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Title

Growth and Nutrient Uptake into Mangosteen (*Garcinia mangostana* L.) Fruit

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Introduction

Physiological disorders associated with inadequate calcium (Ca) nutrition have been reported in numerous tree fruits including mangosteen (Bangerth, 1979; Pludbuntong et al., 2007; Poovarodom and Boonplang, 2008). Mangosteen fruit with low Ca is susceptible to translucent flesh and gamboge disorders. High potassium (K) to Ca ratio was linked to translucent flesh disorder which is a consequence of impaired membrane function. Meanwhile, gamboge disorder was associated with imbalanced calcium-boron ratio. Calcium deficiency increases membrane permeability (Bangerth, 1979) and contributes to the release of solutes from cytoplasm.

Low Ca concentration in fruits are not primarily caused by low Ca supply or low Ca uptake by the plant but by limited ability of the plant to distribute Ca in phloem (Bangerth, 1979). It has been suggested that Ca uptake by the fruit occurred only during the first part of its growth period (Faust, 1989) while other reported that Ca uptake was continuous and linear until harvest (Tromp, 1979; Zavalloni et al., 2001). Accumulation pattern of Ca is unique to each fruit and can differ widely among studies depending on cultivar, climate and cultural practices. As far as we know, there are no data available on mineral accumulation in mangosteen fruit. Therefore, this study was undertaken to investigate the growth and accumulation of Ca, K, Mg and B in mangosteen fruit so that effective methods for controlling the content of these minerals and their balance could be developed. The uptake of Mg was determined due to its antagonistic effect with K and Ca.

Materials and Methods

The experiment was conducted on a twenty-year-old commercial mangosteen orchard in Chantaburi, Eastern Thailand. The soil was a sandy clay loam (Huai Pong series, Typic Paleudults) with pH 4.8, EC 100 $\mu\text{S cm}^{-1}$, organic matter 2.3%, CEC 9.0 cmol kg^{-1} , avail P (BrayII) 375 mg kg^{-1} , exchangeable (NH_4OAc) K, Ca and Mg 81, 377 and 34 mg kg^{-1} , respectively. Hot water B was 0.3 mg kg^{-1} .

Sampling of fruit commenced on February 11th, 2008, approximately one week after fruit set and concluded on May 5th, 2008. Two fruits were collected from each of the 32 mangosteen trees every week for five weeks. Thereafter, one fruit from each tree were collected every two weeks. The fruits were chosen from the outer canopy between 1.5-2 m above the ground and were representative of the average size of fruit on each tree. The fruits were soak briefly in 0.1 M HCl followed by 3 rinses in distilled water to remove residuals from the surface. The long peduncle attached to harvested fruit was cut off at the base of the calyx and discarded. The fruit equatorial diameter and fresh weight were determined. Then each fruit was sliced and chopped with all the rind, flesh and seeds included. Each sample was dried at 70°C and the dry weight was measured. Subsequently, each sample was ashed at 550°C for 5 hr. The ashes were dissolved in 10 mL 1N HCl and 10 mL of distilled water. Concentrations of K, Ca, Mg and B in the aliquot were determined by ICP-OES (Perkin Elmer Optima 4300DV). Sigmaplot 2001 (SPSS Inc., USA) was used for curve fitting and calculation of coefficient of determination.

Results and Discussion

Fruit Growth

Fruit fresh weight, dry weight (rind and flesh) increased throughout the season in a pattern fitted well by a single sigmoid curve with coefficient of determination of 0.99 (Figure 1a). Fruit mass growth during the first four weeks was slow (average 0.52 g d^{-1} fresh weight) since this stage was largely dominated by cell division (stage I). Thereafter the mass increased linearly with fruit age until the last week of sampling at a higher average rate of 1.01 g d^{-1} fresh weight mainly due to cell enlargement (stage II). In this stage most of the final weight

was achieved. The previously observed stage III where the growth rate decreases was not seen in this study since the fruits were collected before they were ripe.

The fruit diameter also increased steadily for 9 weeks before leveling off (Figure 1b). The diameter growth rate was greater at early stage of fruit development compared to fruit mass. There was a strong correlation between fruit weight and diameter (Figure 2) and the relationship was best described by second-order polynomial.

The observed increase in fruit weight with time is similar to the establishing growth pattern of many other fruits (Bollard, 1970). The strong relationship between fruit diameter and weight allows the fruit weight at maturity to be predicted by measuring the fruit diameter, which is much preferred since it is a non-destructive measurement.

Concentration of nutrients in fruit

Concentration of K, Ca, Mg and B in mangosteen fruit declined sharply during the first 5 weeks after fruit set to reach values which remained relatively constant or decreased only gradually until harvest (Figure 3). This was largely due to the rate of nutrient accumulation was less than that of fruit growth at early fruit development. Thereafter, the increase in fruit mass was countered by higher nutrients movement into fruit. Seasonal change of all nutrients can be described by a second-order polynomial function. There was a 3-fold decrease in Ca and B during this period whereas in the case of K, and Mg lesser decline were observed. Similar decline in nutrient concentrations were reported in persimmon (Clark and Smith, 1990), and pomegranate (Mirdehghan and Rahemi, 2007). However, a slightly different behavior was seen in navel orange (Storey and Treeby, 2000) where initial Ca increase was observed.

