Internal Breakdown, Mineral Element Concentration, and Weight of Mango Fruit

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ABSTRACT

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Internal breakdown in mango fruit is a disorder often attributed to a nutrient deficiency, particularly of calcium (Ca), in the fruit. The relationship between internal breakdown in mango fruit and fruit mineral element concentrations and fresh weight was investigated. Fruit were collected weekly from a commercial orchard beginning 4 weeks after fruit set (WAFS) until the fruit were ripe. The concentrations of nitrogen (N), phosphorus (P), potassium (K), Ca, magnesium (Mg), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), and boron (B) and fresh weight of 'Tommy Atkins' mango fruit with and without internal breakdown were compared. Disordered fruit weighed more than healthy fruit 4 WAFS. However, when fruit were ripe there were no significant differences in fruit weight between healthy and disordered fruit. Disordered fruit contained significantly higher concentrations of N, P, Ca, and B than the healthy mango fruit, 4 WAFS. When fruit were ripe, there were no differences in N, K, Ca, Mg, Zn, Mn, Fe, and B concentrations between healthy and disordered fruit. Ripe, healthy fruit had higher Cu and lower P concentrations than ripe, disordered fruit. Internal breakdown could not be specifically linked to a Ca deficiency in mango fruit at any stage of fruit ontogeny.

RESUME

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La "dépression interne" des fruits du manguier ou "internal break-down" a souvent été attribuée à une carence nutritionnelle, particulièrement en Calcium (Ca). La relation entre ce désordre physiologique, la concentration en éléments minéraux et le poids frais des fruits a été investiguée. Des fruits d'un verger commercial ont été collectés sur une base hebdomadaire de la quatrième semaine après le début de la fructification (WAFS) à la maturation. Les concentrations en Azote (N), phosphore (P), Potassium (K), Calcium (Ca), Magnésium (Mg), Zinc (Zn), Cuivre (Cu), Manganèse (Mn), Fer (Fe), Bore (B) ainsi que le poids frais des fruits de la variété Tommy Atkins avec ou sans dépression interne ont été comparés. A 4 WAFS, le poids des fruits malades était supérieur à celui des fruits sains. Par contre, aucune différence significative n'a été trouvée entre les poids pour les fruits mûrs. De même, quatre semaines après le début de la fructification, la concentration des fruits malades en N, P, Ca, et B était significativement plus élevée que celle des fruits sains. Cependant, pour les fruits mûrs avec ou sans dépression interne, aucune différence significative n'a été trouvée en terme de concentration en N, K, Ca, Mg, Zn, Mn, Fe et B. Les fruits sains mûrs révèlent une concentration en Cu plus grande et une concentration en P plus faible que les fruits mûrs avec dépression interne. Ainsi, aucune relation spécifique n'a pu être établie entre la dépression interne des fruits et une carence en Ca à un stade quelconque de la formation des fruits.

INTRODUCTION

The fruit of several commercial mango *(Mangifera indica* L.) cultivars are affected by various physiological disorders such as black tip (Agarwala et al., 1962; Srivastava, 1963;Zhangetal., 1995), internal necrosis (Ram, 1988; Ram et al., 1988), fruit splitting (Lim and Koo, 1985), and internal breakdown (Subramanayam et al., 1971; Verma, 1950; Young, 1957). Internal breakdown is thought to prevail in Indian cultivars or cultivars with an Indian pedigree (Schaffer, 1994; Young, 1957). Depending upon the symptoms and growing regions, internal breakdown is referred to as 'jelly seed', 'soft nose', 'stem-end cavity' (SEC), 'yeasty fruit rot', 'insidious fruit rot', or 'flesh breakdown'. The disorder has been related to several variables, including environmental factors (Lad et al., 1992), cultural practices (Malo and Campbell, 1978), a nutritional imbalance or deficiency (Burdon et al., 1991), fruit weight (Subramanyam et al., 1971) and fruit specific gravity (Krishnamurthy, 1981).

There is much controversy surrounding the nature or cause of internal breakdown in mango fruit. In studies conducted in Florida, increased N fertilization increased the incidence of soft nose (Young, 1957; Young and Miner, 1961; Young et al., 1962). However, in another study in Florida, N fertilization or high leaf N concentrations could not be correlated with the incidence of internal breakdown (Malo and Campbell, 1978). Increased irrigation (Malo and Campbell, 1978) or rain (Katrodia et al., 1988) at the time of fruit development have also been considered to increase the occurrence of internal breakdown in mango. However over a six-year period, no differences in the percentages of disordered 'Sensation' fruit were observed among irrigation treatments that maintained soil matric potentials at -20, -50, or -70 kPa (Farre and Hermoso, 1993).

