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Growth and Physiological Changes of *Averrhoa carambola* as Influenced by Water Availability

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ABSTRAK

Kajian tegasan air ke atas pertumbuhan dan fisiologi yang berkaitan bagi tanaman Averrhoa carambola *dijalankan dalam dua kajian berasingan menggunakan kaedah gabungan tegasan air. Kajian pertama jelas menunjukkan pengurangan pertumbuhan berkait rapat dengan pengurangan kedapatan air. Terdapat korelasi yang signifikan di antara potensi air dan pengurangan kedapatan air. Terdapat korelasi yang signifikan di antara potensi air dan pengurangan konduksi stomata, kadar transpirasi dan kadar fotosintesis. Pengurangan kadar fotosintesis hanya berlaku apabila potensi air daun mengurang sehingga -0.85 MPa. Walau bagaimanapun, pengurangan kandungan klorofil hanya berlaku pada tahap tegasan air yang ketara. Kaitan di antara ciri-ciri fisiologi dan pertumbuhan vegetatif di bincangkan.*

ABSTRACT

Utilizing an integrated soil moisture stress approach, two different experiments were conducted simultaneously to investigate the effects of water stress on growth and related physiological characteristics of Averrhoa carambola. *The first experiment clearly indicated a high correlation between soil water availability and a reduction in plant vegetative growth. In the second experiment, there was a significant correlation between leaf water potential and a reduction in stomatal conductance, transpiration rate and photosynthesis rate. The inhibition of photosynthesis rate was only apparent when leaf water potential was reduced to -0.85 MPa. However, chlorophyll content was only affected by a further reduction in water availability. The relationship between physiological characteristics and vegetative growth is discussed.*

INTRODUCTION

Starfruit *(Averrhoa carambola)* has been recognized as one of the major crops in the Malaysian fruit industry. According to the Department of Agriculture Malaysia (DOA, 1990), establishment of young plants in the field must be carried out during the early rainy season to ensure better root growth. In addition, Coloma (1972) suggested that irrigation should be carried out for the first 2 - 3 years in areas with a prolonged dry season. However, information relating to the effects of water availability on growth and its physiological responses are generally scarce and details of the physiological water status pertaining to this particular crop need further investigation.

It is acknowledged that water status could limit growth and plant development through its effect on plant physiological processes (Kramer 1983; Jones 1990. The responses of plant physiological processes also vary according to the status of water potential developed in a plant. Basically, water stress may reduce leaf water potential which consequently reduces turgor potential in the cell which in turn affects cell expansion (Hsiao and Acevedo 1974). Considering the importance of water requirements of this crop, this study was undertaken to examine the growth and plant physiological characteristics that are influenced by differing water availability. The study also aimed at elucidating the relationship between physiological responses and water status in the plants.

MATERIALS AND METHODS

The experiments were conducted at the Greenhouse Unit at Universiti Pertanian Malaysia, Serdang, Selangor. The average daily temperature ranged between 28-35°C and the relative humidity was between 65-72%. Four-month-old uniform plants of *Averrhoa carambola* of clone B17 grafted on B10 stock plants were planted in pots which were 38 x 30 x 28 cm in size containing 13 kg soil mixture of 3:2:1 (top soil: organic manure: sand). Plants were raised according to the recommendations of DOA (1990).

Two different sets of experiments were conducted simultaneously. In the first experiment, plants were watered to field capacity at intervals of 0, 3 and 6 days for 12 weeks, whilst in the second set of experiments, plants were subjected to water stress for 3, 7, 10, 14, 17 and 21 days. The changes in plant physiological characteristics were monitored for the period of water stress. Both experiments were conducted in a completely randomized design with 4 replications.

Stem extension rate was recorded at weekly intervals. After twelve weeks of treatment, leaves were enclosed in the polythene bags and individual leaf area was recorded using an automatic leaf area meter (Delta-T, Cambridge, UK). Plants were separated into shoots and roots and oven dried at 80°C for 48 hours.