Nutrient Accumulation by fruit

The quantity of individual nutrients accumulated by the fruit was calculated as the product of their elemental concentration and dry mass yield. The rate of accumulation varied among nutrients. At harvest, fruit content of K, Ca and Mg was 5.17, 0.65 and 0.52 mmol fruit⁻¹ respectively, while fruit B content was 9.46 μM fruit⁻¹. The amount of K, Mg and B increased linearly with time. However, the accumulated Ca did not increase linearly as the amount of Ca appeared to increase rapidly initially before tapering off at high fruit age (Figure 3). About 65% of Ca was accumulated in the first 7 weeks after the fruit set (stage I and early stage II) whereas only 50-53% of K, Mg and B were taken up during the same period. In comparison, only 46% of fruit dry weight was acquired in this 7-week period. In the subsequent 6 weeks of development, Ca continued to move into the fruit but rate of accumulation was lower whereas K, Mg and B continued to accumulate throughout the growing season. The linear increase in K, Mg and B accumulation with fruit growth is similar to trends found in other fruits. (Zavalloni et al., 2001; Storey and Treeby, 2002; Mirdehghan and Rahemi, 2007) indicating that these nutrients were transported into fruit via phloem. The results also suggested that B may be relatively phloem-mobile in mangosteen.

It was generally suggested that most Ca entered the fruit during the first part of its growth via xylem and that the Ca content level off during the remaining period (Faust, 1989). In this study, however, we found increase in Ca content until fruit harvest although the rate of increase appeared to be lower. The continue increase in Ca indicates that xylem influx was not completely eliminated or that Ca flow via phloem occurred to some degree (Tromp and Oele, 1972). Measurement of water potential in mangosteen leaf and fruit from the same branch indicates movement of water into the fruit at the end of fruit development (Suntaree Yingjajaval, personal communication). This is consistent with our finding that Ca was transported into fruit late in the growing season. Different plant varieties strongly differ in their ability to maintain the functional xylem vessel during fruit growth (Lang, 1990). In

grape, the xylem inductivity is not reduced and therefore xylem vasculature probably continues to carry nutrients into the peel even in the late stage of fruit development (During et al., 1987; Findlay et al., 1987). Rainfall might increase Ca uptake when temperature and light are not restricting (Wilkinson, 1968). In this orchard condition, a total amount of 312 mm rainfall was recorded during the last 5 weeks of fruit development which might increase the amount of Ca transport into fruit. Our results were in agreement with several previous studies in apples (Wilkinson, 1968; Tromp, 1979; Zavalloni et al., 2001), which observed a steady increase of Ca content in apple fruits.

The pattern of Ca accumulation in mangosteen fruit suggest that in order to raise Ca content effectively, soil or spray application of Ca should not be limited to the early period after the fruit sets but extended to harvest. Late Ca sprays were more effective than early sprays in apple cultivars where Ca uptake continues to harvest (Zavalloni et al., 2001; Casero et al., 2002).

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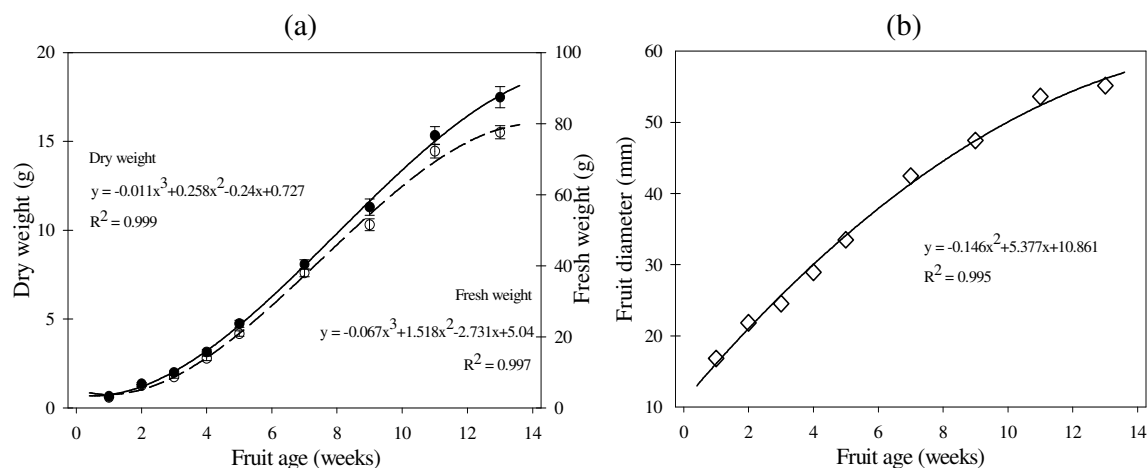


Figure 1 Seasonal changes in fruit fresh weight (○), dry weight (●) (a) and diameter (b) of mangosteen fruit (n=32). Error bars ($\pm$ SE) shown where larger than the symbols.

