiration rates can influence the incidence of blotchy ripening. Gilbert (41), observed the absence of vascular browning with an increase in air movement from the trade winds in the Hawaiian Islands despite the occurrence of cloudy, wet weather. Gilbert postulated that injury was from sub-oxidation, but the winds may have increased the transpiration rates to the point where not as much water was accumulated in the fruit, which in turn probably lessened the chances for blotchy ripening development.

Korbonits (69) found that the dry matter content of tomato fruits was highest from plants grown on drier, heavier loams than those grown on soils with high moisture content. He also found periods of rainy weather reduced the dry matter content of tomato plants and fruit. As found in this study and supported by others (60, 77), plants that produced fruit of low dry matter content are associated with the production of blotchy fruit, and blotchy fruit themselves have been shown to be lower in dry matter content than normal fruit (14). Thus, blotchy fruit are associated with low dry matter content, and Korbonits (69) describes conditions under which fruit of low dry matter are produced. These data indirectly suggest that blotchy ripening is associated with high soil moisture levels and low transpiration rates.

Kidson (62) in working with tomato plants grown in solution cultures, concluded that high humidity did not influence cloud provided there was adequate light. This work also suggests that transpiration influences the production of blotchy ripening. High humidity in combination with low light intensities would definitely tend to reduce transpiration (32). However, high humidity in combination with high light intensity could increase transpiration by heating the leaves of the plant. It may be that high light intensity, even in the presence of high humidity, enhanced transpiration enough to prevent an excessive amount of water from being incorporated into the tomato fruit or increased carbohydrate accumulation.

Data presented by Clay and Hudson (17) also supports the hypothesis that high moisture stresses reduce the incidence of blotchy ripening. They report that very few blotchy fruit were found on plants growing on soils of high salinity.

From the data obtained in this investigation it appears that blossom-end rot tends to be more prevalent under conditions conducive to high moisture stress. A very small percentage of the fruit produced by plants grown under conditions of low moisture stress were affected with blossom-end rot, while 22 percent of the fruit from plants subjected to relatively higher moisture stresses were affected with the disorder (Table 19).

Several workers have indicated that low calcium levels cause blossom-end rot, and recommended liming the soil or applying calcium foliage sprays to correct the disorder (38, 79, 36, 104, 91). The calcium values of fruits and foliage from the high moisture stress treatment, which produced the highest percentage of fruit affected with blossom-end rot, were significantly lower in calcium content than fruits and foliage of plants grown under the intermediate and low moisture stress treatment (Table 20). There was no additional calcium added to either the intermediate moisture stress treatment plots or to the high moisture stress plots. Thus, the low calcium values for fruit from the high moisture stress treatment may have been induced either by conditions conducive to high transpiration or to high K fertilization, and the low quantities of Ca. may only be associated with the incidence of blossom-end rot rather than being the cause of it. Walsh and Clarke (111) also concluded that low calcium content of the fruit by itself does not result in the disorder.

Other work also implies that high soil moisture tensions and/or high transpiration rates could promote blossom-end rot. Hardh (46) suggested that the initial cause of blossom-end rot was a change in enzyme activity due to an abnormal increase in soil and plant concentration. Such conditions could come about because of low available soil moisture levels and/or excessive transpiration. Hulea (54) concluded that blossom-end rot was not caused by bacteria, but by defective water uptake occasioned by climatic or edaphic conditions. Westerhout (112) found that calcium deficiency in the plant did not always produce blossom-end rot and suggested that some other factors are involved in the development of the disorder. Kidson (63) found that an increased osmotic concentration of a nutrient solution resulted in a reduction in the calcium level in the leaves of tomato plants, and Geraldson (38) noted that excessive total salts can cause calcium deficiency. Wilson (115) supports the idea that low available soil moisture levels are conducive to the development of blossom-end rot.

All of the above findings support the hypothesis that tomato plants grown under a high moisture stress tend to produce fruit affected with blossom-end rot and that calcium deficiency by itself may not be the sole cause of it.