Calcium deficiency is considered to be the most probable cause of internal breakdown (Shear, 1975; Young, 1957). However, there is no definitive evidence for the role of Ca in the development of the disorder. In a study of the distribution of P, K, Ca, and Mg in mango fruit susceptible to the soft nose disorder, Burdon et al. (1991) observed that the Ca and Mg concentrations in disordered 'Kent' fruit were lower than those in the healthy 'Kent' fruit. It was also observed that Ca and Mg concentrations were equally low in healthy and disordered 'Beverly' mango fruit. However, the disordered mesocarp of 'Beverly' mangoes contained significantly higher Ca, Mg, K, and P concentrations than the healthy mesocarp (Burdon et al., 1991). Krishnamurthy (1981) found no relationship between internal breakdown and Ca concentrations in the mesocarp of 'Alphonso' mango fruit. Gunjate et al. (1979) reported a reduced incidence of spongy tissue in 'Alphonso' fruit following preharvest or postharvest dips of the fruit in 5 or 20 g L^{-1} $CaCl_2$ or $Ca(NO_3)_2$. However, pre-harvest sprays of 5 g L^{-1} $CaCl_2$ alone or in combination with 0.5 g L^{-1} H_3BO_4 did not reduce the incidence of internal breakdown, and had no effect on the fruit Ca level (Krishnamurthy, 1982). In that study, the post-harvest dips of the fruit into 2.5 or 5 g L^{-1} $CaCl_2$

solution baths for 5 minutes also failed to reduce the incidence of internal breakdown (Krishnamurthy, 1982). In addition, higher Ca concentrations were observed in disordered 'Carabao' fruit than in healthy fruit (Burdon et al., 1991; Lad et al., 1992; Wainright and Burbage, 1989).

Comparing the concentrations of specific nutrients in healthy fruit with those in disordered fruit would help to elucidate the role of mineral nutrition in internal breakdown. The purpose of this study was to compare the concentrations of N, P, K, Ca, Mg, Zn, Cu, Mn, Fe, and B in the fruit, and fruit weight between healthy and disordered mango fruit, and to determine if there is a relationship between these fruit mineral element concentrations and the occurrence of internal breakdown in 'Tommy Atkins' fruit throughout fruit development.

MATERIALS AND METHODS

Location

The study was conducted during the 1996 fruiting season in a commercial orchard in south Miami, Bade County (25.36°N and 80.21 °W). The orchard was established on a Krome soil (loamy, skeletal, carbonatic, hyperthermic Lithic Udorthents). These soils are 0-27.50 cm deep and composed of very gravelly loam or weathered bedrock. They contain 15-20% clay and have a pH of 7.4-8.4 (USDA, 1996). Daytime temperatures during the experimental period averaged 23.6°C and the total rainfall amount was 894.5 mm, with a peak in June.

Plant Materials

Eight 30-year-old trees of 'Tommy Atkins' grafted on 'Turpentine' rootstock were used in the study. No fertilizer was applied during the experiment. However, the trees had received 568 kg ha^{-1} of 6-0-19 (N-P-K) in March 1995,9.94 kg ha'^{1} of Sequestrene-Fe (Geigy 138, 5% Fe) in August 1995, 852.27 kg ha^{-1} of 3-8-12 and 19.32 kg ha^{-1} of Sequestrene-Fe in September 1995, and 19.31 kg ha^{-1} of Sequestrene-Zn (Geigy, 14% Zn) plus 19.32 kg ha^{-1} of Sequestrene-Mn (Geigy, 12% Mn) in December 1995.

Sampling

Three fruit were collected every week from each tree, beginning four weeks after fruit set (WAFS) until the fruit were ripe. There were four two-tree replicates. The fruit were considered to be ripe when the mesocarp was sufficiently soft to allow consumption as a fresh fruit. The samples were placed in paper bags and shaded to prevent water loss that could result from prolonged exposure to the sun during sampling and transportation from the field to the laboratory.

Determination of Fruit Weight and Internal Breakdown

Fruit weight was determined by individually weighing the fruit immediately after collection from the orchard. The presence of internal breakdown was determined after cutting open the fruit samples. Each fruit was first transversely cut at the proximal end, between the peduncle and the base of the stone. The objective of the transverse cut was to assess the presence of stem-end cavity in the fruit. Two additional longitudinal cuts were made on each of the wider flat sides of the stone to expose the interior of the fruit and detect the presence of either jelly seed or soft nose.