Trifoliate terminal leaflets with 2 cm petiole were excised and immediately placed in a pressure chamber (PMS Ins. Utah, U.S.A) to determine leaf water potential. Techniques and precautions for the determination were as described by Turner (1981). Stomatal conductance and transpiration rate were determined using a steady state porometer (L1-1600 Li Cor Inc. Nebraska, U.S.A). Measurements were conducted between 1100-1230 h. The measurements of photosynthesis and respiration rates were based on polarographic methodology (Delliu and Walker 1972; Saka and Chisaka 1985). Chlorophyll content was determined according to Mackinney (1942). Measurements of these plant processes were carried out at the vegetative growth stage of the plants.

RESULTS

Fig. 1 illustrates stem extension as influenced by water stress. The stem elongation of plants irrigated at 6-day intervals was reduced to 56% compared to control at termination. However, there was no significant difference ($P>0.05$) between the control and the plants irrigated at 3-day intervals within a week. A similar trend was observed in leaf area and its biomass (Table 1). Reduction in leaf area was 15% and 47% as compared to the control when plants were subjected to water stress for 3 and 6 days respectively. Contrary to expectations, there was no significant difference ($P>0.05$) between control and 3 days of water stress on root biomass. However, the root:shoot ratio was significantly higher ($P>0.05$) on plants treated with 3 days of water stress as compared to the control and 6 days of water stress. There was a general reduction in all physiological processes as a result of a reduction in a leaf water potential. Inhibition of photosynthetic O_2 evolution and respiratory activities was accompanied by a decrease in stomatal conductance resulting in a lower transpiration rate. The compensation point for assimilation of CO_2 was only achieved after 22 days of water stress as indicated in *Fig. 2.* The results also revealed that the photosynthesis rate was significantly reduced when the leaf water potential dropped to - 0.85 MPa after day 7, suggesting that plant photosynthesis is sensitive to small changes in water stress. Correlations between rates of photosynthesis ($r=0.89$) and transpiration ($r=0.92$) with respect to changes in leaf water potential are presented in *Figures 3* and *4* respectively. These linear responses of leaf photosynthesis and transpiration rates to water stress reflect the behaviour of stomatal functioning in contributing to gas exchange and efficiency of water utilisation. Furthermore, a close relationship between photosynthesis rates and stomatal conductance *(Figure 5)* along with the water witholding process was exhibited by the treated plant. In contrast, chlorophyll content was only significantly reduced after 7 days of water stress which coincided with the reduction of photosynthesis rate as high as 33% compared to day 1.

DISCUSSION

The most pronounced effect of reduction of water availability to the plants was growth inhibition (Begg and Turner 1976; Takami *et al.* 1981; Li *et al.* 1989). Cell enlargement is one of the most sensitive processes affected by a change in plant water status (Hsiao 1973). The relationship between growth reduction and plant water status has been widely reviewed elsewhere (Kramer 1983; Schulze 1986). When plants were grown at 3-day intervals of water stress, root:shoot ratio increased. The change in root: shoot ratio is generally considered an adaptive mechanism of plants exposed to mild water stress. Begg and Turner (1976) suggested that a greater allocation of the limited

The enlargement of ovary following fruit set was shown by the increase in weight, length and diameter of the fruit that developed (*Figs. 1 and 2*). The increase in weight was slower during the first six days after anthesis (~ 12 g/day between Day 3 and Day 6) compared to the increase that took place when fruits were between 7 to 11 days old (77 g/day). Fruits that were of commercial age were between 50-150 g in weight and 16-25 cm in length and were usually sorted based on approximate size (length) before sale. Further maturation of fruits was accompanied by a slowing down of the growth rate. Similar observations for the increase in weight were reported by McCreight *et al.* (1978) for pickling cucumber.

