EFFECT OF POTASSIUM, CULTIVAR, AND SEASON ON TOMATO
BLOTCHY RIPENING, GRAYWALL, AND FRUIT QUALITY

By

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TO MY PARENTS AND TO RON AND TERRY

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Tomatoes (Lycopersicon esculentum Mill.) from four different cultivars, 'Healani', 'Homestead 24', 'Walter' and 'Flora-Dade' were grown under five different applied soil K rates (0, 93, 186, 372, and 745 kg K/ha) during spring and fall seasons to determine the influence of K rate, cultivar, and season on blotchy ripening, graywall, and fruit quality.

Under both spring and fall field conditions, fruits from all four cultivars had more blotchy ripening with decreasing K fertility. At all K rates and with each cultivar both external blotch and internal blotch were more severe in the spring than in the fall. Yellow shoulder, the primary external blotch symptom, was severe in the spring with the cultivars 'Homestead-24', 'Walter', and 'Flora-Dade'. 'Healani' showed resistance to yellow shoulder blotch. During

the fall, yellow shoulder blotch was not a severe problem in any cultivar. 'Healani' was generally the most blotch resistant cultivar and 'Flora-Dade' was the most blotch susceptible. There was more K in both the leaf and pericarp tissue of all cultivars with increasing soil K rate in both seasons. The differential susceptibility between cultivars to blotchy ripening was not associated with cultivar differences in leaf K or pericarp K content during either season.

A graywall inducing bacteria, Erwinia herbicola (Dye), was inoculated in the outer pericarp of immature green tomato fruit to determine the effect of cultivar and K fertility on tissue susceptibility to graywall. All four tomato cultivars developed more graywall with low K (0 kg K/ha) compared to high K (745 kg K/ha) during the spring season. Only 'Flora-Dade' developed less graywall with increasing K rate during the fall season. During both seasons, 'Flora-Dade' and 'Homestead-24' were the two most graywall resistant cultivars while 'Healani' and 'Walter' were the most susceptible cultivars.

Natural graywall (contrasted to bacterially induced graywall) appeared in 'Healani' and 'Homestead-24' fruits grown with low K treatments in a sand culture greenhouse experiment. Both cultivars were free of natural graywall with the high K treatment. 'Flora-Dade' was completely resistant to natural graywall with all K treatments.

Environment, cultivar, and applied soil K all influenced the quality of field grown tomato fruit. During the spring each cultivar except 'Flora-Dade' had a higher pericarp soluble solids and reducing sugar content under 745 kg K/ha than 0 kg K/ha. During the fall only

'Healani' and 'Flora-Dade' had higher soluble solids with 745 kg K/ha, but no difference in reducing sugar content was found between applied soil K rates. 'Healani' was the only cultivar during both seasons to increase in pericarp dry weight with increasing K rate. During both seasons and with each cultivar there was an increase in pericarp acidity with increasing K rate. Fruit from all cultivars decreased in pericarp pH with increasing soil K rate during the spring season.

'Healani' had the highest and 'Flora-Dade' had the lowest pericarp soluble solids, reducing sugars, dry weight, and pH each season. 'Healani' and 'Homestead-24' had the lowest pericarp acidity while 'Walter' had the highest. Reducing sugars, dry weight, and pH were all higher during the spring than fall. Acidity was greater during the fall. Only 'Healani' and 'Flora-Dade' had a higher soluble solids content during the spring than fall. 'Healani' generally had the most desirable quality characteristics while 'Flora-Dade' had the least. Fruit grown without added K generally had the poorest quality.

INTRODUCTION

Tomato, Lycopersicon esculentum Mill., is one of the most widely cultivated vegetable crops in the U.S. and throughout the world. In terms of crop value, it is the number one vegetable grown in Florida, with an annual income of 220 million dollars during 1978-79 (Florida Agricultural Statistics, 1980). Slightly over 450,000 acres were grown for fresh market and processing in the U.S. during 1979, with a crop value of over one billion dollars (U.S.D.A., 1979).

Tomatoes may be affected by a number of physiological and pathological disorders during the maturation and ripening processes. Ultimately these disorders result in reduced yields and/or quality of the fruit. Two of the most troublesome and economically important disorders affecting fruit quality are blotchy ripening (BR) and graywall (GW). Fruits afflicted with either disorder generally are unmarketable.

Blotchy ripening appears externally on the fruit as areas of yellow or orange discoloration intermixed with the normal red areas. Blotchy areas may develop some red color, but never to the extent of normally colored areas. The amount of discoloration may range from very small patches to large areas in which more than half the fruit is discolored. The location of the discolorations may be random throughout the fruit or semi-ordered in which only the shoulder region is

yellow-orange. Internal blotchy ripening symptoms range from slight to severe whitish discoloration of the placenta and pericarp tissue.

In severe cases the outer pericarp appears brownish due to lignification of the vascular strands. Externally the fruit may be perfectly red, but internally it may contain white tissue.

Graywall symptoms appear externally as grayish-brown discolorations in the outer fruit wall. In contrast to BR, GW symptoms appear on immature green fruit. The grayish-brown areas may become slightly depressed and roughened. Internally, severe browning usually appears in the outer pericarp, especially in the areas next to the vascular bundles.

The author's objectives were to determine the effect of applied soil K rate, cultivar, and season on the incidence and severity of BR, bacterially induced GW, and fruit quality. Physiological differences and/or similarities between blotchy and normal tomato tissue were also studied with respect to ethylene evolution and respiration rate. By meeting the above objectives, a better understanding regarding the control of these disorders may result. Numerous factors may influence the severity of BR and GW without being the primary cause. A study of the above factors should be of benefit because the knowledge gained may contribute to the control of these disorders.

LITERATURE REVIEW

Much confusion exists in the literature regarding terminology of uneven tomato ripening disorders. The range of terms used to describe such ripening abnormalities includes blotchy ripening, graywall, vascular browning, internal browning, cloud, waxy patch, and greenback. Inadequate description of the symptoms of these disorders has often prevented comparison and accurate interpretation of research results. Using specific names for what may be different disorders with very similar symptoms or which may be different stages of development of the same disorder has confused the picture.

It is the author's contention that all these terms have been used to describe two separate disorders: BR and GW. A close examination of the literature reveals that BR and GW are unique and distinct disorders. The terms vascular browning, internal browning, and cloud are probably forms of GW and the term greenback is a form of BR. Graywall occurs in green fruit whereas BR by definition can only be identified in fruit which has begun to color. Only when one compares a mild form of GW to a severe case of BR (brownish discoloration of vascular bundle area due to lignification) is there justification for confusion regarding what term should be applied to the disorder.

Researchers in this area of uneven tomato ripening should confine themselves to the terms BR and GW in describing their disorders. Use of additional synonyms to describe these two disorders can only result in further confusion. Hobson et al. (1977) provided an excellent

description of tomato ripening disorders and included illustrations on the separate disorders of BR and GW.

Blotchy Ripening

The first mention of BR in the scientific literature occurred in 1922 in the Annual Report of the Cheshunt Experiment Station (Anon, 1921). Blotchy ripening affected fruits were described to have hard green areas around the calyx and elsewhere, in which the vascular bundles were or were not discolored, while the remainder of the fruit was red. Since 1922 much work on BR has been done throughout the world. The term has come to mean little more than non-uniformly colored fruits.

Bewley and White (1926) described BR as hard green areas arising in any position on the fruit without an abrupt line of demarcation between the green and red areas. In severe cases, the hard areas were waxy or glassy in appearance and the bundles lying beneath these clear glossy areas were brown and necrotic. It is possible that these authors were describing both GW and BR but had classified them all as BR. "Greenback" or "hardback" was placed in a separate category from true BR and was used to describe fruits that had a hard green or orange area around the stem end while the rest of the fruit turned red. The authors found the amount of BR to vary with season, cultivar, and fertility. Blotchy ripening was thought to be the result of primarily K and also N deficiencies. Sunlight or other factors were postulated to influence BR since a small amount of BR occurred on heavily manured plots. Susceptibility to greenback was increased by K and N deficiency and exposure of the deficient fruits to excessive sunlight.

A histological study of BR was made by Seaton and Gray (1936). They also grouped GW and BR symptoms together and they stated that BR is characterized by a failure of areas of the outer fruit wall to color normally. As the fruit approached maturity, these areas remained hard and green and eventually assumed a waxy or glassy appearance (GW?). The vascular bundles lying beneath the blotchy tissue appeared brown and necrotic and in severe cases cavities appeared adjacent to the vascular bundles. First evidence of blotchiness was observed only after the fruit began to develop color. Histological examination revealed that the discolored tissues were parenchyma cells of the fleshy layer and the vascular bundles were not involved. Bands of discolored material were located between the epidermis and bundles which made it appear that the bundles were affected when viewed through the epidermis. The authors stated that the breakdown of cells adjacent to the bundles in the blotchy areas severed the connection to outlying cells for transfer of assimilates and water, and normal ripening was inhibited. It was also thought that BR was caused by withdrawal of water from the fruits during periods of excessive transpiration, occurring two to five days before the fruit ripen.

White (1938) hypothesized that BR may be the result of abnormal carbohydrate metabolism in which translocation of carbohydrates from leaves to fruits was impaired and abnormal water relations may be involved. The failure of blotchy and greenback areas to ripen was thought to be associated with a lack of starch to sugar conversion. Increased K and increased sunlight reduced the amount of BR.

Selman (1943) found that high K fertilization reduced BR in tobacco mosaic virus (TMV) infected and non-infected plants. The percentage of fruit that developed BR increased with TMV infection. Jones and Alexander (1956) reported high K fertility reduced BR and the effect of TMV infection on BR was inconclusive.

Closs (1958) reported that low light intensities 1-2 weeks before coloration caused abnormal ripening and this condition was associated with reduced sugar content. However, he made no separation between GW and BR. Geraldson (1960) also did not clearly distinguish between GW and BR, but reported the incidence and severity of BR was associated with low nutrient concentrations and low nitrate to chloride ratios in the nutrient solution. Cooper (1960) found no correlation between the amount of BR and number of fruits in an inflorescence or position of fruits within the inflorescence. Berry et al. (1964) noted that blotchy outer wall tissue was associated with underlying locular areas of low seed density and associated low auxin activity. The authors hypothesized that these areas of low auxin activity impaired normal metabolism and resulted in BR.

In addition to reports previously cited, many workers have noted that increasing K rate reduces BR. Winsor et al. (1961) reported a reduction in BR and greenback with increasing potash to nitrogen ratio from 1.0 to 2.5. Winsor and Long (1967) and Winsor et al. (1965) found all forms of BR to be markedly reduced by increasing K fertility. Hayslip and Iley (1964, 1965, 1967) studied the influence of N to K₂O ratios on "graywall," even though they were actually looking at a combination of GW and BR as judged by their symptom descriptions. Based on their study, it is impossible to determine the influence of

K on the incidence of the separate disorders. They found much more "graywall" in 'Homestead-24' fruits fertilized with 50 than 400 and 800 lbs K_2O per acre. High N/K_2O fertilizer ratios resulted in much more "graywall" than low N/K_2O ratios. They suggested this disorder might be reduced by using fertilizer with at least twice as much K_2O as N, but also noted that additional climatic factors were necessary for "graywall" development. Jones and Alexander (1962) reported an inverse correlation between K nutrition and BR. Collin and Cline (1966) found that BR resulted from replacement of K in the nutrient solution with Ca or Na, but not NH_4 . Shoulder blotch (greenback) and white wall tissue were attributed to a low K supply and excess light. The premise that K deficiency causes BR was not completely supported because substituting NH_4 for K did not result in increased BR. Van der Boon (1973) concluded that BR incidence was lower at the high K/Ca fertility ratio (5:1) than the low K/Ca ratio (1:5). Van Lune and Van Goor (1977) also reported that BR and greenback lessened with increasing K/Ca ratio. Minges and Boutonnet (1966) and Ozbun et al. (1967) found low K treatments to result in significantly more BR with respect to internal white tissue than high K treatments. A highly significant correlation occurred between white tissue and low K content of the petiole. Turnipseed and Ozbun (1974) reported that a BR resistant breeding line showed a higher K uptake rate than susceptible lines and hypothesized that this may be a factor in BR resistance.

In contrast to the above reports on decreased incidence of BR with increasing K, Clarke (1944) found no clear relationship between K and BR and suggested that sunlight was more important than K in

reducing BR. In several seasons, Cotter (1961) was generally unable to find an effect of varying levels of K, N, B, or TMV infection on BR. Woods (1964a) reported that addition of K_2SO_4 did not reduce the incidence of greenback and total blotch in three out of four years. Woods (1964b) found that varying the N/K ratios from 2:1 to 0.33:1 did not influence the occurrence of any form of blotch in any of four years.

Many environmental factors have been shown to influence BR. Cooper et al. (1964) observed that shading the greenhouse reduced BR. Woods (1963) reported that shading reduced BR only when the plants were grown against the outside greenhouse walls, with most of the reduction being in the amount of greenback. Defoliation resulted in a marked rise in greenback. The incidence of yellow blotch and waxy patch (CW?) was increased by shading. Woods (1965) concluded that there was no consistent relationship between 16°C and 21°C temperatures and either green or yellow blotch. Greenback was least in the lower temperature regime (16°C) in three out of four years. Venter (1965) suggested that greenback was caused by variations in temperature on the fruit pericarp during maturation. Higher fruit temperatures were associated with a greater incidence of greenback. Collin and Cline (1966) stated that shade and high humidity did not increase BR, but exposing greenhouse grown plants to supplementary light produced severe blotch regardless of nutrient treatment. The effect of supplementary light could have been due to the heat given off by the lamps. Lipton (1970) stated that yellow shoulder development was not primarily a heat effect, but mainly a result of short wave radiation. He found more yellow shoulder under high relative humidity (70%-100%)

than low humidity (50%-90%) and attributed this to a higher effective radiation load with the higher relative humidity. Jones and Alexander (1962) reported that BR was increased by subjecting greenhouse grown plants to low temperature followed by high temperatures, or to a regime of high soil moisture, high N, and shade. High levels of BR occurred on plants infected with or free of TMV. Unfortunately, no distinction was made between BR and GW. Matsumoto and Hornby (1974) and Hornby and Matsumoto (1974) concluded that alternating weeks of sunny and cloudy days produced the highest amount of BR. Alternating weeks of different temperature levels with consistent sunny-day light also produced high levels of BR. They hypothesized that varying temperature or light can produce a stress on plants resulting in blotchy fruit.

An extensive histological study of the various external and internal symptoms of BR was conducted by Sadik and Minges (1966). They stated that white and brown tissue are the two types of abnormal tissues present in blotchy fruits. White tissue appeared to be the basic abnormality associated with internal and external symptoms. The presence and location of white tissue in the pericarp determine the type of external symptoms, i.e. blotch, yellow shoulder, yellow streaks, subsurface yellowing, or yellow ring. White tissue may also be found in the septa and placental areas. When the white tissue is adjacent to the fruit surface this externally results in blotch; when the white tissue is separated from the fruit surface by a layer of red tissue the fruit may look perfect externally or have slight subsurface yellowing; when the white tissue is deeply embedded in the pericarp the fruit is not externally discolored. An unknown gas contained in the

white tissue was found to cause the whitish appearance. The hardness of this tissue was caused by cell wall lignification. Starch content of this tissue did not decrease with ripening which indicated a lack of starch hydrolysis.

