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Root morphological characteristics in relation to growth of four tropical fruit seedlings

(Sifat morfologi akar dan hubungannya dengan pertumbuhan anak benih empat jenis buah-buahan tropika)

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Key words: root length, root branching, plant growth, tropical fruits

Abstrak

Sifat morfologi akar dan hubungannya dengan pertumbuhan anak benih empat jenis buah-buahan tropika iaitu manggis (*Garcinia mangostana* L.), rambutan (*Nephelium lappaceum* L.), cempedak (*Artocarpus champeden* L.) dan durian (*Durio zibethinus* Murr.) telah dikaji. Biji benih buah-buahan ini disemai dalam beg polietilena (30 cm x 36 cm) yang mengandungi 10 kg campuran tanah (3 tanah: 2 pasir: 1 tahi lembu). Anak benih berada di semaian dengan naungan 50% selama 15 bulan dan pertumbuhan diukur setiap 3 bulan. Hasil daripada pengukuran menunjukkan perbezaan yang ketara dari segi pertumbuhan dan sifat akar antara jenis buah-buahan yang dikaji. Manggis lambat tumbuh dan mempunyai sistem akar yang kurang berkembang berbanding dengan jenis buah-buahan lain. Ketumpatan panjang akar (KPA) manggis pada peringkat 15 bulan masing-masing 66, 73 dan 78% lebih rendah daripada KPA durian, cempedak dan rambutan. Ketumpatan cabang akar (KCA) manggis juga 21, 27 dan 45% lebih rendah daripada KCA durian, cempedak dan rambutan. Perkaitan yang rapat dan positif antara KPA (r^2 = 0.72) dan KCA (r^2 = 0.96) dengan kadar net asimilasi menunjukkan bahawa akar yang pendek dan kurang bercabang mengurangkan jumlah pengeluaran bahan kering anak benih manggis. Sebaliknya, jenis buah-buahan yang agak cepat tumbuh seperti rambutan, cempedak dan durian mempunyai akar yang lebih panjang dan bercabang. Sehubungan dengan itu, usaha untuk mencepatkan pertumbuhan anak benih buah-buahan yang lambat tumbuh harus menjurus kepada pembaikan sifat morfologi dan fungsi akar.

Abstract

Root morphological characteristics and their relationships with growth habits of four tropical fruit seedlings, namely mangosteen (*Garcinia mangostana* L.), rambutan (*Nephelium lappaceum* L.), cempedak (*Artocarpus champeden* L.) and durian (*Durio zibethinus* Murr.), were studied. Seeds of selected fruit species were sown in black polyethylene bags (30 cm x 36 cm) each filled with 10 kg of potting mixture (3 soil: 2 sand: 1 cow dung). All seedlings were grown under 50% shade for 15 months during which growth measurements were taken every 3 months. Results showed large differences in growth and root characteristics among fruit types. Slow growing mangosteen had poorly developed root system compared to other fruit species. Root length density (RLD) of mangosteen at 15 months was 66, 73 and 78% less than durian, cempedak and rambutan

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respectively. Similarly, root branching capacity (RBD) at 15 months was 21, 27 and 45% less than durian, cempedak and rambutan respectively. Strong and positive correlations between RLD (r^2 = 0.72) and RBD (r^2 = 0.96) with net assimilation rate indicate that shorter root length and poor root branching strongly contributed to lower dry matter production in mangosteen seedlings. In contrast, relatively fast' growing fruit species such as rambutan, cempedak and durian have significantly longer root length and better root branching. In the context of this study, attempts to enhance growth of slow growing fruit seedlings such as mangosteen should be directed towards improving the morphological characteristics and function of roots.

Introduction

Rapid root development is essential to growth and establishment of many plant species. Root is a major vegetative organ involving in the uptake of essential nutrients and other substances for plant growth and development. Therefore, enhanced root growth and nutrient uptake are key factors in increasing shoot growth (Wieble et al. 1992). Leskovar and Stoffella (1995) described that optimum root growth is important in ensuring optimum shoot growth and hence plant yield.