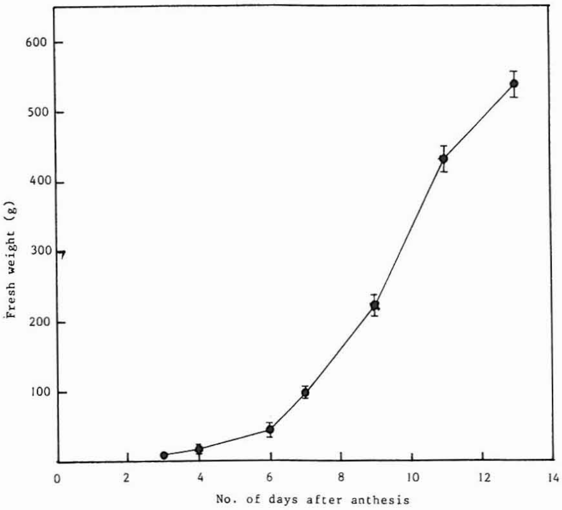

Fig. 1: Mean fresh weight of cucumber fruit during development.

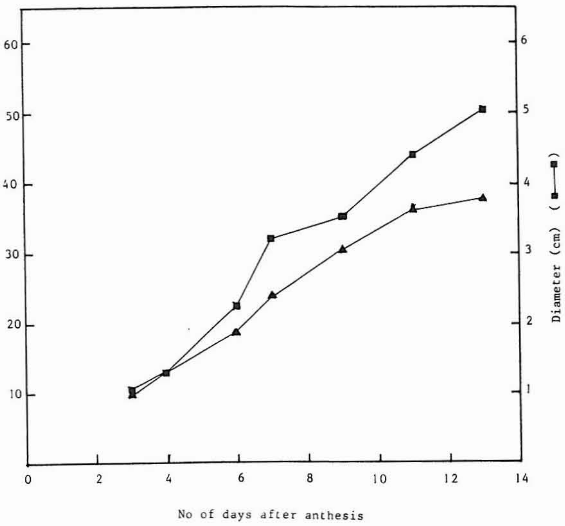

Fig. 2: Mean fruit length and diameter during development.

The increases in length and diameter of the cucumber fruits during the early phases of growth (*Fig. 2*) were found to be more linear than the increase in weight (*Fig. 1*) which tended to follow the sigmoidal type of growth curve. The rate of increase of the diameter of fruits was greater than that of the length. As the fruits became older, the rate of increase of length declined. The diameter of the fruits, however, continued to increase with age and probably accounted for the continued increase in weight. It was also observed that the diameter of the middle section of the fruit was almost always less than the peduncle or blossom ends and the difference was more apparent in mature fruits.

Changes in Chemical Properties.

The moisture content of fruits four days after anthesis was 94.1% and this value increased gradually to 96.4% (s.d = ±0.3%) when fruits were nine days old. No further changes occurred, thereafter.

The ash content of young fruits (Day 4) was found to be 0.61% based on fresh weight. As the fruits develop and mature, the content decreases, and 13 days after anthesis, only 56% of this value remained. In this case, the increase in moisture content alone is not sufficient to account for the dramatic decrease in the ash content. At commercial maturity (6-8 days after anthesis), the ash content ranged from 0.44 - 0.47%, where the mean value was 0.45%. This value is comparable to that reported by Tee *et al.* (1988).

The pH of young cucumber fruits was found to be higher than that of older fruits (*Fig. 3*). The pH decreased from pH 6.8 for Day 3 fruits to 5.8 for Day 11 fruits and little change in pH was then observed. A similar decline in pH was also observed for the 'Chipper' cultivar (McFeeters *et al.* 1982). Studies on the endocarp pH of this cultivar showed that it was much lower than the pH of the overall fruit (McFeeters *et al.* 1982; Handley *et al.* 1983).