Early stages of BR were microscopically observed in immature green fruits about 25 mm in diameter. Sadik and Minges stated that this early disorganization starts in a single or small group of parenchyma cells in the pericarp located around vascular bundles. Lignification of the parenchyma cell walls ultimately leads to cell breakdown and associated ripening abnormalities. In severe cases of BR, brown tissue occurs as strands or bands in tissues around and between the vascular bundles. Brown tissue may extend into the abscission zone and into the septal and placental tissues. Brown tissue is much less common than white tissue, with which it is always associated. This BR brown tissue described by Sadik and Minges differs from that caused by TMV induced internal browning (Wharton and Boyle, 1957) and GW associated browning (Stoner and Hogan, 1950; Hall and Stall, 1967). Immature internally browned or GW fruit, if allowed to ripen, will be "blotchy-ripened." Therefore it is understandable how GW and its associated browning can be confused with true BR containing brown tissue. Even Minges and Sadik (1964) in an earlier report classified typical GW symptoms as a type of BR.

Graywall

One of the first published reports concerning GW was made by Conover in 1949 (Conover, 1949). He called the disorder vascular browning and noted that this malady was first recorded in the South Florida area in 1927 and had been seen annually in Dade county since 1937. In describing the symptoms of vascular browning, Conover stated

vascular browning appears externally on the fruit as a grayishbrown discoloration seen through the somewhat translucent outer wall of the tomato. The margin is usually indistinct and the discolored areas vary from nearly circular to longitudinal sectors in that portion of the fruit wall covering the locules. This discoloration is more noticeable on the sides of the fruit, but has been seen extending from the stem scar to the blossom end. In severely affected fruit, the entire tomato may be discolored and the skin somewhat corrugated but not broken. In cross section the affected area is dark reddish brown and is centered in and around the vascular bundles of the fruit wall . . . the septa and placental tissue are not involved. Fruit of all sizes larger than one-half inch may be affected. pg 283-284.

Conover also noted that vascular browning may show up at any picking and vines bearing affected fruit may subsequently set fruit that mature normally without vascular browning. The disorder was usually more severe where vines were luxuriant and the fruit heavily shaded. Young (1946) reported on a similar occurring tomato disorder in Texas called internal browning and core rot. This disorder was correlated with periods of abundant rain. A disorder almost identical to that described by Conover was reported in New Jersey as internal browning (Haenseler, 1949). Symptoms first appeared on 1/4 to 3/4 grown fruit. The most conspicuous symptom was the brown tissue inside the fruit, and this was most prominent near the stem end. The corky stem scar was often more prominent on infected fruits and the septa were severely browned in advanced cases. No consistent foliage symptoms were associated with internal browning and plants which yielded severely diseased fruits early in the season bore normal fruits thereafter. A tomato disorder characterized by internal browning was also found in tomatoes grown in New York, Pennsylvania, Florida, and New Jersey (Friedman, 1949).

Stoner and Hogan (1950), working in South Florida, used the term GW to describe an almost identical disorder to Conover's vascular browning. The local name GW was derived from the appearance of the condition in green and pink fruits. Internal browning appeared as pale to dark gray areas in the outer fruit wall. As the fruit ripened the gray areas became brownish and were slightly depressed and roughened in the fully ripe fruits. Disintegration and browning of one or many vascular bundles was observed and under severe conditions the core and placenta were discolored. The browning was observed to stop at the stem scar or extend into the pedicel. Based on mechanical inoculations, grafting, and sexual propagation experiments, the authors concluded that GW or internal browning of tomatoes in Florida was not due to a transmissible pathogen. There was no regular pattern in the location on the plant of the affected fruits and there was no concomitant foliage symptom.

In California a condition called GW or thinwall was described by Lorenz and Knott (1942) and was shown to be due to a combination of intense light and heat. The symptoms described for thinwall indicate it is a form of sunburn and entirely different from Florida GW. No mention of internal browning was made.

Studies on the influence of certain environmental factors associated with vascular browning or GW in Florida revealed that shade, mist, cool night temperatures, and to some extent soil compaction all contributed to the incidence of this disorder (Dennison and Hall, 1954; Hall and Dennison, 1955). Affected fruits were usually found on vigorous plants beneath the foliage where they were shaded. Graywall

was frequently found following consecutive days of rain and cloudy weather. The largest amount of GW occurred during the cool seasons of the year.

Cloud was the term used to describe a form of abnormal ripening of tomatoes grown in unheated greenhouses in New Zealand (Kidson and Stanton, 1953a). The authors description of the symptoms of cloud closely resemble those used to describe GW. They reported that fruit affected with cloud had brownish-green areas against the normal red areas and the necrotic browning affected the vascular system and surrounding parenchyma cells. Rapidly growing, heavy yielding plants were very susceptible. Cloud was less severe in heated houses and was also noted to affect outdoor fruit in a wet season. In the greenhouse, treatments which increased vegetative growth and fruit shading all increased the incidence of cloud. The opposite extreme of heavy defoliation also increased cloud incidence. Cloud was decreased by heavy potash fertilization during the winter, and light watering, N, potash, or CaCl_2 treatments throughout the season. The beneficial treatments produced a thinner-stemmed, less rank type of growth. No consistent differences in mineral composition between cloud fruit and healthy fruit were found (Kidson and Stanton, 1953b). No correlation was found between mineral content of the foliage and cloud incidence. Cloud was associated with a low dry matter content of the leaves and fruit. A hypothesis was proposed in which cloud was the result of abnormally low organic matter content in the fruit which might have been caused by excessive water uptake and/or reduced photosynthesis under less illumination. High K levels in the soil reduced cloud and imbalances between K and other elements increased cloud incidence

(Kidson, 1963). No conclusive evidence was obtained on the relationship between trace elements and cloud. The browning near the vascular system characteristic of cloud was polyphenoloxidase browning (Kidson, 1958).

A number of workers have studied the relationship of TMV to internal browning (IBr). The symptoms of IBr and GW are identical and therefore the two terms are probably synonymous. Most workers studying this relationship between TMV and abnormal fruit ripening have only used the term IBr. The identical symptoms between GW and IBr are better appreciated when one compares the following IBr description to that previously presented for GW. Wharton (1956) and Wharton and Boyle (1957) stated that IBr was usually confined to the outer fleshy pericarp, but in severe cases many extend into the septa and central column. The large brown to brownish-gray areas radiated from the stem end and were restricted to the fleshy parenchyma tissue. These areas were most prominent near the fruit shoulder and no sharp line of demarcation existed between discolored and normal green areas. Both immature green and mature green fruit were affected. Symptoms on the red ripe fruits were yellow to brownish streaks with associated sunken areas near the shoulder. Cellular collapse of the large thin-walled parenchyma cells resulted in a furrowing of the fruit surface. The vascular tissue did not appear affected.

Holmes (1949, 1950) was the first to report on the association of IBr with strains of TMV in the affected fruits. TMV resistant plants did not develop IBr. Holmes was unable to reproduce characteristic IBr symptoms in TMV inoculated plants.

Internal browning was reported in Maryland (Cox and Weaver, 1950) and was associated with virus containing plants. Raychaudhuri (1952) was unable to reproduce IBr in tomato fruits by grafting diseased scions onto healthy stocks, even though mottling of the foliage resulted. The leaf sap of IBr affected plants contained strains of virus slightly different from the ordinary TMV strain. The relationship between virus and IBr was further questioned when Raychaudhuri (1953) reported that TMV free plants produced typical IBr fruits. He noted that excess water applied to the fruit resulted in IBr of some virus infested plants and commercial growers also reported IBr to be associated with high soil moisture content.

Further evidence concerning the role of virus in inducing IBr was provided by Boyle (1956). Results from field and greenhouse experiments revealed that: 1) plants inoculated with certain strains of TMV did not produce IBr; 2) cuttings from plants that had produced IBr fruits once do not do so again; 3) strains of TMV originating from plants that have produced IBr fruits caused IBr when introduced into healthy plants as the fruits begin to ripen. The expression of IBr was thought to be a "shock" reaction coming as a result of virus invasion and a hypersensitive response of the host. Boyle and Wharton (1956, 1957b) consistently reproduced IBr by injecting TMV into healthy plants just when the fruits began to ripen. Symptoms were expressed within ten to twenty days when the peduncle of a ripening fruit hand was inoculated hypodermically. Inoculating tomato plants soon after transplanting resulted in foliage symptoms but no fruit IBr.

Those who would doubt Boyle and Wharton's hypothesis that IBr is caused by a shock reaction point out that TMV infection approaches

100% in tomato fields near the end of the season and TMV presence in IBr fruits may be of no etiological significance. They would also point out that Boyle and Wharton (1957a, 1957b) were unable to produce IBr in all virus inoculated plants and in several cases virus free plants produced IBr fruits. Results from four different TMV isolates showed only 15-38% of the plants to have IBr fruits after hypodermically inoculating into the peduncle of the first hand. Less than 2% of the fruit from these inoculated plants showed IBr. Even the most potent TMV isolate was only able to produce 14% IBr from over 5000 fruit from inoculated peduncles. Rich (1958) provided further evidence against Boyle and Wharton's theory. In one year he found no IBr symptoms in the fruit after inoculation with one of the more potent IBr producing strains of TMV. However, in the next year all virus inoculated treatments had more IBr than non-inoculated treatments. High K fertility reduced the amount of IBr in inoculated plants, but not to the level of uninoculated plants. Tompkins and Stark (1964) reported that K did not influence IBr, but heavy shade resulted in more IBr.

Another theory was proposed in which IBr may result from restrictions of the movement of sugars into the developing fruit (Taylor, 1956). Fruit from plants grown under high moisture plus mist had a greater percentage of IBr and were 31% lower in reducing sugars compared to low moisture treatments. Plants producing few IBr fruit and having a relatively high reducing sugar content were also characterized by a higher boron (B) content. Inadequate B nutrition was one proposed factor resulting in sugar deficiency. Maynard et al.

(1959) supported Taylor's theory that reduced sugar movement into the fruit caused by B deficiency results in more IBr. Boyle and Bergman (1967) also found IBr to be markedly affected by soil moisture and cultivar. Years of low rainfall resulted in much less IBr. Gilbert (1960) reported that vascular browning was more severe during wet weather with cool nights. Windy conditions which resulted in air movement around the plants reduced vascular browning during these wet cloudy periods.

The first worker to differentiate GW from IBr was Murakishi (1960a, 1960b). He stated that it was not possible to distinguish between GW and IBr symptoms and both disorders occur simultaneously in the same field. Differentiation was based on whether the affected fruit came from TMV infected plants (IBr) or TMV free plants (GW). This was probably an erroneous separation of the same disease. The severity of both GW and IBr in several cultivars was greater under low light intensity and several TMV-resistant breeding lines were resistant to both GW and IBr. However, two GW resistant varieties were IBr susceptible.

The most recent hypothesis concerning the cause of GW involves a pathogenic bacterial association in the fruit. Beraha and Smith (1964) reported a dry, firm decay of mature green tomatoes to result after bacterial inoculations into the pericarp. Symptoms were typical of GW. Hall and Stall (1967) observed that a GW-like condition on chilled, detached tomato fruits was associated with a bacterial ooze in the stem scar. A pure culture of a bacterium similar to Erwinia ananus Serrano was isolated from the ooze and from brown GW tissue. Injection of the bacterium into the outer pericarp of green fruits

before or after chilling at 3°C induced GW-like symptoms. The severity of browning increased with the length of chilling. Thompson et al. (1960) and more recent reports by Stall and Hall (1968, 1969) also noted that chilling predisposes the fruit to GW. The external symptoms produced by the bacterial inoculations consisted of a brown or grayish-brown discoloration of the outer wall generally limited to the inoculation area. The discolored areas remained firm as the fruit ripened and the symptoms closely resembled those described by Conover (1949). Differential cultivar susceptibility to GW was also noted.

Stall and Hall (1967) reproduced GW symptoms by injecting crude extracts from GW affected tissue into healthy fruits. Treatments that removed or killed the bacteria in these extracts also resulted in a loss of the GW producing principle. It was unlikely that the symptoms produced were the result of TMV contamination because symptoms were not produced with bacteriologically filtered extracts, which would not have removed virus particles. Toxic metabolites produced in and extracted from GW affected tissue were probably not important in GW development since filtration would probably not have removed them.

Graywall was not specific to one bacteria (Stall and Hall, 1968, 1969). Thirty bacterial isolates from GW-diseased fruits incited GW symptoms after inoculation into susceptible fruits. Most of the isolates were species of Bacillus, Erwinia, or Aerobacter. An association was established between numbers of bacteria in the tomato tissue and visible browning. Bacteria occurred in healthy fruit as well as diseased, but were found in higher numbers in diseased fruit. The regular occurrence of bacteria in healthy green and red tomato fruit was previously reported (Samish et al. 1961, 1963). Stall and

Hall concluded that GW expression after bacterial multiplication was associated with hypersensitivity of the tomato tissue. Endophytic bacteria incited GW, but the possibility existed that GW could occur in the absence of bacteria since constant association of bacteria with natural GW was not established.

Studying the interaction between GW and TMV, Stall et al. (1969) reported that differences in GW incidence could not be attributed to presence of TMV. No TMV was found in GW affected fruit from plants not inoculated with virus, but TMV was detected in fruits from virus inoculated plants. Graywall occurred on TMV susceptible as well as TMV resistant plants. They stated the possibility exists that bacteria, like TMV, are a predisposing factor and not the primary causal agent of GW.

Two types of GW resistance mechanisms were postulated (Hall et al. 1970). One would be resistance to entrance of the bacteria and the other would be some factor in the tissue which prevents bacterial development after invasion of the tissue. Using a vacuum infiltration technique, suspensions of bacteria were placed around the stem scar with the stem attached and were infiltrated into the fruit. Typical GW symptoms resulted. Previously reported field resistant cultivars developed less GW than susceptible cultivars. Resistance may have been due to some structural characteristic of the stem scar area. If the stem was removed before infiltration, no cultivar difference was found. The cultivars which showed GW resistance with the infiltration technique had narrower corky rings and smoother shoulders with a general absence of deep creases. The injection technique of hypodermically inserting a bacterial suspension into the pericarp gave

different results compared to the infiltration method. The cultivar most susceptible to GW in the infiltration method ('Homestead-24') was less susceptible to GW with the injection method than many naturally GW resistant lines. Ideally a combination of resistance to entrance and tissue resistance is preferred. It was presumed that environmental changes or virus infection could reduce tissue resistance.

The bacteria occurring in healthy tomato fruit probably enter through the connective tissue at the stem end. They can persist in a latent state because of the inhibiting action of healthy cells, but these harmless commensals may be activated by some physiological disturbance in the tissue. Samish et al. (1961, 1963) reported that bacterial populations within tomato fruit showed a distinct gradient, being largest in the connective tissue at the stem end and decreasing through the central core towards the peripheral and distal tissue. Such a gradient agrees with the location of GW symptoms in the fruit. Samish et al. 1963 also found that fruits harvested from fields using overhead irrigation contained far more bacteria than those harvested from furrow irrigated fields. The greater incidence of GW on fruits harvested from the interior of the canopy or from moist environments supports a bacterial related cause of this disorder. In order for GW to develop, the bacteria must enter the fruit and multiply to a high enough level. The entrance and growth are dependent on the interaction of physiological and biochemical changes in the fruit.