Most studies of root growth are still based on root dry weight measurements (Chapin 1980) which may not actually reflect the volume of soil explored by the roots. McKeand and Allen (1984), in their study on loblolly pine, found a difference in the relationship between nutrient uptake based on root dry weights and that based on root surface area. This result emphasized the need to study root morphology in relation to plant growth.

Root morphological characteristics that affect the absorbing surface area are root length and root radius. Root length density (RLD, root length per unit soil volume) is an important characteristic affecting nutrient absorption. Root acquisition of nutrients is based more on root length or root surface area than root mass (Miller 1986; Baon et al. 1994). Root branching, another important characteristic, determines the root surface in contact with growing medium, thereby the water absorption and nutrient uptake (Wieble et al. 1992). An important component of root branching capacity is the lateral root production. Lateral roots are important for the initiation of tertiary roots. Lack of laterals may reduce the number of tertiary roots and hence reduces nutrient uptake.

There are species differences in tree root system which reflect their strategies for acquisition of below-ground resources and growth capability. However, species differences in root morphology are difficult to quantify. Atkinson (1980) demonstrated consistent differences in mean RLD between species of fruit trees. Similar measurements of root distribution based on mean RLD were conducted by Masri (1991, 1993), Kumar et al. (1993) and Hughes et al. (1995). However, most of these studies did not relate root length and branching characteristics with plant growth. Hence, this work was undertaken to determine the extent to which root characteristics such as root length density and root branching could explain differences in growth of four tropical fruit seedlings, namely mangosteen (*Garcinia mangostana* L.), rambutan (*Nephelium lappaceum* L.), cempedak (*Artocarpus champeden* L.) and durian (*Durio zibethinus* Murr.).

Materials and methods

Growth conditions

Seeds of selected fruit species were collected from research plots at MARDI Research Station in Bukit Tangga, Kedah. They were sown directly into black perforated polyethylene bags (30 cm x 36 cm), each filled with 10 kg of potting mixture. The potting mixture comprising soil, sand and cow dung (3: 2: 1 by volume) was thoroughly mixed using a soil mixer (Zabedah and Rukayah 1988). Prior to seed sowing, each bag was given 30 g of NPK 15:15:15 as basal dressing. When fully germinated, 20 uniform seedlings from each species were randomly selected and transferred into a nursery with 50% shade. Plants were arranged in four blocks using the randomised complete block design with adequate border rows. Irradiance density in the nursery varied from 50 μmol/m^2/s at 0900 h to 400 μmol/m^2/s at 1300 h. All plants received daily irrigation to field capacity. *Malathion* 57% EC was applied to control leaf feeding insects whenever necessary. Seedlings were grown in the nursery for 15 months during which growth measurements were taken at 3-month intervals.

Plant harvests and growth measurements

At each harvest, stem diameter was measured at 5 cm above the collar using a digital caliper (Mitutoyo Corp., Japan). Leaf number per plant was manually counted while the total leaf area was determined by a leaf area meter (Delta-T Device, UK). On completion of these measurements, plants were separated into shoots and roots. Leaves and stems were oven dried separately at 80 °C to constant weights. Total plant dry weight was recorded as the total dry weight of leaves, stems and roots at each harvest.

Soil plus roots from polyethylene bags were gently washed through a 2-mm sieve under running water to free roots from adhering soil particles. Length of cleaned tap-root was measured with a ruler and the number of lateral roots attached was recorded. All live roots attached to the tap-root plus detached roots collected from the sieve were assembled and their root length determined according to Tennant (1975). Root length density (RLD) was estimated by dividing the root length with the soil volume. Root branching density (RBD) was calculated as the number of laterals per unit length of tap-root (Feil et al. 1988).

Instantaneous net assimilation rate and relative growth rate were calculated using equations proposed by Gardner et al. (1986). Dry matter production efficiency was calculated as gram dry weight per unit trunk cross-sectional area.

Design and statistical analysis

The experimental design was a randomized complete block design with four replications. Analysis of variance (ANOVA) and regression analyses were performed using the procedures of Statistical Analysis System (SAS Institute Inc. 1985). Least Significant Difference (LSD) was used for test of significance.