The titratable acidity of the fruits increased with age and appeared to reflect the increase in fruit weight (*Fig. 4*). The most rapid increase in titratable acidity occurred when fruits were between seven to nine days old (2.6 ml 0.1 N NaOH per 100 g per day). As the fruits grew older, the rate of increase declined and the titratable acidity remained fairly constant. Although the types of acids present in this fruit were not analysed, two major acids were found to be present in other cucumbers (Handley *et al.* 1983; McFeeters *et al.*

1982). These were malic and citric acids with malic acid being more predominant.

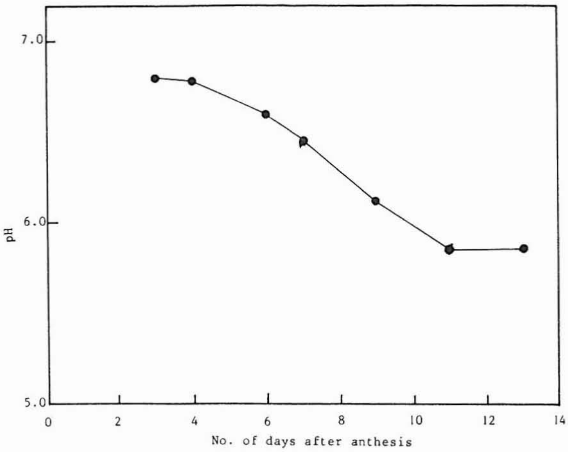

Fig. 3: Changes in the pH of fruit during development and maturation.

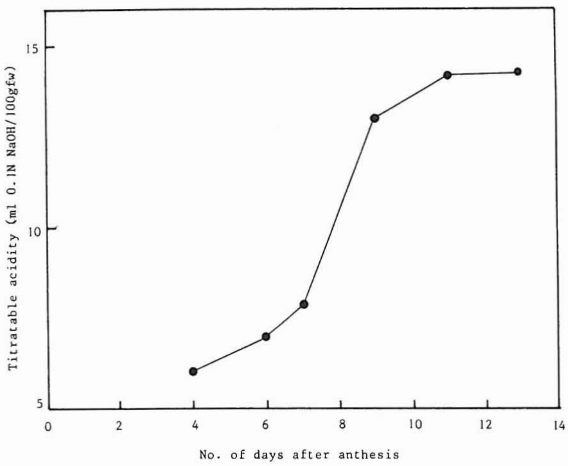

Fig. 4: Titratable acidity during development of fruit.

Total soluble solids (TSS) were found to steadily decrease with growth (*Fig. 5*). The decrease in TSS content was related to some extent to the decrease in the ascorbic acid content (*Fig. 6*). Young immature fruits were found to contain higher concentrations of ascorbic acid compared to more mature fruits. As can be seen in *Fig. 6*, the ascorbic acid concentration decreased with growth and fruits at commercial maturity contained 18.1 mg (± 2.2mg) of ascorbic acid per 100 g of fresh weight of fruit. The decline in the ascorbic acid content was less dramatic after the fruits had reached the commercial age.

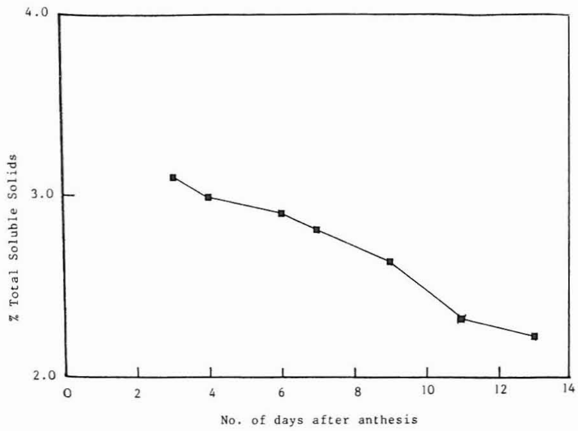

Fig. 5: Changes in TSS of fruit following anthesis.