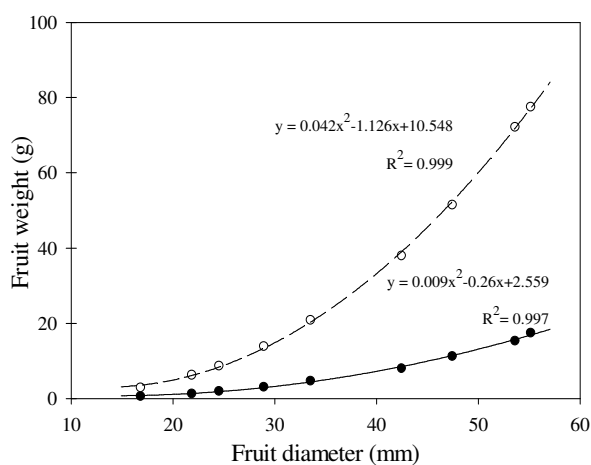


Figure 2 Relationship between fruit fresh weight (○) and dry weight (●) and fruit diameter of mangosteen fruit (n=32)

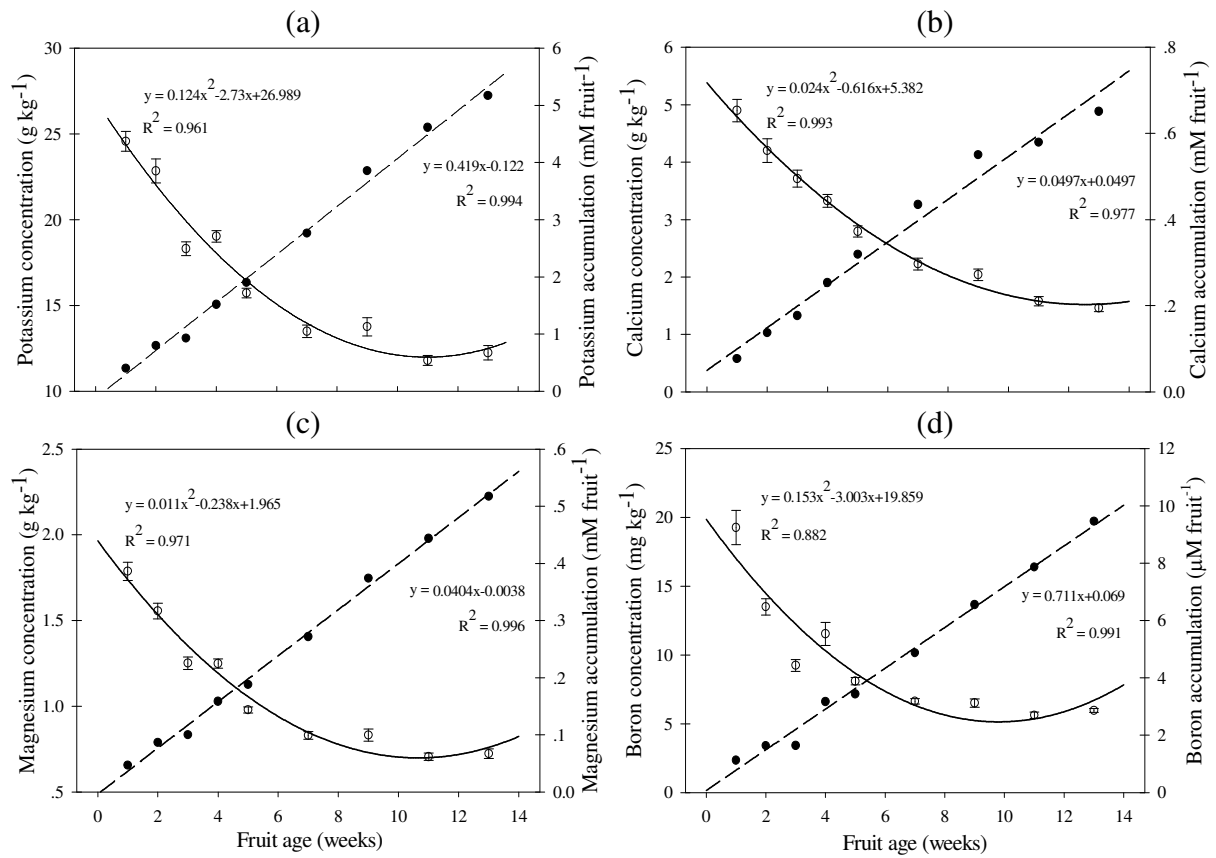


Figure 3 Seasonal changes in K, Ca, Mg and B concentration (○) and accumulation (●) of mangosteen fruit (n=32). Error bars (± SE) shown where larger than the symbols.