Processing of Samples

Collected fruit were washed in a 10 mL detergent solution, rinsed in tap water, washed in 0.6 M HC1, and rinsed twice in distilled water as described by Schaffer et al. (1988). After washing, the fruit were weighed, and cut open, as previously described, and oven dried for 48 to 120 hours, depending upon the size of the fruit. Dried samples were ground in a cyclone mill (UDY Corp., Fort Collins, CO).

For P, K, Ca, Mg, Zn, Cu, Mn, Fe, and B determination, 1 g of ground tissue was weighed in a 40-mL high-form porcelain crucible (Fischer Scientific, Pittsburgh, PA) and ashed at 500°C in a muffle furnace (Furnatrol FA 1730, Bamstead/Thennolyne, Dubuque, LA). The ashed sample was digested with 5 mL of 6M HC 1 and brought to 50 mL with deionized water in a polyethylene volumetric flask. The preparation was shaken and filtered through Whatman # 1 filter paper into a 20-mL polyethylene scintillation vial.

For N determination, 0.2 g of ground tissue was weighed and placed in a 100-mL digestion tube in which 2 g of Kjeldahl mixture and 5 mL H_2SO_4 were added. Glass funnels were placed on the tubes, and the tubes and funnels were placed on a preheated aluminum digestion block at 250° C for 1 hour. The temperature of the digestion block was raised to 380°C for an additional 3-hour period. After the tubes cooled to room temperature, 5 mL of distilled water were added to each tube and the preparation was agitated with a vortex mixer. The digested material was transferred to a 100-mL volumetric flask, and the content was vigorously mixed and filtered through Whatman #1 filter paper into a 20-mL polyethyelene scintillation vial (Hanlon et al., 1994). Nitrogen concentrations were determined by the Total Kjeldahl Nitrogen (TKN) method and K, P, Ca, Mg, Zn, Cu, Mn, Fe, and B were determined by inductively coupled argon plasma spectroscopy (ICAP).

RESULTS

Fruit Fresh Weight

Significant differences in fruit fresh weight existed between healthy and disordered fruit throughout most of the fruit development period (Figure 1). However, no definite pattern was observed in the relationship between fruit weight and internal breakdown. Healthy fruit weighed significantly less than disordered fruit when symptoms of internal breakdown were first detected 8 WAFS, but when the fruit were ripe, the healthy fruit were heavier than the disordered fruit. Healthy fruit weighed more than disordered fruit 9 and 12 WAFS. However, the opposite was observed 11 and 13 WAFS. There were no differences in fruit fresh weight between healthy and disordered fruit 10 WAFS.

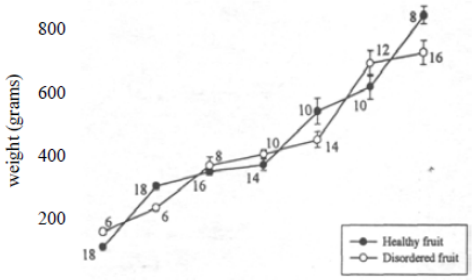
Development of Internal Breakdown Symptoms

Stem end cavity and jelly seed were the first disorders detected in the fruit 8 WAFS. Symptoms of the soft nose disorder appeared only when the fruit were nearly mature. Although fruit sampling commenced 4 WAFS, data presented for fruit mineral concentrations correspond to the time at which internal symptoms were noticed, to allow for comparisons between disordered and healthy fruit.

8 9 10 11 12 13 14

Weeks after fruit set

Figure 1. Weight of healthy and disordered Tommy Atkins' mangoes from first signs of internal breakdown to fruit ripeness. Values on the left or right of symbols represent the numbers of healthy and disordered fruit, respectively. Vertical bars represent ± 1 standard error. Absence of error bars indicates that the standard error bar was smaller than the symbol for the mean.



Mineral Elements

The concentrations of N were higher in disordered fruit than in healthy fruit 8 and 9 WAFS, i.e., during the two weeks after the first signs of internal breakdown were observed (Figure 2A). There were no differences in fruit N concentrations between disordered and healthy fruit 10 WAFS and 12 WAFS, and when the fruit were ripe. Nitrogen concentrations fluctuated more in the disordered fruit than in the healthy fruit. For example, N concentrations hi healthy fruit were fairly consistent from 10 to 13 WAFS, whereas significant fluctuations in fruit N concentrations occurred in disordered fruit.