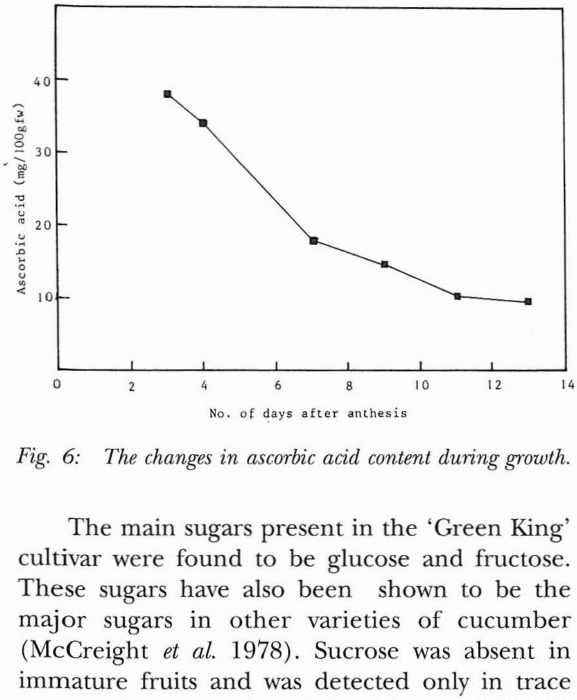

Fig. 6: The changes in ascorbic acid content during growth.

The main sugars present in the 'Green King' cultivar were found to be glucose and fructose. These sugars have also been shown to be the major sugars in other varieties of cucumber (McCreight *et al.* 1978). Sucrose was absent in immature fruits and was detected only in trace amounts in more mature fruits. Pharr *et al.* (1977) reported that sucrose was the major sugar present in the fruit peduncle. Sucrose is believed to enter the fruit from the peduncle, metabolising into glucose and fructose (Pharr *et al.* 1977; Gross and Pharr 1982). In the fruit itself, sucrose was shown to be concentrated at the funiculi (Handley *et al.* 1983), the stalk by which the seed is attached to the placenta of the fruit. This might also be the case with the cucumber cultivar under study.

Fig. 7 shows the changes that take place in the glucose and fructose contents as the cucumber fruits develop and mature. The glucose and fructose concentrations began to increase after anthesis and reached maximum levels nine days later. At this stage, their mean concentrations were 1.10% (ranging from 0.97 - 1.23%) and 1.44% (ranging from 1.24 - 1.64%), respectively. After nine days of growth, the content of the two sugars declined but at a slower rate than the increase and coincided with the rapid phase of fruit development (*Fig. 1*).

The concentration of fructose was higher than the concentration of glucose at all stages of development and maturation of the fruit (*Fig. 7*) with the ratio of fructose to glucose varying between 1.17 and 1.31. Handley *et al.* (1983) who studied the effect of tissue pH on fructose and glucose concentrations of the 'Chipper' cultivar found the fructose content to be always higher than the glucose content in the endocarp of the fruit. The difference in concentrations was less discernible in the mesocarp.

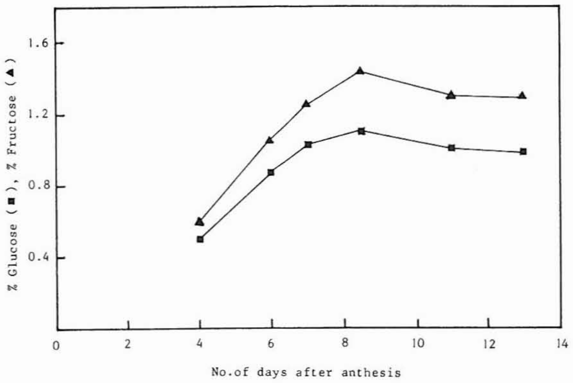

Fig. 7: The average concentrations of glucose and fructose during fruit development.

Since glucose and fructose constituted the majority of the reducing sugar, the increase in the latter reflected the increase in the monosaccharides during growth and was optimum when fruits were nine days old (2.54%). A similar trend was reported by McCreight *et al.* (1978) for several cucumber cultivars. The average maximum reducing sugar concentration of the gynoecious and monoecious cucumbers under study was found to be about 2.5%. They also reported that reducing sugars accounted for about 91% of the total carbohydrates of the 'Chipper' cultivar.