In summary, basically four causes of GW (IBr) have been proposed and are due to the following agents: 1) TMV, 2) environment and/or

nutrition, 3) bacteria, 4) a combination and interaction of two or more of the above.

The causes of both disorders, BR and GW, are elusive and not truly known. Both disorders may occur under varied conditions and may be caused by a complex of factors rather than a single one. Nutritional, environmental, and pathogenic factors may all have their influence and whether they act in primary or secondary roles is not completely understood. Symptoms produced in both disorders may be due to some toxic substance entering the fruit. The marked variability in amount of BR and GW produced within plants, between plants, between cultivars, and between environments implies that there is no simple cause and effect solution.

Fruit Quality of Blotchy Versus Normal Fruit--
Compositional and Biochemical Differences

Several workers have determined compositional differences between blotchy fruit (or blotchy tissue within a red fruit) and normal red fruit. Compared to red tissue, blotchy tissue was found to contain significantly lower amounts of total solids, dry matter, titratable acidity, soluble solids, and reducing sugars (Winsor and Massey, 1958; Eells, 1961; Winsor et.al. 1962; Tompkins and Stark, 1964; Davies, 1966). Winsor and Massey (1958) concluded that there was no evidence for a critical level of any of the constituents below which the fruit would always ripen unevenly.

Malic acid was higher and citric acid lower in blotchy green areas compared to corresponding red areas (Davies, 1966). The malic

acid to citric acid ratio was about double in the green than red areas. Normal tissue was found to have a lower pH than blotchy tissue (Winsor and Massey, 1958).

Several workers found the K content of blotchy fruit walls to be lower than that of normal walls (Winsor and Massey, 1958; Van der Boon, 1973; Hobson and Davies, 1976). Others found no significant difference in K or other mineral concentrations in blotchy versus red tissue (Davies, 1966; Ells, 1961). A higher K content in internally browned tissue compared to normal tissue was reported by Tompkins and Stark (1964).

Biochemical differences exist between blotchy and normal red tissue. The normal reduction in polyphenoloxidase activity that accompanies uniform ripening does not occur in blotchy tissue (Tompkins and Stark, 1964; Davies, 1966; Hobson, 1967). Polygalacturonase activity was much lower in blotchy tissue than red tissue (Hobson, 1964). Protein components and isoenzyme differences between blotchy and normal tissue were of a random nature (Hobson and Davies, 1976). Blotchy tissue had about double the content of pectic substances compared to red tissue (Hobson, 1963), but failure of the blotchy areas to ripen was not thought to be primarily due to reduced pectinesterase activity. Davies (1966) stated that blotchy areas should be considered abnormal and not merely delayed in ripening.

MATERIALS AND METHODS

Blotchy Ripening--Greenhouse

A sand culture experiment was conducted in the greenhouse during the spring-summer of 1978 to determine the influence of cultivar and K treatments on BR. Three tomato cultivars, 'Healani', 'Homestead-24', and 'Flora-Dade' were seeded on April 28 in thirty cm diameter plastic pots filled with sterilized #2 grade sand. Johnson's (Hewitt, 1966) solution (Table 1) was applied daily until first cluster anthesis (mid-June) whereafter four K treatments were applied daily until the conclusion of the experiment. The four K treatments were:

- 1) 1K = Johnson's solution.
- 2) 1/10K = Johnson's solution for all elements except K which was 1/10 the normal level.
- 3) -K = Johnson's solution for all elements except K which was omitted.
- 4) H_2O = Water containing four milliequivalents per liter of $CaCl_2$.

The 1K solution was applied to treatments 3) and 4) for seven day periods in early July and early August to maintain plant growth and fruit set. In the 1/10K treatment, $NaNO_3$ was added to maintain the NO_3 concentration equal to the 1K treatment. In the -K treatment, KNO_3 was replaced with $NaNO_3$ to maintain the NO_3 concentration equal to the 1K treatment.

Table 1. Standard Johnson's solution (1K).

<u>Macroelements</u>		
<u>1 Molar solution</u>	<u>Ml of 1 Molar solution needed per liter of total solution</u>	
KNO ₃	6	
Ca(NO ₃) ₂ •4 H ₂ O	4	
NH ₄ H ₂ PO ₄	2	
MgSO ₄ •7 H ₂ O	1	
<u>Microelements</u>		
	<u>g per liter</u>	
KCl	3.728	(One ml of all micro- elements needed per liter of total solu- tion)
H ₃ BO	1.546	
ZnSO ₄ •7 H ₂ O	0.575	
MnSO ₄ •H ₂ O	0.338	
CuSO ₄ •5 H ₂ O	0.125	
H ₂ MoO ₄	0.081	
<u>Iron</u>		
	<u>g per liter</u>	
FeCl ₃ •6 H ₂ O	8.71	(One ml of iron needed per liter of total so- lution)
Na ₂ H ₂ EDTA	11.99	
<u>Element</u>	<u>Final concentration of nutrient solution (uM)</u>	<u>Final concentration in ppm</u>
N	16000	224
K	6000	235
Ca	4000	160
P	2000	62
S	1000	32
Mg	1000	24
Cl	50	1.77
Fe	32.2	1.80
B	25	.27
Mn	2	.11
Zn	2	.131
Cu	0.5	.032
Mo	0.5	.05

A completely randomized block design was used with four replications per treatment making a total of forty-eight plants (four replications x four K treatments x three cultivars). Twelve fruit were picked from the first three clusters of each plant, so data analyses were based on an average of forty-eight fruit per treatment (twelve fruit per treatment x four replications). The plants, pruned and trained to a single stem, were grown under approximately a 21°C night temperature and ambient day temperature regime. Day temperatures generally ranged between 32°C-36°C. Plants were irrigated to saturation each day with their respective K treatments to prevent both salt accumulation and wilting.

Fruits were harvested at the red ripe stage over a four week period from late July through August and rated for external blotchy ripening (EB) and internal blotchy ripening (IB) symptoms. To determine IB, each fruit was cut cross-sectionally in half. The rating scale used in assessing the amount of BR ranged from 1 to 5. Each number was associated with the following amount of BR, in which the percentages relate to the amount of either external surface area or internal pericarp surface area affected with BR:

- 1 = completely blotch free
- 2 = 0-5% blotch
- 3 = 5-25% blotch
- 4 = 25-50% blotch
- 5 = greater than 50% blotch

Pictorial illustrations of EB and IB are provided in Figures 1 and 2.

Figure 1. Illustration of fruit with an external blotchy ripening rating of 1, 3, and 5.

Figure 2. Illustration of fruit with an internal blotchy ripening rating of 1 (bottom) and 5 (top).

Field Experiments

Field experiments were conducted during the spring and fall 1979 growing seasons to determine the influence of K rate, cultivar, and season on BR, GW, and fruit quality. Tomatoes were grown at the Horticultural Unit in Gainesville on a Kanapaha fine sandy soil very low in organic matter. Spring and fall plots were planted on adjacent areas in a field that had been fallow for several years, thereby ensuring extremely low residual fertility. Soil K analyses measured before planting by acid extraction revealed residual K fertility to be between 30-40 ppm. Soil pH was 6.5. The plots were disked about five weeks before plant and fumigated with ethylene dibromide three weeks before planting. Fertilizer N and P were broadcast at the commercially recommended rates of 270 kg N/ha and 118 kg P/ha. Ammonium nitrate and triple superphosphate were the sources of N and P. Raised beds were then prepared 240 cm apart to be sure that there was no cross feeding. Potassium sulfate was placed in two bands about 15-20cm from the center of the bed. Five different rates of K were used: 0, 93, 186, 372, and 745 kg K/ha (hereafter referred to as 0-K, 93-K, 186-K, 372-K and 745-K). Black polyethylene mulch was applied over the top of the beds. The tomatoes were transplanted 45cm apart. The plants were pruned twice early in the growing season and then were staked and tied.

Four tomato cultivars, 'Healani', 'Homestead-24', 'Walter' and 'Flora-Dade' were grown at the five K rates during each season in a completely randomized block design. There were four replications of eight plants each. Fruits were harvested from the six interior plants. The two end plants served as guard plants. Tomatoes were

transplanted on March 30 for the spring season and on August 8 for the fall season. Commercially recommended fungicides and insecticides were applied twice a week. Supplemental overhead irrigation was applied as needed to keep the soil moisture as near to field capacity as possible.

Blotchy Ripening

Three harvests were made during each season on the following dates: spring -- June 10, June 17, and June 20; and, fall - October 25, November 5, and November 15. At each harvest all red ripe fruits were harvested from the six interior plants of each replication. Ten randomly selected fruits from each harvest lot were rated for EB and IB. A 1 to 5 rating scale, as previously described, was used in assessing the amount of each.

Graywall

Thirty-two randomly selected immature green fruits (6x6 size) were harvested from the six interior plants of each treatment. Four separate harvests (eight fruit per harvest) were made over a two week period in early June for the spring and over a two week period in late October for the fall season.

The original objective was to determine the influence of K rate and cultivar on naturally occurring GW under field conditions. No natural GW appeared during either season, so it was decided to study the influence of K rate and cultivar on GW induced by injection of bacteria. The procedure of Hall and Stall (1967) was followed with minor modifications.

Cells of the bacteria Erwinia herbicola (Dye) were suspended in sterile saline (adjusted to cellular osmotic concentration) and

inoculated into the outer fruit pericarp with an automatic syringe fitted with a 27-guage needle. Approximately 0.1 ml of inoculum containing 10^6 cells per ml was injected into five different locations around the equator of each fruit. After inoculation, fruit were kept at 4°C for four to six days, returned to 20°C for another four to six days, and then rated for symptoms. The four to six days at 4°C served as a chilling treatment that insured the fruit to be in a GW susceptible condition. Fruits were also inoculated with 0.1 ml of sterile saline to act as controls.

Bacterial suspensions were prepared by allowing the bacteria to multiply in nutrient broth and then the cells were centrifuged from the broth and resuspended in sterile saline. Inocula were standardized to 50% transmittance as determined by a Spectronic 20 at 600nm. A suspension of this turbidity contained approximately 10^8 viable cells per ml as determined by a dilution plate technique. The final concentration of 10^6 cells per ml was obtained by dilution.

The rating scale used in assessing the amount of GW development ranged from 0 to 5. Each of the five individual inoculation sites per fruit was rated separately and results are expressed as the average of these five GW ratings. Each treatment consisted of eight fruit x four replications. Each number in the individual inoculation site rating scale was associated with the following amount of GW development as seen through the outer fruit wall:

0 = no discoloration

1 = slight tissue discoloration

2 = light browning

- 3 = moderate browning
- 4 = deep browning
- 5 = extreme deep browning

A pictorial illustration of different amounts of GW development is provided in Figure 3.

Fruit Quality Measurements

Fruit quality analyses were conducted on a total of forty fruit per treatment. Ten fruit from four different replications were randomly selected. For the spring analyses, all the fruit were picked in the red ripe stage on June 20 and for the fall fruits were picked in the red ripe stage on November 5. Locule plus placenta tissue was separated from the pericarp tissue and both were frozen at -20°C until analyzed. The following quality analyses were performed for both pericarp and locule tissues: % soluble solids, pH, and % acidity. In addition, % reducing sugars, % dry weight, and mineral composition of the pericarps were analyzed.

Samples were thawed and thoroughly homogenized at high speed in a Waring Blendor for one minute. A portion of the homogenate was centrifuged at ten thousand rpm for fifteen minutes in a Sorvall RC2-B centrifuge. Titratable acidity was determined by titrating ten ml of the supernatant and one hundred forty ml of pre-boiled CO_2 free distilled water to pH 8.1 with 0.1N NaOH. Results are expressed as % citric acid [titratable acidity (in ml) $\times$ 0.064]. The pH was determined from the ten ml supernatant-one hundred forty distilled water mixture with a Beckman Model 3500 digital pH meter.

Percent soluble solids were determined from several drops of the supernatant with a Bausch and Lomb table top refractometer.

Figure 3. Illustration of fruit with a graywall rating of 1 (lower left), 2 (upper left), 3 (upper right), and 4 (lower right).

Percent dry weight was determined by drying fifty g of the homogenate at 70°C for forty-eight hours.

Percent reducing sugars were determined as follows: twenty-five g of the homogenate was blended with two hundred mls of 95% ethanol for one minute. The slurry was rinsed into a mason jar with 95% ethanol and placed in a boiling water bath for thirty minutes. The samples were then filtered through Whatman # four paper under suction using a Buchner funnel. The final volume was adjusted to five hundred ml with 95% ethanol. A twenty ml aliquot was pipetted into a one hundred ml volumetric flask and brought to volume with distilled water. Reducing sugars were determined on a one ml aliquot of this dilution after the procedure of Ting (1956). Sugar concentrations were determined on a Bausch and Lomb Spectronic 100 spectrophotometer set at 745nm.

Pericarp K, Ca, Mg, and P concentrations were determined as follows: oven-dried pericarp tissue was ground in a Wiley Mill to pass a #40 sieve and stored in air-tight bottles. One g of ground tissue was ashed in a muffle furnace at 475°C for eight hours. The ash was dissolved in 1N HCl. Potassium was determined by flame photometry, Ca and Mg by atomic absorption spectrophotometry, and P by colorimetric spectrometry at the Soil Science Laboratories, University of Florida.

Leaf mineral analyses were determined in the same manner. Several recently matured leaves and petioles near the top of each plant were sampled at the end of each growing season; late June for the spring and late November for the fall season. Results are based on four replications per treatment. By the end of both growing

seasons the plants in which K was not applied to were very chlorotic relative to plants grown at the higher K rates.

Environmental conditions were different between seasons as indicated in Table 2. As the fruits were maturing during the spring, average minimum and maximum temperatures were increasing, daylengths were getting longer, and relative humidity was increasing. During the fall, average minimum and maximum temperatures were decreasing, daylengths were getting shorter, and relative humidity was decreasing.

Graywall--greenhouse

Several additional greenhouse experiments were conducted to determine the influence of cultivar and K nutrition on GW development. The only experiment in which natural GW was studied, in contrast to bacterially induced GW, was during the fall-winter of 1978-79. Tomatoes were grown in thirty cm diameter plastic pots filled with sterilized #two grade sand. Three tomato cultivars, 'Healani', 'Homestead 24', and 'Flora-Dade', were seeded on September 20 and watered daily with Johnson's solution (Table 1) until first cluster anthesis, which occurred in late November. After this, four different K treatments, as previously described for the greenhouse-BR experiment, were given daily until conclusion of the experiment. The four K treatments were 1K, 1/10K, -K, and H₂O. Two-seven day periods of the 1K treatment were applied during mid-December and mid-January to the -K and H₂O treatments. All the fruit of marketable size on each plant were analyzed for natural GW symptoms and classified as either having GW or not having GW. No distinction was made between the severity of symptoms. Each treatment consisted of at least fifty to sixty fruit (four replications x thirteen to fifteen fruit per plant). Forty-eight total plants were grown in a completely randomized block design

Table 2. Monthly temperature averages during the 1979 Spring and Fall growing seasons at the Horticultural Unit, Gainesville, Florida.