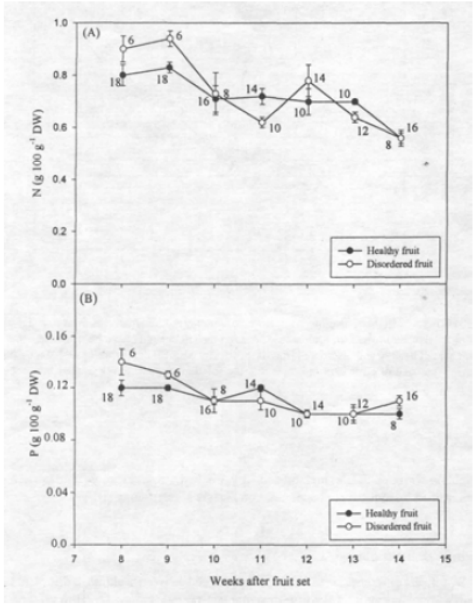
Concentrations of P in healthy fruit were significantly lower than those in disordered fruit 8 and 9 WAFS, i.e., during the first two weeks after symptoms of internal breakdown appeared (Figure 2B). Phosphorus concentrations hi healthy fruit were nearly equal to those in disordered fruit during the remaining period of fruit development, except 11 WAFS, when P concentrations were higher in the healthy fruit than in the disordered fruit. The P concentrations in disordered fruit did not show any significant changes from 10 to 13 WAFS, whereas a significant fluctuation occurred in the P concentration in healthy fruit 11 WAFS. There was a significant increase in the P concentration in the disordered fruit when those fruit were ripe, i.e., 14 WAFS.

The concentrations of K in healthy and disordered fruit fluctuated throughout fruit ontogeny. Fruit K concentrations in the healthy fruit were not significantly different from those observed in the disordered fruit at 8 and 10 WAFS, and when the fruit were ripe (Figure 3A). The K concentrations in healthy fruit were higher than that in disordered fruit at 11 and 13 WAFS, whereas disordered fruit contained higher fruit K concentrations than healthy fruit at 9 and 12 WAFS.

Concentrations of Ca in healthy fruit were similar to those in disordered fruit throughout the sampling period. No differences in fruit Ca concentrations were observed between healthy and disordered fruit 8 WAFS, i.e., when the symptoms of internal breakdown were first detected, although variability in Ca concentrations among the disordered fruit was much greater than in the healthy fruit (Figure 3B). Calcium concentration in the disordered fruit was significantly higher than the concentration in the healthy fruit 9 WAFS, whereas healthy fruit contained significantly higher Ca concentrations than disordered fruit 11 WAFS. From 12 WAFS until the fruit were ripe, there were no differences in fruit Ca concentrations between healthy and disordered fruit.

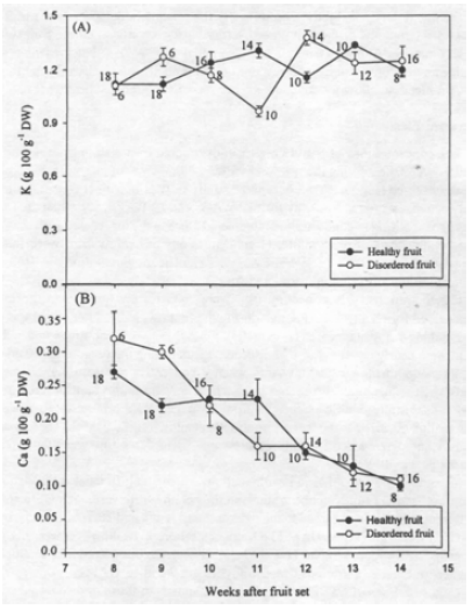
Figure 2. Concentrations of N and P in healthy and disordered Tommy Atkins' mangoes from first signs of internal breakdown to fruit ripeness. Values of the left of right of symbols represent the numbers of healthy and disordered fruit, respectively. Vertical bars represent ± 1 standard error. Absence of error bars indicates that the standard error bar was smaller than the symbol for the mean.

Figure 3. Concentrations of K and Ca in healthy and disorder Tommy Atkins' mangoes from first signs of internal breakdown to fruit ripeness. Values on the left or right of symbols represent the numbers of healthy and disordered fruit, respectively. Vertical bars represent ± 1 standard error. Absence of error bars indicates that the standard error bar was

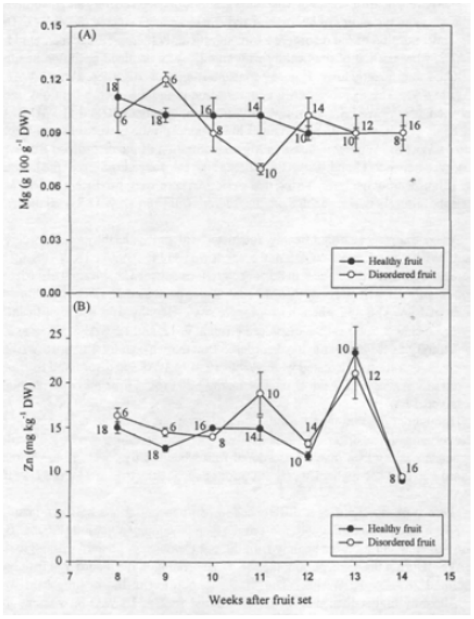


smaller than the symbol for the mean.