CONCLUSION

The results obtained showed that while the length and weight of the fruits increased with age, the effects of growth on the chemical properties of fruits were more varied. For example, the moisture content remained fairly constant throughout growth. The pH, ascorbic acid content and total soluble solids, on the other hand, experienced a drop in value but there was an increase in value for the sugar content and titratable acidity. Fruits of commercial age were only a fraction (10-20%) of the weight that could be achieved by the fruits during growth but they contained the optimum concentrations of sugars and levels of ascorbic acid present in a maturing fruit.

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REFERENCES

ADAM, P. 1980. Nutrient Uptake by Cucumbers from Recirculating Solution. *Acta Hortic.* **98**: 119-126.

AOAC. 1970. *Official Methods of Analysis.* Assoc. Official Analytical Chemists, Washington, DC.

COOPER, A.J. 1975. Crop Production in Recirculating Nutrient Solution. *Scientia Hortic.* **3**: 251-258.

GISLEROD, H.R. 1978. Experiment with Roses in Different Systems of Recirculating Nutrient Solution and Different Growing Media. *Acta Hortic.* **82**: 99-108.

GISLEROD, H.R. and A.R. SELMER-OLSEN. 1980. The Responses of Chrysanthemum to Variations in Salt Concentration when Grown in Recirculating Nutrient Solution. *Acta Hortic.* **98**: 201-209.

GROSS, K.C. and D.M. PHARR. 1982. A Potential Pathway for Galactose Metabolism in *Cucumis sativus* L., A Stachyose Transporting Species. *Plant Physiol.* **69**: 117-121.

HANDLEY, L.W., D.M PHARR and R.F. MCFEETERS. 1983. Carbohydrate Changes during Maturation of Cucumber Fruit. *Plant Physiol.* **72:** 498-502.

HURD, R.G. 1978. The Root and its Environment in the Nutrient Film Technique of Water Culture. *Acta Hortic.* **82**: 87-97.

LIM, E. S. 1988. NFT-trough System for Soilless Crop Production. *Berita Penyelidikan, U.P.M.* **3(1)**: 1, 7.

MCCREIGHT, J.D., R.L. LOWER and D.M. PHARR. 1978. Measurement and Variation of Sugar Concentration of Pickling Cucumber. *J. Am. Soc. Hort. Sci.* **103:** 145-147.

MCFEETERS, R.F., H.P. FLEMING and R.L. THOMPSON. 1982. Malic and Citric Acids in Pickling Cucumbers. *J. Food Sci.* **47**: 1859-1861, 1865.

PHARR, D.M., H.N. SOX, R.D. LOCY and S. C. HUBER. 1977. Identification and Distribution of Soluble Saccharides in Pickling Cucumber Plants and their Fate in Fermentation. *J. Am Soc. Hort. Sci.* **102**: 406-409.

SALMAH, Y. and M. SUHAILA. 1987. Physico-chemical Changes in Guava (*Psidium guajava* L.) during Development and Maturation. *J. Sci Food Agric.* **33**: 31-39.

TEE, E.S., MOHD. ISMAIL NOOR, MOHD. AZUDIN and KHATIJAH IDRIS. 1988. *Nutrient Composition of Malaysian Foods.* ASEAN Food Habits Project National Sub-Commitee on Protein : Food habits Research and Development, Malaysia. UPM: Serdang.

ZAHARAH, A.R., H. ABD. GHANI, A.R. KHALIP. 1985. Pengeluaran Tanaman Sayuran melalui Sistem Hidroponik. In Proceedings of *Biologi untuk Industri* ed. M.T. Noraini, A. Ismail, H. Osman, H. Roznah, M. Zainon and A.M.A. Zubaid. p 393-400. UPM: Serdang.

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