<u>Month</u>	<u>Season</u>	<u>Temperature (°C)</u>	
		<u>Maximum °C</u>	<u>Minimum °C</u>
April	Spring	28.3	12.2
May		31.1	14.4
June		32.8	17.2
September	Fall	32.8	18.3
October		27.8	12.2
November		24.4	10.0

(four replications x four K treatments x three cultivars). Plants were grown under approximately 15°-21°C night temperatures and 26°C-30°C day temperatures with the exception of a one week period in early January when the night temperatures were just above freezing (i.e. 2°C-5°C). This was due to an unusual cold spell accompanied by a failure of the greenhouse heating system.

Another greenhouse experiment was conducted during the fall of 1979 to complement the fall 1979 GW field studies. Plants of four cultivars, 'Healani', 'Homestead-24', 'Walter', and 'Flora-Dade', were grown as above until first cluster anthesis when two K treatments were applied. The high K treatment consisted of daily applications of Johnson's solution (1K). The low K treatment consisted of daily applications of Johnson's solution in which K was omitted. All other nutrients were applied at the same rate as in the high K treatment. For each cultivar a total of seventy-two fruit per treatment (high versus low K) were compared for bacterial induced GW development. The materials and methods for inoculating, storing, and rating the fruit were the same as for the field studies. A total of forty-eight plants were grown (six replications x two K treatments x four cultivars) in a completely randomized block design. Night temperatures were approximately 21°C and day temperatures usually varied between 28°C-32°C.

Ethylene Measurements

Ethylene evolution for yellow and red tissue disks taken from the same fruit was determined. Outer pericarp disks 1.0 cm in diameter were taken with a cork borer from field grown fruits exhibiting yellow shoulder. Each pair of yellow and red disks was taken from the same fruit at a similar longitudinal position. The disks were blotted on

tissue paper to remove any adhering cell sap, weighed, and placed in 9.0 ml volume glass vials capped with silicone stoppers at 25°C. After one hour, 0.5 ml gas samples were withdrawn from the vials with one ml gas-tight disposable syringes. Samples were injected into a Hewlett-Packard 5710A flame-ionization gas chromatograph fitted with a 1.83m x 0.32cm Cu tubing column packed with activated alumina. The flow rate of N carrier gas was forty ml/min and operating temperatures were 150°C, 100°C, and 150°C for the injection port, oven, and detector respectively. The chromatograph was connected to a Soltec recorder set at attenuation one and run at a chart speed of thirty cm/hr. A 0.1 ppm ethylene standard was regularly injected as a reference gas for calibration.

Differences in ethylene evolution (ul/kg/hr) between yellow and red disks were tested by the Student's t-test for paired samples at the 1% level.

Oxygen Consumption

Respiration rates for yellow and red tissue slices taken from the same fruit were determined by O_2 consumption measurements using a Gilson Single Valve Differential Respirometer. Outer pericarp slices, approximately one g fresh weight, were taken with a scalpel from field grown Flora-Dade tomato fruits exhibiting yellow shoulder. Each pair of yellow and red tissues was taken from the same fruit at a similar longitudinal position. The tissue slices were blotted on tissue paper, weighed, and placed in respiratory flasks. The flask center well contained 0.4 ml of 10% NaOH to absorb CO_2 during O_2 uptake measurements. The flasks and contents were equilibrated for thirty

minutes at 25°C with the stopcocks open before respiratory measurements were started. Results are expressed on a fresh weight basis. The O₂ consumption rates represent the average of thirty paired tissue samples each taken from a different fruit. Differences in O₂ consumption (ul/g/hr) were tested by the Student's t-test for paired samples at the 1% level.

Statistical Analyses

Analyses of variance, regression, and t-tests for the experimental data were performed with the aid of the Northeast Regional Data Center in Gainesville. Appropriate square root transformations were made on rating data (i.e. EB, IB, GW) and arc sin transformations were made on % data (i.e. soluble solids, acidity, reducing sugars, mineral content, dry weight). Statistics used in the data tables were based on the transformed analyses (Snedecor and Cochran, 1967). In the analyses of variance tables (see Appendix) the cubic and quartic potassium sources of variation and their interactions were pooled into the error term because in most cases they were not significant.

RESULTS

Influence of Potassium and Cultivar on Blotchy Ripening of Greenhouse Grown Tomatoes

Fruit of each cultivar showed a significant increase in both EB and IB with the three deficient K treatments (1/10K, -K, H₂O) compared to the optimum 1K treatment (Tables 3,4). There was no significant difference between the EB or IB ratings with the three deficient K treatments within any cultivar. With the 1/10K, -K, and H₂O treatments, no difference in EB and IB was found between 'Healani' and 'Homestead-24'. 'Flora-Dade' had more EB and IB with these deficient treatments than the other two cultivars. At the 1K level, 'Healani' had the least amount of EB and IB and 'Flora-Dade' the most.

Yellow shoulder was the primary form of EB affecting 'Flora-Dade' with the reduced K treatments, and to a limited extent with the 1K treatment. Yellow shoulder was not observed in 'Healani' or 'Homestead-24'. There was no noticeable correlation between fruit size and BR or fruit cluster and BR in any cultivar. Blotchy ripening ratings were therefore averaged over all three clusters and expressed on a per plant basis.

Influence of Potassium, Cultivar, and Season on External Blotchy Ripening of Field Grown Tomatoes

There was no noticeable effect of time of harvest on EB during either season with any cultivar (Tables 5,6). Fruits were harvested

Table 3. Effect of reduced potassium levels after first cluster anthesis on external blotch of three tomato cultivars grown in greenhouse sand cultures. Spring, 1978.

Cultivar ^y ^x	<u>K treatment^z</u>			
	1K	1/10K	-K	H ₂ O
'Healani'	1.9e	3.0bc	3.0bc	2.8c
'Homestead-24'	2.1d	2.9c	2.9c	2.9c
'Flora-Dade'	3.2b	4.4a	4.2a	4.3a

^zMean separation by Duncan's multiple range test at the 5% level.

^yRatings were 1 to 5 with 1 being blotch free.

^xTreatments were applied after first cluster anthesis.

Table 4. Effect of reduced potassium levels after first cluster anthesis on internal blotch of three tomato cultivars grown in greenhouse sand cultures. Spring, 1978.

Cultivar ^y ^x	<u>K treatment</u> ^z			
	1K	1/10K	-K	H ₂ O
'Healani'	2.2e	3.4c	3.6bc	3.6bc
'Homestead-24'	2.5d	3.6bc	3.6bc	3.6bc
'Flora-Dade'	3.8b	4.7a	4.6a	4.6a

^zMean separation by Duncan's multiple range test at the 5% level.

^yRatings were 1 to 5 with 1 being blotch free.

^xTreatments were applied after first cluster anthesis.

Table 5. Ratings of external blotch at three different harvest dates of fruit from four tomato cultivars field grown under five potassium levels during the spring 1979 season.

Cultivar	Harvest date	<u>K rate (Kg/ha)^z^y</u>					Mean
		0	93	186	372	745	
'Healani'	6-10	2.8	2.1	1.7	1.4	1.3	1.9
	6-17	3.1	2.2	1.8	1.3	1.2	1.9
	6-20	3.0	2.4	1.8	1.6	1.2	2.0
'Homestead-24'	6-10	4.1	3.6	3.4	3.1	2.7	3.4
	6-17	3.7	3.5	3.2	3.0	2.7	3.2
	6-20	3.8	3.5	3.2	2.8	2.4	3.1
'Walter'	6-10	3.8	3.4	3.0	2.7	2.3	3.0
	6-17	4.1	3.1	3.0	2.6	2.2	3.0
	6-20	3.7	3.2	2.8	2.4	2.2	2.9
'Flora-Dade'	6-10	3.8	3.4	3.0	2.6	2.2	3.0
	6-17	4.0	3.4	2.9	2.6	2.2	3.0
	6-20	3.6	3.1	2.7	2.6	2.1	2.8

^zValues represent the mean of 40 fruits.

^yRatings were 1 to 5 with 1 being blotch free.

Table 6. Ratings of external blotch at three different harvest dates of fruit from four tomato cultivars field grown under five potassium levels during the fall 1979 season.

Cultivar	Harvest date	<u>K rate (Kg/ha)^{zy}</u>					Mean
		0	93	186	372	745	
'Healani'	10-25	1.7	1.5	1.3	1.2	1.1	1.4
	11-5	1.7	1.4	1.3	1.2	1.1	1.3
	11-15	1.6	1.4	1.3	1.2	1.1	1.3
'Homestead-24'	10-25	2.7	2.4	2.0	1.8	1.7	2.2
	11-5	2.7	2.3	2.1	1.8	1.7	2.1
	11-15	2.6	2.3	2.0	1.9	1.6	2.1
'Walter'	10-25	2.5	2.2	1.9	1.7	1.7	2.0
	11-5	2.6	2.2	2.0	1.8	1.6	2.0
	11-15	2.5	2.1	1.8	1.7	1.6	1.9
'Flora-Dade'	10-25	2.8	2.3	2.0	1.8	1.7	2.1
	11-5	2.9	2.6	2.1	1.8	1.6	2.2
	11-15	2.8	2.5	2.0	1.8	1.7	2.2

^zValues represent the mean of 40 fruits.

^yRatings were 1 to 5 with 1 being blotch free.

three different times over a ten day period in the spring and over a three week period in the fall. Only slight variations in EB between harvest dates were noticeable. The variability was slightly greater during the spring season, especially at 0-K. Results from Tables 5 and 6 were averaged and condensed into Table 7. The lack of effect of harvest date on EB indicates that some factors other than short term weather fluctuations predispose fruit to EB. There did not appear to be any correlation between fruit size or fruit cluster and BR for any cultivar during either season.

During both seasons and within each cultivar there was significantly less EB with increasing K fertility (Table 7). External blotchy ripening decreased quadratically with increasing K rate for all cultivars during both seasons. The amount of EB was reduced more between the increments of 0-K to 93-K and 93-K to 186-K compared to 186-K to 372-K and 372-K to 745-K. The significant interaction of Pot.Q x Cult. (Appendix Table 3) indicates that the nature of the quadratic response to K was different between cultivars. The significant Seas.xCult. interaction indicates the cultivars responded differently in each season. The significant triple interaction of Pot. Q x K x Seas. x Cult. is difficult to interpret but implies that the K response was different between cultivars and seasons. 'Healani' had the least amount of EB during both seasons. During the spring, 'Walter' and 'Flora-Dade' exhibited about the same degree of EB at all K rates. 'Homestead-24' had slightly more EB, especially at the higher K rates. 'Homestead-24' and 'Flora-Dade' did not differ in the amount of EB averaged over all K rates in the fall, while 'Walter' had slightly less EB than 'Homestead-24' and 'Flora-Dade'. Each cultivar

Table 7. Rating of external blotch of fruit from four tomato cultivars field grown under five potassium levels during the spring and fall 1979 seasons.

Cultivar	Season	K rate (Kg/ha) ^{zy}					F value ^z	Mean ^{yx}
		0	93	186	372	745		
'Healani'	Spring	2.9	2.2	1.8	1.5	1.3	L**Q**	1.9d
	Fall	1.6	1.4	1.3	1.2	1.1	L**Q*	1.3e
'Homestead-24'	Spring	3.9	3.5	3.2	3.0	2.6	L**Q**	3.2a
	Fall	2.6	2.3	2.0	1.9	1.7	L**Q**	2.1c
'Walter'	Spring	3.9	3.3	2.9	2.6	2.2	L**Q**	3.0b
	Fall	2.6	2.2	1.9	1.7	1.7	L**Q**	2.0d
'Flora-Dade'	Spring	3.8	3.3	2.9	2.6	2.1	L**Q**	2.9b
	Fall	2.8	2.5	2.0	1.8	1.7	L**Q**	2.2c

^zSignificant K rate effects were linear (L) or quadratic (Q) at the 5% (*) or 1%(**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

^xRatings were 1 to 5 with 1 being blotch free.

had more EB during the spring than the fall season. This seasonal difference was more pronounced at the lower K rates. Increasing K rate reduced EB more in the spring than in the fall for each cultivar.

Yellow shoulder was the predominant form of EB during the spring. 'Healani' was the only cultivar that showed resistance to yellow shoulder. It was free of yellow shoulder under all K rates except the 0-K rate, when only a small yellow ring around the stem scar was noticed. The other three cultivars during the spring had an abundance of yellow shoulder, even at the higher K rates. Yellow shoulder EB symptoms generally did not appear on the fruit of any cultivar during the fall. The very few fruits found having yellow shoulder in the fall came from 'Homestead-24', 'Walter', and 'Flora-Dade' grown at the lowest K rates. During the fall, EB symptoms appeared as an over-all non-uniform red coloration of the fruit.

Fruit having yellow shoulder symptoms during the spring were randomly located on the plant. Yellow shoulder appeared on those fruits exposed to the sun as well as on those fruits deep inside the canopy hidden from direct sunlight. Direct sunlight exposure did not appear to be essential for yellow shoulder development, although it seemed more fruit exposed to direct sunlight had yellow shoulder as compared to shaded fruit. It should be emphasized that yellow shoulder is entirely different from sunburn.

Fruit from plants grown with the 0-K level abscised from the plant more easily compared to fruit from plants treated with the higher K rates. No visible soluble salt injury to any of the cultivars occurred during either season at the 745-K rate.

Influence of Potassium, Cultivar, and Season on Internal Blotchy
Ripening of Field Grown Tomatoes

There was no noticeable effect of time of harvest on IB during either season (Tables 8,9). Results indicate only slight variations in IB between harvest dates and no obvious trend between time of harvest and IB was apparent over the period analyzed. Results from Tables 8 and 9 were averaged and condensed into Table 10.

During both seasons and within each cultivar, there was significantly less IB with increasing K fertility (Table 10). Internal blotchy ripening decreased quadratically with increasing K rate for all cultivars during both seasons. The amount of IB was reduced more between the increments of 0-K to 93-K and 93-K to 186-K compared with 186-K to 372-K and 372-K to 745-K. The quadratic response was more apparent during the fall season. A significant Pot. Q.xSeas. interaction (Appendix Table 4) supports this. The significant interaction of Pot.Q.xCult. indicates that the nature of the quadratic response of IB versus K rate was also different for the cultivars. The significant Seas.xCult. interaction indicates the cultivars responded differently between seasons. 'Healani' had the least amount of IB averaged over all K rates during both seasons. However, at 372-K and 745-K during the fall there was no difference in IB between 'Healani', 'Homestead-24', and 'Walter'; or in the spring between 'Healani' and 'Walter' at 745-K. During the spring all four cultivars showed a significant difference in IB susceptibility. 'Healani' was most resistant, followed by 'Walter', 'Homestead-24', and 'Flora-Dade', which was the most IB susceptible. There was no difference in the amount of IB between 'Homestead-24' and 'Walter' in the fall. 'Healani' fruit had the

Table 8. Ratings of internal blotch at three different harvest dates of fruit from four tomato cultivars field grown under five potassium levels during the spring 1979 season.