Figure 4. Concentrations of Mg and Zn in healthy and disordered Tommy Atkins' mangoes from first signs of internal breakdown to fruit ripeness. Values on the left or right of symbols represent the numbers of healthy and disordered fruit, respectively. Vertical bars represent ± 1 standard error. Absence of error bars indicates that the standard error bar was smaller than the symbol for the mean.



There were no differences in Mg concentra-



tions between healthy and disordered fruit when the symptoms of internal breakdown were first detected (8 WAFS). The Mg concentration of the disordered fruit significantly increased between 8 and 9 WAFS, whereas that of the healthy fruit significantly declined such that healthy fruit had significantly lower fruit Mg concentrations than disordered fruit 9 WAFS (Figure 4A). The increase in Mg concentration in the disordered fruit observed between 8 and 9 WAFS was followed by significant declines 10 and 11 WAFS. In

the healthy fruit, no significant changes in Mg concentrations were observed from 9 to 11 WAFS. Another increase in Mg concentration of the disordered fruit was observed between 11 and 12 WAFS, whereas the Mg concentrations of the healthy fruit significantly declined during that period. There were no differences in Mg concentrations between healthy and disordered fruit from 12 WAFS until the fruit were ripe,

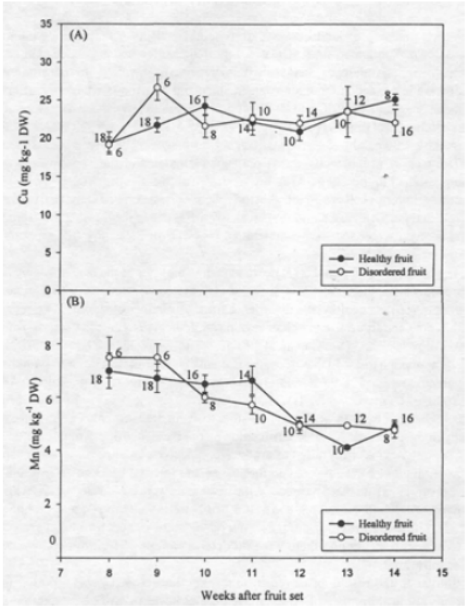
Concentrations of Zn significantly fluctuated with time in healthy and disordered fruit. When the symptoms of internal breakdown were first noticed 8 WAFS, there were no significant differences in Zn concentrations between healthy and disordered fruit (Figure 4B). Healthy and disordered fruit also contained similar concentrations of Zn at 13 WAFS and when the fruit were ripe. Healthy fruit had significantly lower Zn concentrations than disordered fruit at 9,11, and 12 WAFS, whereas Zn concentrations were lower in the disordered fruit than in healthy fruit at 10 WAFS. Zinc concentrations fluctuated widely from 10 to 14 WAFS in disordered fruit and from 11 to 14 WAFS in healthy fruit, fluctuating ± 30 to 60% from the concentrations observed 10 WAFS

Throughout the sampling period, Cu concentrations remained fairly similar in healthy compared to disordered fruit. However, Cu concentrations were significantly higher in healthy fruit than in disordered fruit when the fruit were ripe, whereas disordered fruit had higher Cu concentrations than healthy fruit at 9 WAFS (Figure 5A).

There were no significant differences in Mn concentrations between healthy and disordered fruit throughout most of the fruit development period (Figure 5B). The Mn concentrations of healthy fruit did not

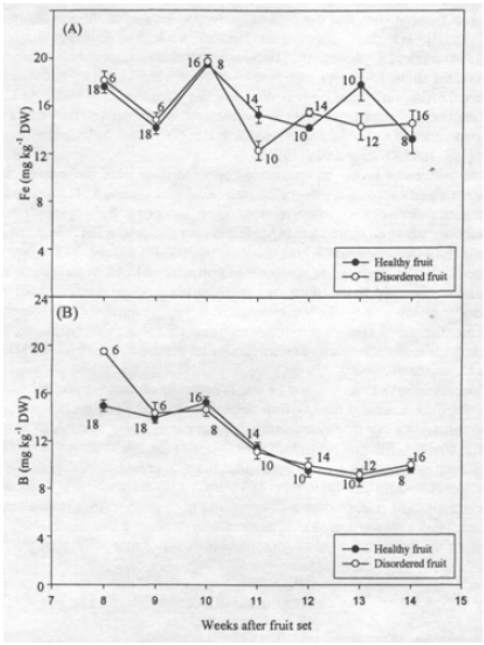
Figure 5. Concentrations of Cu and Mn in healthy and disordered 'Tommy Atkins' mangoes from first signs of internal breakdown to fruit ripeness. Values on the left or right of symbols represent the numbers of healthy and disordered fruit, respectively. Vertical bars represent ± 1 standard error. Absence of error bars indicates that the standard error bar was smaller than the symbol for the mean.