The different nitrogen sources and amounts of potassium applied to the three different treatments in this study apparently had no significant affect on the amount of these elements accumulated by the plants and fruits (Table 20). The low, high, and intermediate moisture stress treatments received the same quantity of phosphorous, but plants and fruits subjected to the low moisture stress treatment accumulated significantly more phosphorous than plants subjected to the other treatments (Table 20).

Although the low moisture stress treatment received a large amount of calcium, there was apparently ample calcium already available in the soil, as indicated by the fact that the amounts of calcium found in tomato fruit and foliage tissue from the low moisture stress treatment and the amount of calcium found in fruit and foliage tissue from the intermediate moisture stress treatment were not significantly different.

The relative amounts of calcium and sodium accumulated by tomato plant foliage and fruit under conditions conducive to high moisture stress agree with data presented by Kidson (66, 67). He found that increasing the osmotic pressure of nutrient solutions, in which tomato plants were grown, resulted in reductions in the amount of calcium in the leaves and a ten-fold rise in the sodium content. Kidson (66) found that the high osmotic concentrations of a nutrient solution was accompanied by reduced incidence of cloud, just as the high moisture stress treatment was accompanied by a reduced incidence in blotchy ripening (Table 19).

Fruit and plant tissue from the low moisture stress treatment contained significantly more zinc than plants and fruit tissue from the intermediate and high moisture stress treatments (Table 20). Kidson (63) found that when fruit ripened under conditions inducing cloud there was an indication that applications of 0.05 ppm of zinc was associated with increased severity of cloud symptoms. The low moisture stress treatment was associated with an increased amount of blotchy ripening (Table 20) and was associated with tomato fruit and foliage tissue with higher zinc concentrations even though no additional zinc was added. No direct cause and effect relationship was established between mineral composition and the incidence of blotchy ripening. It appears more likely that the conditions that contribute to the incidence of blotchy ripening also affects the mineral composition of tomato foliage and fruit rather than mineral composition directly inducing blotchy ripening.

Thus, the data already presented in the pollination study along with the data from the seed density determinations underlying normal and blotchy locules suggest that poor pollination and unequal distribution of seed in the fruit are associated with development of blotchy ripening. The moisture stress to which tomato plants are subjected also appears to play an important role in the development of blotchy ripening. It could well be that both poor pollination and conditions conducive to low moisture stress contribute to the development of blotchy ripening.

GENERAL DISCUSSION AND CONCLUSIONS

The objective of this investigation was to evaluate factors that might be associated with blotchy ripening in tomato fruit. Inducing the disorder might result in a better understanding of factors that cause it. After reviewing the literature it was suspected that water relations or inadequate quantities of carbohydrates for fruit development were responsible for blotchy ripening. A series of experiments were devised to induce the disorder by manipulating the water relations of the plant and by attempting to lower the quantity of carbohydrates for fruit production by reducing light intensities.

Data from these investigations suggest that both available soil moisture and amount of water lost by the plant through transpiration influences dry matter content, percent soluble solids, and percentage of fruit with uniform pigmentation. Conditions conducive to low transpiration rates in combination with high levels of available soil moisture favored development of blotchy ripening.

Information pointing to the role of low evaporation-high soil moisture levels in promoting the development of blotchy ripening may be found in reports where rainy, cloudy weather (59, 55, 56, 44, 63) was associated with development of blotchy fruit. These findings were interpreted as being associated with reduced transpiration that could upset the plant's water balance.

When available soil moisture levels were allowed to drop to 20 percent in combination with conditions conducive to high rates of transpiration, there was less incidence of blotchy ripening. Lower levels of soil moisture appeared to be associated with less blotchy ripening. High fertilizer application rates (120, 121, 105, 90, 71), reported to have reduced blotchy ripening, may have influenced the water balance of the plant by increasing the osmotic concentration of the soil. These fertilizer practices would tend to reduce the disorder by reducing the amount of water available to the plant.