Cultivar	Harvest date	K rate (Kg/ha) ^{zy}					Mean
		0	93	186	372	745	
'Healani'	6-10	4.2	3.4	3.2	2.7	2.5	3.2
	6-17	4.0	3.3	2.8	2.8	2.5	3.1
	6-20	4.2	3.6	2.9	2.6	2.3	3.1
'Homestead-24'	6-10	4.9	4.4	3.8	3.2	2.7	3.8
	6-17	4.7	4.2	4.0	2.9	2.8	3.7
	6-20	4.7	4.1	3.7	3.0	2.7	3.6
'Walter'	6-10	4.4	3.9	3.3	3.0	2.5	3.4
	6-17	4.2	3.8	3.5	2.9	2.3	3.3
	6-20	4.3	3.8	3.3	2.8	2.4	3.3
'Flora-Dade'	6-10	5.0	4.8	4.7	4.4	3.9	4.6
	6-17	5.0	4.7	4.5	4.0	3.8	4.4
	6-20	5.0	4.8	4.7	4.2	3.8	4.5

^zValues represent the mean of 40 fruit.

^yRatings were 1 to 5 with 1 being blotch free.

Table 9. Ratings of internal blotch at three different harvest dates of fruit from four tomato cultivars field grown under five potassium levels during the fall 1979 season.

Cultivar	Harvest date	K rate (Kg/ha) ^{zy}					Mean
		0	93	186	372	745	
'Healani'	10-25	3.2	2.5	2.2	2.0	1.8	2.3
	11-5	3.3	2.4	2.2	2.0	1.7	2.3
	11-15	3.2	2.3	2.1	1.9	1.7	2.2
'Homestead-24'	10-25	3.5	3.1	2.5	2.1	1.9	2.6
	11-5	3.3	3.1	2.2	1.9	1.9	2.5
	11-15	3.6	3.0	2.3	2.0	1.8	2.5
'Walter'	10-25	3.5	3.0	2.1	1.9	1.8	2.5
	11-5	3.4	2.9	2.2	1.9	1.7	2.4
	11-15	3.4	3.1	2.4	2.0	1.9	2.6
'Flora-Dade'	10-25	4.5	4.1	3.6	3.3	3.1	3.7
	11-5	4.4	4.1	3.6	3.3	3.1	3.7
	11-15	4.3	3.9	3.7	3.4	2.9	3.6

^zValues represent the mean of 40 fruits.

^yRatings were 1 to 5 with 1 being blotch free.

Table 10. Rating of internal blotch of fruit from four tomato cultivars field grown under five potassium levels during the spring and fall 1979 season.

Cultivar	Season	K rate (Kg/ha)					F value ^z	Mean ^y ^x
		0	93	186	372	745		
'Healani'	Spring	4.2	3.4	2.9	2.7	2.4	L**Q**	3.1d
	Fall	3.2	2.4	2.1	2.0	1.8	L**Q**	2.3f
'Homestead-24'	Spring	4.8	4.2	3.8	3.1	2.7	L**Q**	3.7b
	Fall	3.5	3.0	2.3	2.0	1.8	L**Q**	2.5e
'Walter'	Spring	4.3	3.9	3.4	2.9	2.4	L**Q**	3.4c
	Fall	3.4	3.0	2.2	1.9	1.8	L**Q**	2.5e
'Flora-Dade'	Spring	5.0	4.8	4.6	4.2	3.8	L**Q**	4.5a
	Fall	4.4	4.0	3.6	3.4	3.1	L**Q**	3.7b

^zSignificant K rate effects were linear (L) or quadratic (Q) at the 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

^xRatings were 1 to 5 with 1 being blotch free.

least amount of IB in the fall and 'Flora-Dade' had the most. Internal blotchy ripening was significantly greater during the spring than fall for each cultivar. Increasing K rate reduced IB to a greater extent in the spring than fall for each cultivar except 'Flora-Dade'.

White tissue associated with the outer pericarp and placental regions was the predominant form of IB which occurred during both seasons. This hard white tissue extended outward from the outer pericarp to the skin in those fruits severely affected with yellow shoulder EB. In those fruits appearing normally red from the outside but having a white outer pericarp on the inside, several layers of red cells were found adjacent to the skin. Strands of necrotic brown tissue interspersed within the white tissue of the outer pericarp were noticeable in severe cases of IB.

Fruit having an IB rating above 3.0 were considered to have an objectionable interior color but still edible, while fruit having a rating above 4.0 were considered inedible. On this basis 'Flora-Dade' fruit were objectionable at all K rates during both seasons and during the spring were inedible at all rates except 745-K. This cultivar has been reported to yield well and produces very firm fruit which is conducive to long distance transport, but the interior color under the experimental conditions was inferior to other cultivars. 'Healani', 'Homestead-24', and 'Walter' produced good interior color fruit at 93-K or greater in the fall and in the spring at 186-K for 'Healani', 372-K for 'Walter', and 745-K for 'Homestead-24'.

Fruits free of EB were found to have a range of IB symptoms from none to relatively severe. Fruits exhibiting severe yellow shoulder

EB always had very severe IB symptoms. There was never any fruit found that had EB but was free of IB. For any fruit, IB symptoms were equal to or greater than EB symptoms. It was imperative to cut open the fruits in evaluating for BR because EB was not always an accurate indication of the amount of IB, as was noticed with 'Flora-Dade'.

The reduction in IB during the fall compared to the spring season may be attributed to the differing environmental conditions during the maturation and ripening processes as previously discussed. Considering the overall results, 'Flora-Dade' was the most susceptible cultivar to BR, 'Healani' the most resistant, and 'Walter' and 'Homestead-24' were intermediate, with 'Walter' having slightly more resistance than 'Homestead-24'.

Influence of Potassium, Cultivar, and Season
on Leaf Potassium Content

During both seasons and within each cultivar there was significantly more %K in the leaf tissue with increasing K fertility (Table 11). Leaf K content increased quadratically with increasing K rate for all cultivars during both seasons. The significant Pot.QxSeas. interaction (Appendix Table 5) indicated the quadratic response of increasing leaf K with increasing K rate was different between seasons. Also the significant Seas.xCult. interaction indicated the cultivar response between seasons differed. No significant difference in leaf K content was found between any of the cultivars during the spring. Leaf K content averaged over all K rates in the fall showed 'Flora-Dade' and 'Walter' to have less K than 'Homestead-24'. No difference in average leaf K was noticed between 'Flora-Dade' and

Table 11. Potassium content (% dry weight) of leaves of spring and fall 1979 field grown tomatoes from four cultivars grown under five soil potassium levels.

Cultivar	Season	K rate (Kg/ha)					F ^z	Mean ^y
		0	93	186	372	745		
	Spring		<u>% leaf K</u>					
'Healani'		.31	.56	.86	1.21	2.01	L**Q**	.99d
'Homestead-24'		.30	.54	.74	1.28	1.92	L**Q**	.96d
'Walter'		.31	.65	.83	1.18	1.95	L**Q*	.98d
'Flora-Dade'		.34	.63	.75	1.13	1.80	L**Q*	.93d
	Fall							
'Healani'		.25	.90	1.20	1.98	2.24	L**Q**	1.31ab
'Homestead-24'		.29	1.04	1.30	2.04	2.18	L**Q**	1.37a
'Walter'		.26	.78	1.37	1.88	1.94	L**Q**	1.25bc
'Flora-Dade'		.28	.83	1.11	1.86	1.96	L**Q**	1.21c

^zSignificant K rate effects were linear (L) or quadratic (Q) at the 5% (*) or 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

'Walter', 'Walter' and 'Healani', and 'Healani' and 'Homestead-24'. During the fall no single cultivar showed consistently lowest or highest %K values at all K rates. Average leaf K content was significantly greater during the fall than spring for each cultivar; however, at the 0-K level all cultivars had slightly less leaf K in the fall than spring. The greater leaf K content in the fall compared to the spring was most evident at 93-K, 186-K, and 372-K.

Influence of Potassium, Cultivar, and Season
on Pericarp Potassium Content

During both seasons and within each cultivar there was significantly more %K in the fruit pericarp tissue with increasing K fertility (Table 12). Pericarp K content increased quadratically with increasing K rate for all cultivars during both seasons. No large differences in pericarp K at any K rate were observed between cultivars or seasons. Pericarp K contents averaged over all K rates revealed no cultivar differences during both seasons (Appendix Table 6). No seasonal difference in pericarp K was found with 'Homestead-24', 'Walter', and 'Flora-Dade'. 'Healani' had a slightly less pericarp K content in the spring than fall.

The largest increase in pericarp K per applied K increment occurred between 0-K to 93-K. This was observed in all four cultivars during both seasons. The range in pericarp K content from 0-K to 745-K was slightly greater during the fall season than the spring for each cultivar.

Influence of Potassium, Cultivar, and Season on
Pericarp Calcium, Magnesium, and Phosphorus Content

There was no significant difference in pericarp Ca content with increasing K rate (Table 13). 'Healani' had the lowest pericarp

Table 12. Potassium content (% dry weight) of fruit pericarps of spring and fall 1979 field grown tomatoes from four cultivars grown under five soil potassium levels.

Cultivar	Season	<u>K rate (Kg/ha)</u>					F value ^z	Mean ^y
		0	93	186	372	745		
	Spring	<u>% pericarp K</u>						
'Healani'		1.62	2.09	2.33	2.54	2.66	L**Q**	2.25c
'Homestead-24'		1.64	2.19	2.48	2.58	2.76	L**Q**	2.33bc
'Walter'		1.58	2.21	2.51	2.67	2.78	L**Q**	2.35ab
'Flora-Dade'		1.65	2.18	2.46	2.66	2.84	L**Q**	2.36ab
	Fall							
'Healani'		1.69	2.25	2.49	2.75	2.95	L**Q**	2.43a
'Homestead-24'		1.64	2.27	2.47	2.70	2.99	L**Q**	2.41ab
'Walter'		1.70	2.17	2.45	2.74	3.01	L**Q**	2.41ab
'Flora-Dade'		1.52	2.11	2.42	2.69	2.96	L**Q**	2.34abc

^zSignificant K rate effects were linear (L) or quadratic (Q) at the 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

Table 13. Calcium content (% dry weight) of fruit pericarps of spring and fall 1979 field grown tomatoes from four cultivars grown under five soil potassium levels.

Cultivar	Season	<u>K rate (Kg/ha)</u>					F value ^z	Mean ^y
		0	93	186	372	745		
	Spring			<u>% Ca</u>				
'Healani'		.08	.07	.07	.07	.08	n.s.	.07e
'Homestead-24'		.13	.12	.12	.12	.13	n.s.	.12d
'Walter'		.11	.11	.11	.12	.12	n.s.	.11d
'Flora-Dade'		.13	.14	.15	.14	.14	n.s.	.14c
	Fall							
'Healani'		.11	.13	.13	.12	.11	n.s.	.12d
'Homestead-24'		.14	.15	.14	.14	.15	n.s.	.14c
'Walter'		.17	.17	.15	.15	.17	n.s.	.16b
'Flora-Dade'		.18	.17	.19	.17	.18	n.s.	.18a

^zK rate effects were not significant (n.s.) at the 5% level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

Ca content and 'Flora-Dade' the highest during both seasons. Each cultivar contained more pericarp Ca in the fall than spring at each K rate.

During the spring each cultivar increased slightly in pericarp Mg content with increasing K rate (Table 14). During the fall no increase in pericarp Mg was found in any cultivar with increasing K rate. During both seasons 'Healani' had the lowest pericarp Mg content. No difference was found between 'Homestead-24', 'Walter', and 'Flora-Dade' during either season. Each cultivar contained more pericarp Mg during the fall than the spring season.

Pericarp P content did not significantly differ between K rates for any cultivar or season (Table 15). During both seasons 'Healani' had the lowest pericarp P content. No difference was found between 'Homestead-24', 'Walter', and 'Flora-Dade' during either season. Each cultivar contained more pericarp P in the fall than spring.

Influence of Potassium, Cultivar, and Season on Bacterially Induced Graywall Development

During the spring season with each cultivar there was significantly less GW with increasing K fertility (Table 16). The type of decreasing GW response varied with each cultivar and ranged from linear with 'Walter', quadratic with 'Healani', and cubic with 'Homestead-24' and 'Flora-Dade'. During the fall only 'Flora-Dade' decreased linearly with increasing K rate. While the response was not significant, 'Homestead-24' had slightly more GW at 0-K compared to the higher K rates. 'Healani' and 'Walter' did not show any trend of decreasing GW with increasing K rate during the fall. 'Flora-Dade' was the most GW resistant cultivar during the spring.

Table 14. Magnesium content (% dry weight) of fruit pericarps of spring and fall 1979 field grown tomatoes from four cultivars grown under five soil potassium levels.

Cultivar	Season	K rate (Kg/ha)					F value ^z	Mean ^y
		0	93	186	372	745		
	Spring		<u>% Mg</u>					
'Healani'		.08	.09	.09	.09	.09	L*	.09d
'Homestead-24'		.11	.12	.12	.12	.12	L**	.12c
'Walter'		.11	.11	.11	.13	.12	L**Q**C**	.12c
'Flora-Dade'		.11	.12	.14	.13	.14	L*	.13c
	Fall							
'Healani'		.14	.14	.14	.13	.14	n.s.	.14b
'Homestead-24'		.17	.16	.15	.16	.18	n.s.	.16a
'Walter'		.18	.16	.17	.15	.18	n.s.	.17a
'Flora-Dade'		.15	.15	.17	.15	.17	n.s.	.16a

^zSignificant K rate effects were linear (L), quadratic (Q), cubic (C), or not significant (n.s.) at the 5% (*) or 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

Table 15. Phosphorus content (% dry weight) of fruit pericarps of spring and fall 1979 field grown tomatoes from four cultivars grown under five soil potassium levels.

Cultivar	Season	<u>K rate (Kg/ha)</u>					F value ^z	Mean ^y
		0	93	186	372	745		
	Spring			<u>% P</u>				
'Healani'		.40	.39	.39	.39	.38	n.s.	.39d
'Homestead-24'		.43	.46	.46	.44	.44	n.s.	.45b
'Walter'		.46	.43	.45	.46	.45	n.s.	.45b
'Flora-Dade'		.45	.47	.45	.49	.46	n.s.	.46b
	Fall							
'Healani'		.41	.42	.43	.41	.43	n.s.	.42c
'Homestead-24'		.49	.48	.49	.48	.48	n.s.	.48a
'Walter'		.49	.49	.51	.50	.51	n.s.	.50a
'Flora-Dade'		.52	.50	.53	.50	.50	n.s.	.51a

^zK rate effects were not significant (n.s.) at the 5% level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

Table 16. Rating of bacterially induced graywall of spring and fall field grown tomatoes from four cultivars grown under five soil potassium levels.

Cultivar	Season	K rate (Kg/ha)					F ^z	Mean ^y _x
		0	93	186	372	745		
'Healani'	Spring	2.5	0.9	0.9	0.5	0.5	L**Q**	1.1c
	Fall	2.4	2.7	2.3	2.4	2.3	n.s.	2.4a
'Homestead-24'	Spring	1.7	0.7	0.6	0.5	0.3	L**Q**	0.8d
	Fall	1.0	0.6	0.7	0.6	0.6	n.s.	0.7de
'Walter'	Spring	3.0	1.3	0.8	0.9	0.8	L*	1.3c
	Fall	1.9	1.6	1.9	2.1	1.8	n.s.	1.9b
'Flora-Dade'	Spring	0.6	0.5	0.7	0.3	0.3	L**C**	0.5e
	Fall	0.7	0.6	0.3	0.3	0.2	L**	0.4c

^zSignificant K rate effects were linear (L), quadratic (Q), cubic (C) or not significant (n.s.) at the 5% (*) or 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

^xRatings were 0 to 5 with 0 being graywall free.