Results

Plant growth

Dry matter production efficiency (DMPE) of all fruit species is shown in *Table 1*. Time course response showed that DMPE of all fruit species increased progressively with time. Rambutan was the most efficient, followed by cempedak and durian. Mangosteen was very inefficient in dry matter production. At 15 months, the average DMPE of mangosteen was about 34–57% less than other fruits. Similarly, instantaneous relative growth rate (RGR) also increased progressively with time *(Table 1)*. Durian and rambutan had the highest RGR while cempedak was intermediate and mangosteen showed the least. At 15 months, the RGR of mangosteen was 20, 16 and 11% less than durian, rambutan and cempedak respectively. Instantaneous net assimilation rate (NAR) of rambutan was most superior followed by cempedak, durian and mangosteen. Again, mangosteen had the lowest NAR at all growth stages. At 15 months, the NAR of mangosteen was 59, 48 and 44% less than rambutan, durian and cempedak respectively.

Table 1. Dry matter production efficiency, net assimilation rate and relative growth rate of four fruit species at five growth stages

Fruit species	Dry matter production efficiency (g/cm^2 TCA) after sowing					Net assimilation rate ($g/cm^2/week$) after sowing					Relative growth rate (g/g/week) after sowing				
	3 mth	6 mth	9 mth	12 mth	15 mth	3 mth	6 mth	9 mth	12 mth	15 mth	3 mth	6 mth	9 mth	12 mth	15 mth
Mangosteen	1.97d	5.85c	7.39d	8.65d	10.41c	3.68c	4.88b	6.77c	9.17c	9.93c	0.35c	0.43c	0.50c	0.53c	0.56d
Rambutan	14.17a	18.15a	21.11a	23.11a	24.48a	8.41a	9.35a	12.95b	16.52a	24.10a	0.55a	0.63a	0.67a	0.67a	0.67b
Cempedak	4.11c	9.10b	15.65b	15.68b	15.78b	6.95b	9.90a	15.40a	15.97a	17.65b	0.51b	0.55b	0.61b	0.63b	0.63c
Durian	8.78b	9.36b	10.75c	11.41c	15.70b	5.99b	8.72a	12.38b	13.58b	19.23b	0.54a	0.62a	0.66a	0.68a	0.70a

Mean values within each plant age with the same letter are not significantly different at $p < 0.05$ according to LSD
TCA = trunk cross-sectional area

Table 2. Root morphological characteristics of four tropical fruit species at five growth stages

Fruit species	Length of tap-root (cm) after sowing					No. lateral roots/plant after sowing				
	3 mth	6 mth	9 mth	12 mth	15 mth	3 mth	6 mth	9 mth	12 mth	15 mth
Mangosteen	15.8b	21.6b	27.8b	28.8b	29.4b	14.8b	15.5c	18.8c	24.3c	28.0c
Rambutan	15.5b	18.6b	23.4bc	27.5bc	28.5bc	16.3b	22.8b	33.5b	42.5b	48.0b
Cempedak	16.1b	16.7b	17.6c	21.1c	21.6c	16.0b	18.8bc	31.0b	33.3b	37.5b
Durian	21.5a	40.2a	44.1a	48.0a	55.8a	51.5a	55.8a	63.0a	64.8a	62.0a

Mean values in each column with the same letter are not significantly different at $p < 0.05$ according to LSD test

Root growth

Length of tap-root did not differ significantly among mangosteen, rambutan and cempedak seedlings at various stages of plant growth *(Table 2)*. However, durian consistently showed longer tap-root. At 15 months, its tap-root was almost doubled in length compared to those of rambutan, cempedak or mangosteen seedlings.

Lateral root production differed among the four fruit species. Mangosteen, rambutan and cempedak had about similar numbers of laterals at 3 months. However, the number of lateral roots of mangosteen increased by only 75% as compared to 200% and 138% increments in rambutan and cempedak respectively after 15 months of growth. Consistently, durian produced a significantly larger number of lateral roots at all growth stages.