Figure 6. Concentration of Fe and B in healthy and disordered 'Tommy Atkins' mangoes from first signs of internal breakdown to fruit ripeness. Values on the left or right of symbols represent the numbers of healthy and disordered fruit, respectively. Vertical bars represent ± 1 standard error. Absence of error bars indicates that the standard error bar was



smaller than the symbol for the mean.

change significantly from 8 to 11 WAFS. During the same period, the Mn concentration in the disordered fruit had declined 20% by 10 WAFS. The Mn concen-



tration in the healthy fruit was significantly higher than that of the disordered fruit at 11 WAFS, whereas the reverse was observed at 13 WAFS. When the fruit were ripe, no differences in Mn concentrations were observed between healthy and disordered fruit.

The Fe concentrations in healthy fruit were similar to those in disordered fruit from 8 to 10 WAFS and when the fruit were ripe (Figure 6A). Iron concentrations were higher in healthy fruit at 11 and 13 WAFS, whereas disordered fruit contained slightly higher Fe concentrations at 12 WAFS.

Healthy fruit had similar B concentrations as disordered fruit throughout most of the fruit development period, except at 8 WAFS, at which time B concentration was significantly higher in the disordered fruit than in the healthy fruit (Figure 6B).

DISCUSSION

No relationship existed between fruit weight and the occurrence of internal breakdown. Subramanyam et al. (1971) reported an increased incidence of internal breakdown in ' Alphonso' mangoes with increasing fruit weight. In that study, the fruit were harvested at the mature-green stage and allowed to ripen in ventilated wooden boxes at 28 ± 30°C and 60-90% relative humidity. When the fruit were ripe, the percentages of disordered fruit were 18.2%, 25.4%, 36.4%, and 44.5% for weight classes of <200 g, 200-250 g, 250-300 g, and >300 g, respectively. There are large differences in weight between 'Alphonso' mangoes and the 'Tommy Atkins' mangoes used in this study. 'Tommy Atkins' fruit weigh approximately 500 g at maturity (Figure 1). It is possible that the lack of correlation between the fruit fresh weight and the incidence of internal breakdown was due to the fact that the 'Tommy Atkins' fruit exceeded the weight range reported in the study of 'Alphonso" mangoes.

The incidence of internal breakdown in mango may not be the result of a nutrient deficiency since there were few differences in the concentrations of fruit mineral elements between healthy and disordered fruit. A number of studies have related high N concentrations to the incidence of physiological disorders in mango. Young (1957) observed an increasing incidence of soft nose with increased N fertilization of 'Kent' mango trees. In that study, the percentages of fruit with definite symptoms of soft nose were 7.7%, 9.6%, and 11.9% harvested from trees that received 90,180, or 360 g of N, respectively. It was also observed that the severity of the disorder was higher for trees in acidic, sandy soils

than for trees in calcareous soils. A study of the effects of N and K fertilization on the incidence of internal breakdown in Tommy Atkins' fruit failed to produce conclusive evidence for a relationship between high N concentrations in the leaves and internal breakdown (Malo and Campbell, 1978). In that 5-year study, the treatments were 0.68,1.36, and 2.72 kg of K tree^{-1} year^{-1}, and 0.34, 0.68, and 1.36 kg of N tree^{-1} year^{-1} (Malo and Campbell, 1978). In these previous studies, mineral element concentrations were only determined in leaves and there were no determinations of fruit mineral element concentrations.

Similar to the results observed in this study, Lad et al. (1992) reported that various application rates of N, P, and K did not have a significant effect on the occurrence of spongy tissue in 'Alphonso' mango, but N concentration in the fruit before ripening was not reported. The relationship between leaf N and internal breakdown has raised some controversy (Young, 1957; Young and Miner, 1961; Malo and Campbell, 1978). There is almost no information on the relationship between N concentration in mango fruit throughout fruit development and the incidence of the disorder. During the accelerated growth phase of mango fruit, cell enlargement takes place. During this period, excessive N in the fruit mesocarp may accentuate the cell enlargement process and, consequently, contribute to weakening of the structural arrangement of the cell wall polysaccharides. Higher N concentrations in the disordered fruit may also have resulted from *de novo* synthesis of enzymes such as the hydrolases, a-amylase, and cellulases. An increase in the activity of these enzymes results in the breakdown of the starch molecules, cell wall softening, and also cell wall deterioration. Other enzymes such as ACC synthase, ACC oxydase, malic enzyme, and pectin methylesterase may also be involved. A study of the chemical composition of 'Alphonso' fruit indicated the activities of malic enzyme (7.2 µmol mm^{-1} mg^{-1} protein) and pectin methylesterase (1.60 µeq min^{-1} mg^{-1} protein) in disordered fruit were significantly higher than the activity levels (4.6 &mol min^{-1} mg^{-1} protein and 0.97 µeq mm^{-1} mg^{-1} protein, respectively) of the enzymes in healthy fruit (Krishnamurthy, 1981).