'Homestead-24' was the second most resistant cultivar. 'Healani' and 'Walter' were the most GW susceptible cultivars. During the fall 'Flora-Dade' and 'Homestead-24' were the most GW resistant cultivars and 'Healani' and 'Walter' were the most susceptible. The most dramatic reduction in GW development during the spring occurred between the increment of 0-K to 93-K with all cultivars except 'Flora-Dade'. Graywall development averaged over all K rates indicated no seasonal difference with 'Flora-Dade' and 'Homestead-24'. Both 'Healani' and 'Walter' had more GW during the fall than spring and this was evident at all K rates except 0-K.

Symptoms of GW induced by bacteria were identical to those previously published. No fruit tissue discoloration was observed after inoculation with bacteria free sterile saline solution.

Influence of Potassium and Cultivar on Bacterially
Induced Graywall Development of Greenhouse Grown Tomatoes

The amount of bacterially induced GW differed between cultivars and between K treatments in a fall 1979 greenhouse experiment (Table 17). Fruits from 'Homestead-24' and 'Flora-Dade' developed more GW with the low K treatment than with the high K treatment. No difference in GW incidence was noted between the low and high K treatments for 'Healani' and 'Walter'. Under both K regimes 'Flora-Dade' and 'Homestead-24' were the most GW resistant cultivars while 'Healani' and 'Walter' were the most GW susceptible cultivars.

Influence of Storage Temperature on Bacterially Induced
Graywall Development

Results from several non-replicated fall experiments show that the amount of GW development is dependent on the length of chilling at

Table 17. Rating of bacterially induced graywall in fall greenhouse grown tomatoes under high and low potassium treatments.

Cultivar	<u>K treatment</u> ²	
	High K	Low K
'Healani'	2.2a	2.1a
'Homestead-24'	0.2c	0.8b
'Walter'	2.1a	2.1a
'Flora-Dade'	0.2c	0.8b

²Mean separation by Duncan's multiple range test at the 5% level.

4°C. Comparisons of data in Tables 16 and 18 and in Tables 17 and 19 reveal that GW develops to a greater extent with longer chilling times. Exposing the inoculated fruit to one day or no days at 4°C resulted in slightly less GW incidence with increasing K rate for all cultivars. In the fall field experiment, one day of chilling appeared to result in decreasing GW with increasing K rate for all cultivars (Table 18). During the fall greenhouse study, elimination of the chilling period resulted in slightly more GW developing with the low K treatment compared to the high K treatment for each cultivar (Table 19).

Influence of Potassium and Cultivar on Natural Graywall Development

The only experiment in which tomato fruit developed natural GW on the plant (contrasted to laboratory bacterially induced GW) occurred during a winter greenhouse study. The results show a differential K level and cultivar response (Table 20). No GW was found in any cultivar grown with the optimum 1K treatment. With the reduced K treatments of 1/10K, -K, and H₂O a large percentage of the fruits from 'Healani' and 'Homestead-24' developed GW. No difference in natural GW incidence was found between the 1/10K, -K, and H₂O treatments within either cultivar. With these reduced K treatments 'Healani' appeared to have a slightly higher % of fruits affected with GW than 'Homestead-24'. 'Flora-Dade' was completely resistant to GW even with the reduced K treatments.

Influence of Potassium, Cultivar, and Season on Pericarp Soluble Solids

During the spring each cultivar except Flora-Dade had significantly higher pericarp soluble solids (SS) content when grown at 745-K

Table 18. Rating of bacterially induced graywall resulting from one day of chilling at 4°C followed by six days of storage at 20°C. Fall field experiment.

Cultivar	<u>K rate (Kg/ha)</u>				
	0	93	186	372	745
'Healani'	0.9	0.8	0.8	0.6	0.4
'Homestead-24'	0.1	0.0	0.0	0.0	0.0
'Walter'	0.4	0.2	0.2	0.0	0.0
'Flora-Dade'	0.1	0.0	0.0	0.0	0.0

^zValues represent the mean of 8 fruits.

^yRatings were 0 to 5 with 0 being graywall free.

Table 19. Rating of bacterially induced graywall after five days at 20°C without any previous chilling exposure. Fall greenhouse experiment.

Cultivar	<u>Treatment</u> ^{zy}	
	High K	Low K
'Healani'	0.3	0.5
'Homestead-24'	0.0	0.2
'Walter'	0.3	0.4
'Flora-Dade'	0.0	0.1

^zValues represent the mean of 8 fruits.

^yRatings were 0 to 5 with 0 being graywall free.

Table 20. Percentage of fruits showing natural graywall symptoms from fall-winter greenhouse grown tomatoes under four different potassium treatments.

Cultivar	<u>Treatment^z</u>			
	1K	1/10L	-K	H ₂ O
'Healani'	0	58	52	55
'Homestead-24'	0	42	36	35
'Flora-Dade'	0	0	0	0

^zValues represent the average of 50 to 60 fruit.

compared to 0-K (Table 21). The increasing SS response with increasing K rate was highly variable between cultivars. 'Healani' responded in a cubic fashion, 'Homestead-24' quadratically, and 'Walter' linearly. The greatest increase in SS occurred between the 0-K to 93-K increment with 'Healani' and 'Walter'. Very little or no change in SS occurred between 186-K and 745-K for any cultivar in the spring. 'Healani' had the highest SS and 'Flora-Dade' had the lowest SS at all soil K rates. No difference in SS was apparent between the two intermediate cultivars of 'Homestead-24' and 'Walter'.

During the fall both 'Healani' and 'Flora-Dade' had higher SS at 745-K compared to 0-K. No significant change in SS occurred with increasing K rate for 'Homestead-24' or 'Walter'. At all K rates 'Healani' contained the highest SS and 'Flora-Dade' had the lowest SS. 'Walter' had the second highest SS.

'Healani' and 'Flora-Dade' generally had higher SS during the spring than fall. No seasonal difference was apparent within either 'Homestead-24' or 'Walter'.

Influence of Potassium, Cultivar, and Season on Pericarp Acidity

During both seasons and within each cultivar there was a significant increase in pericarp acidity with increasing K rate (Table 22). All cultivars during both seasons increased in acidity quadratically.

During the spring season there was no difference in acidity between 'Healani' and 'Homestead-24' or between 'Walter' and 'Flora-Dade'. Both 'Walter' and 'Flora-Dade' contained a slightly higher acid content than 'Healani' and 'Homestead-24'. During the fall

Table 21. Pericarp % soluble solids of spring and fall field grown tomatoes from four cultivars under five soil potassium levels.

Cultivar	Season	K rate (Kg/ha)					F ^z	Mean ^y
		0	93	186	372	745		
'Healani'	Spring	4.9	5.3	5.4	5.4	5.5	L**Q**C*	5.3a
	Fall	4.9	5.0	5.1	5.1	5.1	L**Q*	5.0b
'Homestead-24'	Spring	4.5	4.6	4.8	4.8	4.8	L**Q*	4.7d
	Fall	4.7	4.7	4.7	4.8	4.7	n.s.	4.7d
'Walter'	Spring	4.6	4.8	4.9	4.9	4.9	L*	4.8cd
	Fall	4.8	4.9	4.8	5.0	4.9	n.s.	4.9c
'Flora-Dade'	Spring	3.9	4.1	4.1	4.0	4.1	n.s.	4.0e
	Fall	3.8	3.8	3.9	3.9	4.1	L*	3.9f

^zSignificant K rate effects were linear (L), quadratic (Q), cubic (C), or not significant (n.s.) at the 5% (*) or 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

Table 22. Pericarp % acidity of spring and fall field grown tomatoes from four cultivars under five soil potassium levels.

Cultivar	Season	K rate (Kg/ha)					F ^z	Mean ^y
		0	93	186	372	745		
'Healani'	Spring	.19	.22	.23	.26	.29	L**Q**	.24e
	Fall	.25	.27	.30	.33	.34	L**Q**	.30c
'Homestead-24'	Spring	.16	.21	.24	.26	.29	L**Q**	.23e
	Fall	.25	.28	.31	.35	.35	L**Q**	.31bc
'Walter'	Spring	.18	.24	.27	.30	.31	L**Q**	.26d
	Fall	.30	.32	.34	.36	.40	L**Q**	.34a
'Flora-Dade'	Spring	.21	.25	.26	.28	.30	L**Q**	.26d
	Fall	.26	.30	.33	.33	.36	L**Q*	.32b

^zSignificant K rate effects were linear (L) or quadratic (Q) at the 5% (*) or 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

season there was no difference in acidity between 'Healani' and 'Homestead-24' or between 'Homestead-24' and 'Flora-Dade'. 'Walter' had the highest acidity.

Acidity was greater in fall than in the spring for all cultivars at each K rate.

Influence of Potassium, Cultivar, and Season on Pericarp pH

During the spring season the pericarp pH of each cultivar decreased significantly with increasing K rate (Table 23). The response was linear with 'Healani' and 'Homestead-24', quadratic with 'Flora-Dade', and cubic with 'Walter'. 'Healani' had the highest pH and 'Flora-Dade' had the lowest at all K rates. There was no pH difference between 'Homestead-24' and 'Walter'.

During the fall season no cultivar showed a significant change in pericarp pH with increasing K rate. 'Healani' had the highest pH and 'Flora-Dade' had the lowest at all K rates. 'Walter' had the second highest pH values which were significantly greater than 'Homestead-24'.

For all four cultivars, pericarp pH was higher in the spring than in the fall. Locule pH was also determined and results (not shown) were in agreement with those found for pericarp pH. However, locule pH was about 0.1 unit less (more acidic) than pericarp pH for each cultivar.

Influence of Potassium, Cultivar, and Season on Pericarp Reducing Sugars

During the spring season all cultivars except 'Flora-Dade' had an increase in pericarp reducing sugars with increasing K rate (Table 24). At all K rates, 'Healani' had the highest reducing sugar content

Table 23. Pericarp pH of spring and fall field grown tomatoes from four cultivars under five soil potassium levels.

Cultivar	Season	K rate (Kg/ha)					F ^z	Mean ^y
		0	93	186	372	745		
'Healani'	Spring	4.63	4.62	4.61	4.58	4.56	L**	4.60a
	Fall	4.52	4.53	4.53	4.49	4.51	n.s.	4.52b
'Homestead-24'	Spring	4.57	4.55	4.55	4.49	4.48	L**	4.53b
	Fall	4.41	4.44	4.46	4.44	4.45	n.s.	4.44d
'Walter'	Spring	4.56	4.55	4.54	4.48	4.47	L**Q*C*	4.52b
	Fall	4.44	4.47	4.51	4.49	4.46	n.s.	4.47c
'Flora-Dade'	Spring	4.42	4.38	4.37	4.33	4.32	L**Q*	4.36e
	Fall	4.32	4.29	4.30	4.32	4.34	n.s.	4.31f

^zSignificant K rate effects were linear (L), quadratic (Q), cubic (C), or not significant (n.s.) at the 5% (*) or 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

Table 24. Pericarp % reducing sugars of spring and fall field grown tomatoes from four cultivars under five soil potassium levels.

Cultivar	Season	K rate (Kg/ha)					F ^z	Mean ^y
		0	93	186	372	745		
'Healani'	Spring	4.53	4.61	4.74	4.80	4.86	L**Q*	4.71a
	Fall	3.57	3.64	3.66	3.72	3.69	n.s.	3.66d
'Homestead-24'	Spring	3.90	3.99	4.04	4.04	4.11	L**Q**C**	4.02c
	Fall	3.51	3.31	3.48	3.44	3.33	n.s.	3.41f
'Walter'	Spring	4.17	4.21	4.27	4.29	4.26	L*Q*	4.24b
	Fall	3.15	3.24	3.08	3.16	3.03	n.s.	3.13g
'Flora-Dade'	Spring	3.51	3.53	3.48	3.56	3.42	n.s.	3.50e
	Fall	2.61	2.44	2.59	2.61	2.46	n.s.	2.54h

^zSignificant K rate effects were linear (L), quadratic (Q), cubic (C), or not significant (n.s.) at the 5% (*) or 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

and 'Flora-Dade' had the lowest. 'Walter' had the second highest reducing sugar content.

During the fall season no cultivar showed a significant change in reducing sugar content with increasing K rate. Variability between levels was very high. With all K rates, 'Healani' had the highest reducing sugar content and 'Flora-Dade' had the lowest. 'Homestead-24' had a significantly higher reducing sugar content than 'Walter'.

Each cultivar had a significantly higher reducing sugar content in the spring at each K rate than in the fall. Differences between cultivars and between seasons were much larger than differences between K rates.

Influence of Potassium, Cultivar, and Season on Pericarp Dry Weight

'Healani' was the only cultivar whose pericarp dry weight increased significantly with increasing K rate for each season (Table 25). Pericarp dry weight of 'Walter' increased with increasing K rate only during the fall. 'Homestead-24' and 'Flora-Dade' had no significant change in dry weight with increasing K rate in either season. During both seasons and at each K rate, 'Healani' had the highest dry weight and 'Flora-Dade' had the lowest. No significant difference in dry weight was observed during either season between 'Homestead-24' and 'Walter'. All cultivars had a significantly higher dry weight content during the spring compared to the fall season.

Ethylene Evolution and Oxygen Consumption Rates of Blotchy Versus Red Tissue

Ethylene evolution was significantly greater in the yellow tissue compared to the red tissue (Table 26). This was consistently true

Table 25. Pericarp % dry weight of spring and fall field grown tomatoes from four cultivars under five soil potassium levels.

Cultivar	Season	K rate (Kg/ha)					F ^z	Mean ^y
		0	93	186	372	745		
'Healani'	Spring	5.94	6.09	6.01	6.12	6.16	L*	6.06a
	Fall	5.35	5.42	5.50	5.76	5.77	L**Q*	5.56b
'Homestead'	Spring	5.55	5.56	5.65	5.69	5.65	n.s.	5.62b
	Fall	5.10	5.24	5.22	5.28	5.10	n.s.	5.19cd
'Walter'	Spring	5.66	5.71	5.61	5.59	5.63	n.s.	5.64b
	Fall	5.17	5.28	5.28	5.28	5.33	L*	5.27c
'Flora-Dade'	Spring	5.13	5.22	5.11	5.09	5.14	n.s.	5.14d
	Fall	4.51	4.52	4.55	4.60	4.61	n.s.	4.56e

^zSignificant K rate effects were linear (L), quadratic (Q), or not significant (n.s.) at the 5% (*) or 1% (**) level within cultivars and seasons.

^yMean separation between cultivars by Duncan's multiple range test at the 5% level.

Table 26. Ethylene evolution rates of yellow (blotchy) versus red outer pericarp tissue.