Large differences in RLD were observed between mangosteen and other fruit species *(Figure 1)*. At all growth stages, the RLD of mangosteen was significantly lower than the other fruit species. For rambutan, cempedak and durian, a significant increase in their respective RLD was observed at 12 months of age. However, these RLDs decreased tremendously at 15 months, probably due to root growth being restricted by the bag size. Relatively, the RLD of mangosteen was 66, 73 and 78% less than durian, cempedak and rambutan after 15 months of growth.

Root branching density (RBD) is defined as the number of laterals per unit length of tap-root. Again, mangosteen consistently had lower RBDs than other fruit species throughout the 15-month period. These values were significantly lower than other fruit species as early as 6 months after sowing *(Figure 2)*. Root branching of rambutan showed a steady increase with time but the RBDs of durian and cempedak fluctuated considerably during the period. At 15 months, the RBD of mangosteen was 21, 27 and 45% less than durian, cempedak and rambutan respectively.

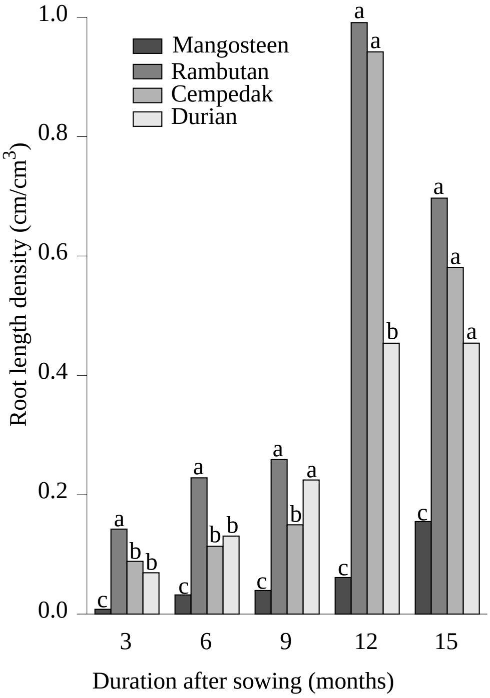

Figure 1. Root length density of four tropical fruit species at five growth stages after sowing. Mean values within each plant age with the same letter are not significantly different at $p < 0.05$ according to LSD

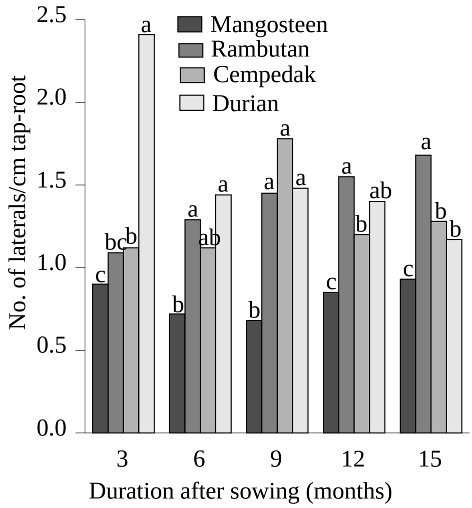

Figure 2. Root branching density of four tropical fruit species at five growth stages after sowing. Mean separations are as described in Figure 1

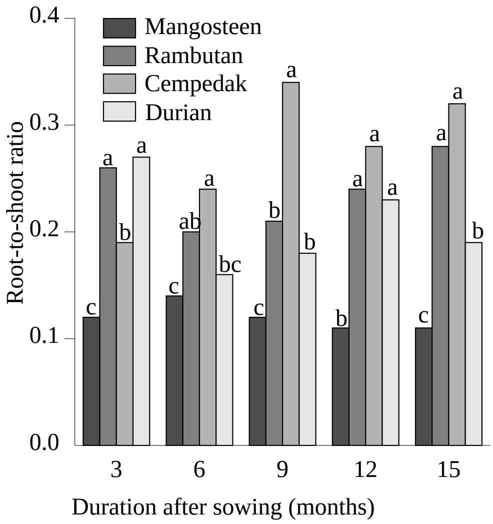

Figure 3. Root-to-shoot ratio of four tropical fruit species at five growth stages after sowing. Mean separations are as described in Figure 1

Root-to-shoot ratio

The root-to-shoot ratio of mangosteen seedlings was significantly smaller than all other three fruit species at all stages of plant growth *(Figure 3)*. At 15 months, cempedak had the largest root-to-shoot ratio, followed by rambutan and durian. The average root-to-shoot ratio for these three fruit species was almost double that of mangosteen.