No differences in Ca concentrations were observed between disordered and healthy fruit at the beginning and at the end of the sampling period, i.e., when the fruit were youngest and when the fruit were ripe. These results are in agreement with observations made by Burdon et al. (1991) who observed no differences in Ca concentrations between disordered and healthy fruit of 'Beverly' trees at the same site, whereas significant differences in the percentages of disordered fruit existed between'Kent'and'Beverly'(Burdon et al., 1991). Similarly, Krishnamurthy (1981) was unable to correlate internal breakdown in 'Alphonso' mango with Ca deficiency in the fruit. The disordered mesocarp of 'Beverly' fruit had higher Ca concentrations than healthy mesocarp (Burdon et al., 1991). In that study, the fruit mesocarp was divided into exterior and ulterior portions of the mesocarp, and apical, mid, and stem-end sections. In our study, fruit tissues were not separated, i.e., each fruit was considered as a whole. Consequently, the differences between the results reported in this chapter and those reported by Burdon et al. (1991) may be related to fruit sectioning procedures. Internal breakdown may be the result of redistribution or compartmentalization of nutrients within the fruit (Burdon et al., 1991).

Leaf Ca concentrations have been considered to be a valuable criterion for predicting internal breakdown in mango (Malo and Campbell, 1978; Young, 1957; Young and Miner, 1961). Young (1957) and Young and Miner (1961) indicated that soft nose in 'Kent' was correlated with low foliar Ca concentrations, whereas Malo and Campbell (1978) did not find any relationship between leaf Ca concentrations and internal breakdown in 'Tommy Atkins' mangoes. However, the use of foliar analysis for predicting fruit disorders may not be the best criterion. Calcium primarily moves in the transpiration stream in the xylem (Kirkby and Pilbeam, 1984; Mengel and Kirkby, 1982), which is well developed in leaves. However, the xylem is reduced in the mesocarp of most fruit, and the vascular system mainly consists of phloem (Esau, 1977), in which Ca moves slowly. These anatomical differences predispose mango fruit to limited Ca absorption compared to the leaf. Thus, in mango, leaves are probably stronger sinks for Ca than fruit. Therefore, the fruit nutritional status should be a better criterion to use for diagnostic purposes related to internal breakdown. Internal breakdown does not affect mango varieties with fibrous fruit (Malo and Campbell, 1978). This may be related to a more efficient vascular network in fibrous fruit. In addition to internal breakdown, Ca deficiency in the fruit has been associated with several other mango fruit disorders. Agarwala et al. (1962) observed that Ca concentrations in healthy 'Safeda' and Tamboori' fruit were more than twice those observed in fruit affected by the black tip disorder. Subramanyam (1971) also observed higher Ca concentrations in the healthy tissues (85 mg 100 g^{-1}) compared to disordered tissues (74 mg 100 g^{-1}) of 'Alphonso' fruit affected by internal breakdown. Gunjate et al. (1979) observed that dipping mango fruit in 5 or 20 g L^{-1} $CaCl_2$ or $Ca(NO_3)_2$ significantly reduced the incidence of spongy tissue and that treated fruit contained appreciably higher Ca concentrations than untreated fruit. However, Krishnamurthy (1982) did not observe any reduction of spongy tissue or an increase in the Ca concentrations when 'Alphonso' fruit were treated with 5 g L^{-1} $CaCl_2$ in pre-harvest sprays, or with 5 g L^{-1} $CaCl_2$ alone or in combination with 0.5 g L^{-1} H_3BO_4 in post-harvest dips.

Disordered fruit contained higher P concentrations than healthy fruit when the disorder was first detected and when the fruit were ripe. These results are in agreement with observations previously reported by several researchers. Agarwala et al. (1962) observed that black tip-disordered tissues of' Safeda' and 'Tamboori' fruit contained higher P concentrations than the healthy tissues, and that the P content decreased from the apex towards the base of the fruit. In a similar study of internal breakdown, Burden et al. (1991) observed that the P concentration was higher in disordered 'Kent' and 'Beverly' mangoes than in healthy fruit. Disordered tissue of affected immature fruit also had a higher P level than healthy portions of the mesocarp.