Cultivar	Season	Ethylene evolution (ul C ₂ H ₄ /kg fresh weight/hr) ^z	
		Yellow tissue	Red tissue
'Homestead-24'	Summer 1979	11.4	5.0
	Fall 1979	15.4	7.2
	Summer 1980	11.1	7.7
'Walter'	Summer 1979	16.3	8.4
	Fall 1979	8.9	5.3
	Summer 1980	9.8	6.3
'Flora-Dade'	Summer 1979	7.4	4.4
	Fall 1979	10.2	3.7
	Summer 1980	7.0	3.4

^zC₂H₄ evolution was significantly greater in the yellow tissue than red tissue for all cultivars and seasons as determined by the Student's t-test at the 1% level.

with three different cultivars during several different growing seasons. The yellow tissue produced about twice as much ethylene as the red tissue. This was true on both a fresh weight and dry weight basis. Results in Table 26 are expressed on a fresh weight basis. Ethylene measurements from green tissue were always less than one ul/kg/hr.

Respiration rate, as measured by O_2 consumption, was also significantly greater in the yellow tissue compared to the red (Table 27). This was true on both a fresh and dry weight basis. Results in Table 27 are expressed on a fresh weight basis.

Table 27. Oxygen consumption rates of yellow (blotchy) versus red outer pericarp tissue.

Cultivar	Oxygen consumption (ul O ₂ /g fresh weight/hr) ^z	
	Yellow tissue	Red tissue
'Flora-Dade'	55.3	28.7

^zO₂ consumption was significantly greater in the yellow tissue than red tissue for all cultivars and seasons as determined by the Student's t-test at the 1% level.

DISCUSSION

Blotchy Ripening

An initial experiment was conducted to determine the effects of various K treatments on BR of greenhouse grown tomatoes. No difference in BR was found between the 1/10K, -K, and H₂O treatments for any cultivar, indicating that K is the most important nutrient regulating BR. If other nutrients had an effect, more BR would have occurred with the H₂O treatment which lacked all nutrients (except Ca). The results indicate that a high K supply is needed during the fruiting stage since all plants had high K during vegetative growth.

Differential cultivar susceptibility to BR was apparent. 'Flora-Dade' was the most blotch susceptible cultivar with all K treatments. 'Healani' was the most blotch resistant with the optimum 1K treatment, but was not significantly different from 'Homestead-24' with the reduced K treatments.

The statistical differences between the mean EB ratings (Table 5) of 'Homestead-24' versus 'Walter' and 'Flora-Dade' in the spring and between 'Walter' versus 'Homestead-24' and 'Flora-Dade' in the fall are too small to be of practical significance. This statistical difference can be attributed to the large number of fruit sampled (120 per K rate) and to the low coefficient of variation (2.6). 'Healani' was the only cultivar that showed a high degree of EB resistance and any future researchers attempting to reduce EB by a breeding program should certainly consider using 'Healani' as a source of resistance.

Fruit having a rating over 3.0 were considered unmarketable but even at the O-K level, 'Healani' fruit were marketable. During the spring the other three cultivars needed applications of at least 186-K (372-K for 'Homestead-24') to produce marketable fruit.

The drastic reduction in EB, IB, and lack of yellow shoulder during the fall compared to the spring can be attributed to the different environmental conditions between seasons. As the fruits were maturing and ripening during the spring season, the temperature was getting hotter (Table 2), the days were getting longer, the relative humidity was increasing, and more daily afternoon showers occurred. During the fall season, as the fruits matured and ripened, the temperature was getting cooler, the days were getting shorter, the relative humidity was decreasing, and fewer daily afternoon showers occurred. The results agree with Lipton (1970) who found more yellow shoulder development under high relative humidity (70-100%) than low relative humidity (50-90%). It is impossible to conclude any specific environmental cause and effect relationship on BR but certainly all these environmental factors must be considered along with cultivar and K rate to influence the degree of BR. Yellow shoulder symptoms may be associated with a lack of the uniform ripening gene. Venter (1965) found that dark green shoulder varieties had a higher fruit temperature near the calyx and were more susceptible to yellow shoulder than light green varieties. 'Healani', free from yellow shoulder, has the uniform ripening gene whereas the other three yellow shoulder susceptible cultivars lack this gene.

Tissue Analyses

Leaf K content was analyzed to determine whether there was a direct association between BR and leaf K. In each season and cultivar, BR decreased with increasing leaf K. However, leaf K content was not directly related to differential BR susceptibility between cultivars. During the spring, no obvious cultivar differences in leaf K were noted at any one K rate, whereas significant differences in cultivar BR were observed. If leaf K content was directly responsible for determining the degree of BR, then at any given K rate 'Flora-Dade', the most blotch susceptible cultivar, should have had the least leaf K and 'Healani', the most blotch resistant cultivar, should have had the highest leaf K content. This was not found. The differential susceptibility between cultivars to BR was not associated with differential leaf K contents between cultivars during either season. Also, BR was much greater for each cultivar during the spring than fall at the 0-K rate, but leaf K content was not higher in the spring than fall for any cultivar. The other soil K rates resulted in a higher leaf K content during the fall than spring.

Pericarp K content was measured to determine the relationship between fruit K content and fruit BR. If there is a direct association between fruit K content and BR then fruit pericarp analyses should provide a better measure of the role of K than leaf measurements.

Blotchy ripening decreased with increasing pericarp K for all cultivars during both seasons. However, as was found to be true with leaf K, no direct relationship was observed between pericarp K content and differential susceptibility to BR between cultivars. During both seasons no large cultivar differences in pericarp K content were

apparent at any given K rate while large differences in cultivar BR were recorded. If pericarp K content was solely responsible for regulating the amount of BR, then on the basis of the results for pericarp K content no noticeable differences in BR should have been observed between cultivars at any given K rate. Conversely, if pericarp K was directly responsible for determining the degree of BR, then at any given K rate 'Flora-Dade' should have had the least pericarp K content and 'Healani' the most. This also was not found. Blotchy ripening was greater during the spring than fall for each cultivar while no noticeable differences in pericarp K content between seasons were recorded.

Pericarp Ca, Mg, and P were analyzed to determine whether they were correlated with differential BR susceptibility between cultivars. No correlation between BR susceptibility and pericarp content of any of these elements was found. While BR decreased with increasing K rate, pericarp Ca and P did not change for any cultivar during either season. Pericarp Mg content slightly increased only during the spring with increasing K rate. Differences between cultivars in pericarp Ca, Mg, and P content were minimal and no differences in pericarp content of any of these elements was found which would explain differences in cultivar susceptibility to BR.

Leaf Ca, Mg, and P contents (data not shown) were also determined for each cultivar and season. Both Ca and Mg contents decreased with increasing K rate. This K-Ca and K-Mg cation antagonistic relationship was observed for all cultivars. There was no significant difference in P content with increasing K rate for any cultivar during either season. Differences between cultivars in leaf Ca, Mg, and P

content were minimal and no differences in leaf content of any of these elements was found which would explain differences in cultivar susceptibility to BR.

In general, leaf K and pericarp Ca, Mg, and P concentrations were similar to those previously reported by Geraldson (1963). Pericarp K concentrations were lower than found by Geraldson.

Graywall

'Flora-Dade' was the only cultivar which showed a decrease in GW development with increasing K rate over both seasons. 'Healani', 'Homestead-24', and 'Walter' all showed a decrease in GW with increasing K rate during the spring but not during the fall. Differing environmental conditions between spring and fall may have differentially influenced the GW-K response within these three cultivars. Potassium nutrition played an important role in reducing GW in the spring but was less effective in the fall especially with the most susceptible cultivars.

Results of the fall greenhouse experiment closely resemble the fall field results. 'Healani' and 'Walter' were the most GW susceptible cultivars in both fall experiments and no GW-K relationship was found with either cultivar. 'Flora-Dade' and 'Homestead-24' were the most GW resistant cultivars. In both fall experiments 'Flora-Dade' decreased in GW incidence with increasing K nutrition while 'Homestead-24' showed this response more noticeably in the greenhouse than field. There was a marked difference in GW development between the two resistant cultivars of 'Flora-Dade' and 'Homestead-24' compared to the susceptible cultivars of 'Healani' and 'Walter' in both experiments.

The relationship between GW development and K nutrition during the fall season with 'Healani' and 'Walter' appeared to be dependent on the length of time the fruits were exposed to chilling. The reduced chilling times showed a decrease in GW with increasing K for 'Healani' and 'Walter' (Tables 18 and 19). The four day chilling period showed no difference in GW with increasing K for 'Healani' and 'Walter' (Tables 16 and 17). Possibly the tissue resistance that developed under high K rates was overcome when 'Healani' and 'Walter' fruits were held for four to six days at 4°C. Therefore no GW-K response was found. When these fruits were not chilled or chilled for only one day this tissue resistance that developed under high K was not overcome and a GW-K response was found. Chilling for four to six days generally did not overcome the high K resistance with 'Homestead-24' and 'Flora-Dade'. These cultivars may contain a stronger bacteriostatic or bacteriocidal factor inside the fruit. In both reduced chilling experiments the actual amount of GW development was very minimal, even under the low K rates.

Natural GW incidence was found to be influenced by both cultivar and K nutrition. 'Flora-Dade' had complete resistance to natural GW under all K treatments while 'Healani' and 'Homestead-24' had resistance only under the 1K level. No large difference in GW incidence was found between the 1/10K, -K, and H₂O treatments. This indicates that low K is a primary nutrient related to GW susceptibility. If other nutrients were directly responsible for GW development, then more GW should have occurred under the H₂O treatment compared to the other treatments. This was not found.

During several weeks in January night temperatures dropped well below the chilling range of 12.5°C. Temperatures as low as 2°C were recorded on several nights. This may have caused chilling injury which rendered the fruit more susceptible to GW. Previous workers have shown the importance of chilling temperatures in storage on subsequent GW development (Hall and Stall, 1967; Stall and Hall, 1968, 1969). Fruit from the optimum 1K treatment may not have been as susceptible to chilling induced GW as compared to the reduced K treatments.

The results from the GW experiments reveal that 'Flora-Dade' was the most resistant cultivar while 'Healani' and 'Walter' were the most GW susceptible. In general, reduced K nutrition resulted in more GW development.

Results from the BR and GW experiments showed that 'Healani' was BR resistant but GW susceptible whereas 'Flora-Dade' was BR susceptible but GW resistant.

Fruit Quality

Fruit quality comparisons between cultivars, as determined by SS, indicated that 'Healani' had the best quality while 'Flora-Dade' had the poorest quality. 'Healani' and 'Flora-Dade' fruit grown during the spring were higher in SS quality than the fall. In general, the lowest quality fruit were obtained under the 0-K level. Locule SS content (data not shown) was about the same as found in the pericarp. This was true for all cultivars during both seasons. Lower and Thompson (1967) also reported this similarity between pericarp and locule SS.

A consistent relationship of increasing pericarp acidity with increasing K rate existed for all cultivars during both seasons. These results agree with those of previous workers who also found increasing K rates to be counterbalanced by an increase in tissue organic acid anions and concomitant acidity (Lee and Sayre, 1946; Hester, 1951, Carangal et al. 1954; Bradley, 1962; Davies, 1964; Davies and Winsor, 1967; and Adams et al. 1973).

Results over both seasons indicated that 'Healani' and 'Homestead-24' had the lowest pericarp acidity while 'Walter' was the cultivar having the highest acidity. Acidity differences between cultivars were not very large. Acidity for all cultivars was higher during the fall than spring. Similar results were obtained by Dennison et al. (1952) who reported that fruit grown during the cooler months had a higher acid content compared to fruit produced during warmer months.

Locule acidity was also determined and results (not shown) were consistent with those obtained for pericarp acidity. The only difference was that locule acidity was about 1.5 to 2 times greater than pericarp acidity. This difference was also reported by Lower and Thompson (1967) and Anderson (1957) who both found the locular jelly tissue to have the highest acid content and the outer pericarp tissue to have the lowest acid content.

Although the type of response varied between seasons and cultivars, increasing K rate resulted in a decrease in pericarp pH for all cultivars during the spring. This corresponds well with the increase in acidity also observed (Table 22). During the fall no cultivar showed a K rate-pericarp pH response even though all cultivars

increased in acidity with increasing K rate. This lack of correlation between pH and acidity is difficult to explain. Both pH and acidity are measures of acid content and they are generally highly correlated. However, the relationship between these factors is not always good. Anderson (1957) found pH and titratable acidity were not always inversely related. Lower and Thompson (1967) also reported a poor correlation between pH and titratable acidity in certain tomato lines.

Results over both seasons indicated that 'Healani' was the cultivar having the highest pH while 'Flora-Dade' had the lowest pH. A direct association between cultivar acidity and cultivar pH was not apparent. Pericarp pH for all cultivars was lower during the fall than spring and this was associated with a higher acid content during the fall than spring season.

The effect of K rate on reducing sugar content was influenced by environment and cultivar. Increasing K rate resulted in an increase in reducing sugar content only during the spring, but not for all cultivars. Based on reducing sugar content, 'Healani' had the best quality and 'Flora-Dade' the poorest. 'Walter' had a higher reducing sugar content than 'Homestead-24' during the spring, but less during the fall. All cultivars had a higher reducing sugar content during the spring.

A direct association between SS (Table 21) and reducing sugars was not always observed. The association was high during the spring season, but not as obvious during the fall. Between cultivars and between seasons, the association between SS and reducing sugars was

generally high. 'Healani' contained both the highest SS and the highest reducing sugars. 'Flora-Dade' contained both the lowest SS and the lowest reducing sugars.

A strong association existed between mean reducing sugars and mean dry weight for cultivars and seasons. 'Healani' had both the highest reducing sugars and the highest dry weight while 'Flora-Dade' had both the lowest reducing sugars and the lowest dry weight. Reducing sugars and dry weight were both higher for each cultivar during the spring compared to the fall season.

Season, cultivar, and K rate all had an influence on tomato fruit quality. All these factors must be considered before any generalizations concerning quality measurements can be made. Data from all the quality measurements indicated that fruit grown without added K (0-K) resulted in the poorest quality fruit while the higher K rates produced better quality fruit. In general the cultivar 'Healani' was of high quality while 'Flora-Dade' had the least desirable quality characteristics. Fruits grown during the spring were generally of better quality than those grown during the fall. However, BR was greater during the spring and this would overshadow the other quality factors.

Ethylene and Respiration

Ethylene evolution and respiration rate are the most common measurements taken when studying climacteric fruit ripening. During the ripening process in tomato fruit both ethylene evolution and respiration rate are characteristically low in the mature green stage, rise to a peak as the fruit begins to turn color, and then decrease upon red coloration. Ethylene is believed to be the fruit ripening hormone

in tomato (Burg and Burg, 1965) and deficiencies in its production prevent normal ripening.

The author initially hypothesized that incomplete ripening, manifested by yellow shoulders, was physiologically the result of a deficiency in ethylene or respiration which was also a threshold level that would trigger normal ripening. The above results tend to refute this belief. Both ethylene evolution and respiration rate were significantly higher in the abnormal yellow tissue compared to the normal red tissue, suggesting that a lack of ethylene or respiration was not the cause of yellow shoulder. The fact that a higher ethylene evolution and respiration rate were found in the yellow tissues might imply that the yellow tissue was closer to the climacteric peak while the red tissue was well past this stage. In any case, the yellow tissue was in a different physiological state than the red tissue.