Discussion

Biomass production is commonly used to characterize plant growth. A vigorous growing plant usually has a larger biomass accumulation than the slow growing ones. Large variations in growth rate were observed among fruit species studied. Mangosteen plants exhibited the lowest DMPE and NAR, and hence lower RGR than other fruit species. As plant growth is correlated with an increase in biomass (Fetcher et al. 1983), lower dry matter production clearly denotes the slow growth habit of mangosteen following seed germination. These findings agree with Rukayah and Zabedah (1992) who found that dry matter production of mangosteen is low, especially during the first 12 months of growth. Rambutan is the highest dry matter producer, followed by cempedak and durian. This is not surprising since rambutan and cempedak seedlings growth relatively 'fast' even under field conditions.

Root morphological characteristics have significant contribution to differences in seedling growth. Root length density is one characteristic affecting nutrient absorption in soil. Lower RLD reduces absorbing surface area of roots and hence reduces nutrient uptake. Mangosteen which showed the slowest growth, consistently had lower RLD than the other fruit species throughout the study. Positive correlation between RLD and NAR of mangosteen ($y = 4.52 + 39.90x$, $r^2 = 0.72^{**}$) was observed, suggesting greater dry matter production with longer root length. Similarly, rambutan which had the fastest growth, consistently had the highest RLD. Since root acquisition of nutrients is based more on root length and root surface area (Miller 1986; Baon et al. 1994), RLD is therefore an important root characteristic affecting nutrient absorption.

Branching structure of root system is central to their function (Fitter 1991). Lack of lateral roots was evidently observed in mangosteen, the slowest grower. Durian produced the largest number of laterals followed by rambutan and cempedak. Lack of laterals has strong implications on the ability of roots to absorb nutrients. Reduced number of laterals may have reduced tertiary root production that is important in nutrient uptake. Laterals provide an important means for increasing the absortive area as well as the volume of substrate exploited by roots (Charlton 1991). Inefficient lateral root production leads to poor root branching. Root branching is indeed critical in nutrient and water absorption and hence plant growth. Mangosteen, a slow grower, had significantly poorer root branching capacity than the other fruit species studied. Regression analysis shows strong positive correlation between RBD and NAR in mangosteen ($y = -2.66 + 0.47x$, $r^2 = 0.96^{**}$). This indicates that poor root branching significantly reduced dry matter production and hence plant growth due to restricted root functions. Wieble et al. (1992) stated that poor branching of root system will limit contact between root surface and growing medium, thereby restricting water absorption and nutrient uptake.

Poorter and Remkes (1990) concluded that slow growing plants usually maximize root rather than shoot functions and have larger root-to-shoot ratios. This is not true in the case of slow growing mangosteen. In comparison with the other three fruit species, the root-to-shoot ratio of mangosteen was significantly small, suggesting that less dry matter being allocated to roots. This in turn had reduced root functions and hence resulted in slow growth of mangosteen seedlings.

Conclusion

Results of this experiment show that root morphological characteristics, particularly root length and root branching, have strong relationship with plant growth. Relatively 'fast' growing fruit species such as rambutan, cempedak and durian, usually have greater root length and better root branching than slow growing mangosteen seedlings which have extremely shorter root length and poor root branching. Slow growing mangosteen also allocates less dry matter to roots than rambutan, cempedak or durian. Since root morphological characteristics such as root length density, number of laterals and root branching density are strongly associated with seedling growth, attempts to accelerate growth of slow growing fruit species such as mangosteen should, therefore, be directed towards improving root growth and functions.

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