Reduced light intensities usually accompanying rainy, cloudy weather cannot be completely ignored as contributing to blotchy ripening through their affect on photosynthetic activity. Reduced photosynthesis may be a factor contributing to the incidence of blotchy ripening, but water balance of the plant is still thought to be the dominate factor associated with its occurrence. Light intensities on the low moisture, the intermediate, and the high moisture stress treatments were nearly the same, but more blotchy fruit were produced by plants grown under low moisture stress conditions than under intermediate or high moisture stress conditions.

Although other reports have indicated that shading increased blotchy ripening (124, 118, 57) and that removal of part of the fruit from the plant reduced the disorder through less competition for carbohydrates (30), they were not found to influence the development of blotchy ripening in these studies.

Data collected in these studies suggest that blotchy ripening and blossom-end rot are caused by moisture imbalance, blotchy ripening appearing more frequently under low moisture stress conditions and blossom-end rot being more prevalent under high moisture stress conditions. Similar findings have also been reported by Carolus et al. (14).

Investigations conducted by Butters (12) and Carolus et al. (14) illustrate differences in severity of blotchy ripening and the difference in quantity of water required to produce a crop during different years. In taking these studies into consideration plus the sporadic occurrence of blotchy ripening, it appears as if a complex of factors may contribute to the development of blotchy ripening.

Blotchy tissue was associated with underlying areas of low locular seed density. Because seeds are an important source of diffusable auxins, lower seed numbers might be linked to lower auxin levels beneath blotchy tissue. Skoog and Robinson (102), Audus (3), and Mitchell et al. (82) have indicated that lower auxins levels are associated with less transition of polysaccharides to sugars. White (114) indicated that blotchy tissue was associated with decreased starch hydrolysis and sugar content, and Ells (35) found soluble solids content of juices from blotchy tissues to be lower than those from non-blotchy tissues. The results of Ells and White suggest that starch was not being broken down to sugars in blotchy tissue. Low seed numbers, through auxin imbalance and less starch hydrolysis could be linked to lower respiratory metabolism, which in turn could be linked to lycopene development through consideration of the energy requirements for pigment synthesis.

Data from studies where pollen was placed on one side of the stigma, or a section of the stigma and style was removed shortly after pollination indicated that these practices induced more blotchy fruit than were produced on control plants. These results suggest that poor pollination early in the season, possibly caused by adverse weather, may influence the concentration of blotchy areas by lowering seed numbers in some locules. The lower seed number could in turn influence the expression of blotchy ripening through the development of an auxin imbalance within the fruit.

Several reports indirectly suggest that environmental conditions early in the season could be involved in the expression of blotchy ripening (35, 43, 59, 35), and indicated that it was more prevalent during the earlier harvests. Flowers that produced the early fruit would be more likely to encounter adverse weather and would be most likely to be poorly pollinated. The possibility also exists that the first fruit harvested would also be most likely to encounter adverse weather near the time of ripening. Thus, weather conditions could affect some process other than fertilization nearer the time of color development (18, 92, 97).

If poor pollination does influence the incidence of blotchy ripening, by reducing seed number in certain locules, it may be that this alone will not induce the disorder. As already indicated, conditions conductive to lower moisture stress are associated with the incidence of blotchy ripening. It may be that fruits with low seed numbers in certain locules must encounter conditions conducive to low moisture stress, such as cloudy, rainy weather sometime after pollination in order for blotchy fruit to appear. Blotchy ripening may not appear on fruit with locules of low seed number if growing conditions are favorable throughout the season.

However, if fruits having some locules of low seed number encounter unfavorable weather conditions, these areas either may not be able to obtain needed materials for pigment development, possibly because of translocation interference (98), or such areas cannot utilize material already available (31, 48, 49, 50, 51, 64).

The interaction of low locular seed number and conditions of low moisture stress, interacting together would help explain the sporatic outbreaks of blotchy ripening within and between seasons.

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