Gas exchange rates were higher in tissue disks compared to previously reported rates for whole fruit. Lee et al. (1970) also found ethylene production to be much greater in disks than whole fruit. They reported that ripening in disks was similar to that in whole fruit. Disks passed through a respiratory climacteric which was accompanied by increased ethylene production. Lycopene development and normal ripe fruit aroma were also reported for the disks.

Wounding increases respiration and ethylene evolution. The wound response was considered to be uniform between both tissue types over the one hour tissue incubation time.

SUMMARY AND CONCLUSIONS

In a greenhouse experiment, fruit from three cultivars ('Healani', 'Homestead-24', and 'Flora-Dade') had more BR with reduced K compared to high K fertility. 'Flora-Dade' had the most BR with all K treatments. 'Healani' had the least amount of BR with the high K treatment. There was no difference in amount of BR between 'Healani' and 'Homestead-24' with the reduced K treatments. There was no difference in the amount of BR between the reduced K treatments (1/10K, -K, H₂O) for any cultivar.

Field grown fruits from four cultivars ('Healani', 'Homestead-24', 'Walter', and 'Flora-Dade') all contained less BR with increasing soil K rates (0, 93, 186, 372, and 745 kg K/ha) in both spring and fall seasons. The amount of BR was reduced more between the increments of 0-K to 93-K and 93-K to 186-K than between 186-K to 372-K and 372-K to 745-K. 'Healani' generally had the least amount of BR during both seasons. There was no practical difference in the amount of EB between 'Homestead-24', 'Walter', and 'Flora-Dade' during either season. 'Flora-Dade' had the most IB during both seasons. Blotchy ripening was greater during the spring than fall season for each cultivar. This was more noticeable at the lower K rates.

Yellow shoulder was the predominant form of EB during the spring with 'Homestead-24', 'Walter', and 'Flora-Dade'. 'Healani' was the only cultivar that showed resistance to yellow shoulder. Yellow

shoulder symptoms generally did not appear on the fruit of any cultivar during the fall. The drastic reduction in yellow shoulder EB during the fall compared with the spring was attributed to differing environmental conditions between seasons.

There was a significantly higher K content in both the leaf and pericarp tissue with increasing soil K rate in both seasons and with all cultivars. However, the differential susceptibility between cultivars to BR was not associated with cultivar differences in leaf K or pericarp K content during either season.

Pericarp Ca and P did not differ between soil K rates. Pericarp Mg increased with increasing K rate only during the spring. No differences in pericarp Ca, Mg, or P content were found which would explain differences in cultivar susceptibility to BR.

Fruits from all four cultivars had less bacterially induced GW development with increasing soil K rate in the spring. Only 'Flora-Dade' had a decrease in GW development with increasing K rate in the fall. 'Flora-Dade' and 'Homestead-24' were the most GW resistant cultivars while 'Healani' and 'Walter' were the most GW susceptible in each season.

Results of a fall greenhouse experiment generally agreed with the fall field results. 'Healani' and 'Walter' were the most GW susceptible cultivars and neither showed a difference in GW development between high K and low K treatments. 'Flora-Dade' and 'Homestead-24' were the most resistant cultivars and both had more GW under low K compared to high K treatments.

The relationship between GW development and K nutrition during the fall was dependent on the length of chilling (4°C) exposure. Reducing or eliminating the chilling treatment of inoculated fruits resulted in slightly less GW development with increasing K for all cultivars.

Natural GW (contrasted to bacterially induced GW) was influenced by cultivar and K nutrition. 'Healani' and 'Homestead-24' showed GW resistance only under the high K treatment. Low K treatments resulted in a large incidence of natural GW appearing in the fruit of both cultivars. 'Flora-Dade' was completely resistant to GW under all K treatments.

Internal fruit quality was evaluated for the four different cultivars grown during the spring and fall at the five different soil K rates. Each cultivar except 'Flora-Dade' had higher pericarp SS at 745-K than 0-K in the spring. 'Healani' and 'Flora-Dade' had higher SS under 745-K than 0-K in the fall. No change in pericarp SS occurred with increasing K rate for 'Homestead-24' or 'Walter'. 'Healani' had the highest SS and 'Flora-Dade' had the lowest SS each season. 'Healani' and 'Flora-Dade' generally had higher SS during the spring than fall. No seasonal difference occurred with 'Homestead-24' or 'Walter'.

There was an increase in pericarp acidity with increasing K rate for each cultivar during both seasons. 'Healani' and 'Homestead-24' had the lowest pericarp acidity in both seasons, while 'Walter' had the highest acidity. Pericarp acidity was highest during the fall than spring for all cultivars.

Fruit from all cultivars had a decrease in pericarp pH with increasing K rate in the spring. No cultivar showed a change in pH with increasing K rate in the fall. 'Healani' had the highest pH and 'Flora-Dade' had the lowest. Each cultivar had a higher pH in the spring than in the fall.

All cultivars except 'Flora-Dade' had an increase in pericarp reducing sugars with increasing K rate in the spring. No cultivar showed a change in reducing sugars with increasing K rate in the fall. 'Healani' had the highest reducing sugar content and 'Flora-Dade' had the lowest each season. Each cultivar had a higher reducing sugar content in the spring than in the fall.

'Healani' was the only cultivar during both seasons to have an increase in pericarp dry weight with increasing K rate. 'Walter' had an increase in pericarp dry weight with increasing K rate only during the fall. 'Healani' had the highest pericarp dry weight and 'Flora-Dade' had the lowest in each season. All cultivars had higher pericarp dry weights during the spring than fall season.

Environment, cultivar, and soil K rate were all shown to influence tomato fruit quality. Data from all the measurements indicated that fruits grown without added soil K (0-K) were of the poorest quality. In general, 'Healani' was the cultivar having the most desirable quality characteristics while 'Flora-Dade' fruits had the least desirable quality characteristics.

Both ethylene evolution and oxygen consumption rates were higher in the blotchy (yellow shoulder) tissue compared to the normal red tissue.

APPENDIX

Appendix Table 1. Analyses of variance for treatment effects on external blotchy ripening of greenhouse grown tomatoes.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.001540
Cultivar	2	.727176** ^z
Potassium	3	.244477**
Pot. x Cult.	6	.004557
Error	33	.002023

^zSignificant at the 1% (**) level.

Appendix Table 2. Analyses of variance for treatment effects on internal blotchy ripening of greenhouse grown tomatoes.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.003937* ^z
Cultivar	2	.421959**
Potassium	3	.245818**
Pot. x Cult.	6	.006575**
Error	33	.001062

^zSignificant at the 5% (*) or 1% (**) level.

Appendix Table 3. Analyses of variance for treatment effects on external blotchy ripening of field grown tomatoes.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.000226
Season	1	3.188589** ^z
Cultivar	3	1.097193**
Seas. x Cult.	3	.031281**
Pot. L	1	2.597134**
Pot. Q	1	.474974**
Pot. L x Seas.	1	.135998**
Pot. Q x Seas.	1	.002825
Pot. L x Cult.	3	.006767**
Pot. Q x Cult.	3	.004946*
Pot. L x Seas. x Cult.	3	.020438**
Pot. Q x Seas. x Cult.	3	.016493**
Error	133	.001483

^zSignificant at the 1% (**) or 5% (*) level.

Appendix Table 4. Analyses of variance for treatment effects on internal blotchy ripening of field grown tomatoes.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.006255* ^z
Season	1	2.792707**
Cultivar	3	1.158870**
Seas. x Cult.	3	.032420**
Pot. L	1	3.632573**
Pot. Q	1	.621202**
Pot. L x Seas.	1	.000981**
Pot. Q x Seas.	1	.024172**
Pot. L x Cult.	3	.044033**
Pot. Q x Cult.	3	.017281**
Pot. L x Seas. x Cult.	3	.002065
Pot. Q x Seas. x Cult.	3	.003877
Error	133	.001796

^zSignificant at the 5% (*) or 1% (**) level.

Appendix Table 5. Analyses of variance for treatment effect on leaf potassium content.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.000006
Season	1	.007959** ^z
Cultivar	3	.000107
Seas. x Cult.	3	.000115*
Pot. L	1	.127369**
Pot. Q	1	.019611**
Pot. L x Seas.	1	.000054
Pot. Q x Seas.	1	.005748**
Pot. L x Cult.	3	.000090
Pot. Q x Cult.	3	.000028
Pot. L x Seas. x Cult.	3	.000024
Pot. Q x Seas. x Cult.	3	.000010
Error	133	.000041

^zSignificant at the 1% (**) or 5% (*) level.

Appendix Table 6. Analyses of variance for treatment effects on pericarp potassium content.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.000063* ^z
Season	1	.000285**
Cultivar	3	.000015
Seas. x Cult.	3	.000073*
Pot. L	1	.025037**
Pot. Q	1	.007466**
Pot. L x Seas.	1	.000176**
Pot. Q x Seas.	1	.000005
Pot. L x Cult.	3	.000023
Pot. Q x Cult.	3	.000005
Pot. L x Seas. x Cult.	3	.000003
Pot. Q x Seas. x Cult.	3	.000013
Error	133	.000023

^zSignificant at the 5% (*) or 1% (**) level.

Appendix Table 7. Analyses of variance for treatment effects on pericarp calcium content.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.000015** ^z
Season	1	.001143**
Cultivar	3	.000545**
Seas. x Cult.	3	.000043**
Pot. L	1	.000000
Pot. Q	1	.000002
Pot. L x Seas.	1	.000006
Pot. Q x Seas.	1	.000001
Pot. L x Cult.	3	.000002
Pot. Q x Cult.	3	.000005
Pot. L x Seas. x Cult.	3	.000001
Pot. Q x Seas. x Cult.	3	.000007
Error	133	.000004

^zSignificant at the 1% (**) level.

Appendix Table 8. Analyses of variance for treatment effects on pericarp magnesium content.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.000009
Season	1	.001360** ^z
Cultivar	3	.000159**
Seas. x Cult.	3	.000014*
Pot. L	1	.000037**
Pot. Q	1	.000001
Pot. L x Seas.	1	.000007
Pot. Q x Seas.	1	.000042**
Pot. L x Cult.	3	.000002
Pot. Q x Cult.	3	.000006
Pot. L x Seas. x Cult.	3	.000001
Pot. Q x Seas. x Cult.	3	.000002
Error	133	.000005

^zSignificant at the 1% (**) or 5% (*) level.

Appendix Table 9. Analyses of variance for treatment effects on pericarp phosphorus content.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.000032** ^z
Season	1	.000344**
Cultivar	3	.000271**
Seas. x Cult.	3	.000005
Pot. L	1	.000001
Pot. Q	1	.000000
Pot. L x Seas.	1	.000002
Pot. Q x Seas.	1	.000002
Pot. L x Cult.	3	.000003
Pot. Q x Cult.	3	.000003
Pot. L x Seas. x Cult.	3	.000008
Pot. Q x Seas. x Cult.	3	.000003
Error	133	.000006

^zSignificant at the 1% (**) level.

Appendix Table 10. Analyses of variance for treatment effects on bacterially induced graywall (field).

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	2.777858** ^z
Season	1	11.881739**
Cultivar	3	19.540631**
Seas. x Cult.	3	3.774218**
Pot. L	1	10.637136**
Pot. Q	1	2.637572**
Pot. L x Seas.	1	3.338433**
Pot. Q x Seas.	1	1.195111*
Pot. L x Cult.	3	.143810
Pot. Q x Cult.	3	.199049
Pot. L x Seas. x Cult.	3	.691913
Pot. Q x Seas. x Cult.	3	.723435
Error	133	.260935

^zSignificant at the 1% (**) or 5% (*) level.

Appendix Table 11. Analyses of variance for treatment effects on bacterially induced graywall (greenhouse).

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	5	2.58** ^z
Cultivar	3	6.98**
Potassium	1	1.68*
Pot. x Cult.	3	0.59
Error	19	0.21

^zSignificant at the 1% (**) or 5% (*) level.

Appendix Table 12. Analyses of variance for treatment effects on pericarp soluble solids.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.000137** ^z
Season	1	.000128**
Cultivar	3	.006038**
Seas. x Cult.	3	.000101**
Pot. L	1	.000541**
Pot. Q	1	.000223**
Pot. L x Seas.	1	.000049
Pot. Q x Seas.	1	.000027
Pot. L x Cult.	3	.000016
Pot. Q x Cult.	3	.000020
Pot. L x Seas. x Cult.	3	.000027
Pot. Q x Seas. x Cult.	3	.000003
Error	133	.000016

^zSignificant at the 1% (**) level.

Appendix Table 13. Analyses of variance for treatment effects on pericarp acidity.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.000106* ^z
Season	1	.028030**
Cultivar	3	.001333**
Seas. x Cult.	3	.000225**
Pot. L	1	.027897**
Pot. Q	1	.005753**
Pot. L x Seas.	1	.000292**
Pot. Q x Seas.	1	.000076
Pot. L x Cult.	3	.000100
Pot. Q x Cult.	3	.000055
Pot. L x Seas. x Cult.	3	.000055
Pot. Q x Seas. x Cult.	3	.000118*
Error	133	.000038

^zSignificant at the 5% (*) or 1% (**) level.

Appendix Table 14. Analyses of variance for treatment effects on pericarp pH.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.001465
Season	1	.182250** ^z
Cultivar	3	.347485**
Seas. x Cult.	3	.004508*
Pot. L	1	.022529**
Pot. Q	1	.001464
Pot. L x Seas.	1	.064838**
Pot. Q x Seas.	1	.008741*
Pot. L x Cult.	3	.001245
Pot. Q x Cult.	3	.002210
Pot. L x Seas. x Cult.	3	.002511
Pot. Q x Seas. x Cult.	3	.002474
Error	133	.001414

^zSignificant at the 1% (**) or 5% (*) level.

Appendix Table 15. Analyses of variance for treatment effects on pericarp reducing sugars.

<u>Sources of variation</u>	<u>df</u>	<u>Mean Squares</u>
Replication	3	.000005
Season	1	.024926** ^z
Cultivar	3	.006737**
Seas. x Cult.	3	.000379**
Pot. L	1	.000002
Pot. Q	1	.000054**
Pot. L x Seas.	1	.000129**
Pot. Q x Seas.	1	.000010
Pot. L x Cult.	3	.000053**
Pot. Q x Cult.	3	.000010
Pot. L x Seas. x Cult.	3	.000019*
Pot. Q x Seas. x Cult.	3	.000004
Error	133	.000006

^zSignificant at the 1% (**) or 5% (*) level.

Appendix Table 16. Analyses of variance for treatment effects on pericarp dry weight.

<u>Sources of variation</u>	<u>df</u>	<u>Mean squares</u>
Replication	3	.000044 ^z
Season	1	.004412**
Cultivar	3	.003171**
Seas. x Cult.	3	.000051*
Pot. L	1	.000106**
Pot. Q	1	.000041
Pot. L x Seas.	1	.000030
Pot. Q x Seas.	1	.000027
Pot. L x Cult.	3	.000044*
Pot. Q x Cult.	3	.000016
Pot. L x Seas. x Cult.	3	.000019
Pot. Q x Seas. x Cult.	3	.000000
Error	133	.000014

^zSignificant at the 5% (*) or 1% (**) level.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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