Krishnamurthy (1981) also found higher P concentrations in 'Alphonso' fruit affected by spongy tissue (0.19 g 100 g^{-1}) than in healthy fruit (0.12 g 100 g^{-1}). It is difficult to find an explanation for the presence of elevated P concentrations in disordered tissue. Internal breakdown is considered to be a ripening disorder (Subramanyam, 1971). As such, it involves a number of biochemical processes such as softening, climacteric respiration, and ethylene production (Gomez-Lim, 1997). Phosphorylases are among the enzymes involved in starch degradation by adding phosphate to glycosidic molecules forming monosaccharide phosphate (Smith, 1993). There is no detailed information on the production of these substances in disordered mangoes. However, it is possible that the high P concentrations observed in the disordered fruit tissues are related to increased demand for phosphate-based substances such as ATP in the ripening tissues due to an increased respiratory rate and/or accelerated degradation of starch molecules, making the disordered fruit stronger sinks for P than healthy fruit.

There were no differences in fruit K concentrations between disordered and healthy fruit when the disorder first appeared or when the fruit were ripe. Young et al. (1962) and Malo and Campbell (1978) were also unable to correlate internal breakdown with leaf K levels. However, Burdon et al. (1991) reported that K concentrations in the disordered mesocarp of mature green 'Beverly' mangoes were significantly higher than those in the healthy mesocarp. Krishnamurthy (1981) reported lower concentrations of K in internal breakdown-affected fruit compared to healthy fruit. The differences between each of those studies and between those studies and the present study may be due to differences in the maturity stage at harvest. Immature and mature green fruit were used by Burdon et al. (1991) whereas Krishnamurthy (1981) used fruit that had ripened off the tree. In the present study, fruit were collected on a weekly basis until on-tree ripening occurred. Also, differences in K fertilization may have interfered with the fruit K concentrations observed in each study. No information was given on the fertilization programs applied to the orchards where the fruit samples were collected by Burdon et al. (1991) and Krishnamurthy (1981).

The differences in Mg concentrations between disordered and healthy fruit were not significant during most of the fruit development period. This result is in agreement with results previously reported for' Alphonso' fruit affected by internal breakdown, where no differences in Mg levels were found between disordered and healthy fruit (Krishnamurthy, 1981). Agarwala et al. (1962) reported higher Mg concentrations in the distal region of mango fruit affected by black tip compared to the intermediate or proximal portions. Although, black tip has been confused with internal breakdown it is probably an unrelated disorder. Burdon et al. (1991) observed that the disordered mesocarp of fruit with internal breakdown had higher Mg levels than healthy mesocarp. Further studies are needed to determine the role of fruit Mg concentrations in internal breakdown of mango fruit.

Concentrations of Zn, Mn, and Fe and B generally did not significantly differ between disordered and healthy fruit throughout the sampling period, although the B concentration in disordered fruit was significantly higher than that of healthy fruit 8 WAFS. The general lack of differences in Zn, Mn, Fe, and B between disordered and healthy fruit suggests that these micronutrients do not play a significant role in the incidence of internal breakdown. The higher Cu concentrations in ripe, healthy fruit compared to disordered fruit may be more related to fungicide application rates than to the incidence of the internal breakdown. Many of the fungicides used to control anthracnose of mango in south Florida contain Cu.

CONCLUSIONS

Indisputable evidence for the role of any nutrient element including Ca in the occurrence of internal breakdown is lacking. No relationship between fruit Ca concentrations and internal breakdown was found. Thus, this study does not support the hypothesis that internal breakdown results from Ca deficiency. Further studies are needed to elucidate the role of mineral nutrition in the development of internal breakdown of mango fruit. Such studies should include the use of radioactive markers for Ca and possibly other elements so that the incorporation of these elements in different tissues of the fruit could be followed. Fruit nutritional studies with mature mango trees in containers, whereby specific elements could be withheld to try to induce the disorder, may be essential to determine the role of mineral nutrient elements in internal breakdown. Except for P and Cu, there were no significant differences in mineral element concentrations between disordered and healthy fruit when the fruit were ripe. At the early stages of internal breakdown, N, P, Ca, and B concentrations were significantly higher in disordered fruit than in healthy fruit. These results indicate that a nutritional imbalance established early during fruit ontogeny may be responsible for internal breakdown. It is also possible that an unknown factor triggered the biochemical processes that resulted in those elevated N and P concentrations in the disordered fruit, resulting in the early ripening of the mesocarp.

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