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Growth, photosynthesis and biomass allocation of different kenaf (*Hibiscus cannabinus* L.) accessions grown on sandy soil

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Abstract

Growth, photosynthesis, and biomass allocation of kenaf accessions were investigated. Forty kenaf accessions from tropical and subtropical regions of the world were grown on marginal sandy soil in a field at Kelantan to determine differences in their growth, photosynthesis and biomass allocation. The experiment was arranged using three replicates in a randomized complete block design. Basal diameter, plant height, leaf number, leaf area and photosynthesis were measured, these being the determinants of growth and biomass production. Plant roots, stems and leaves were separated and biomass content determined at harvest. Accession 35 had the highest value for basal diameter (17.44 mm), plant height (251.73 cm), leaf quantity (81.55), leaf area (1455.62 cm^2 $plant^{-1}$) and photosynthesis (16.92 µmol $m^{-2}s^{-1}$), followed by accession 28. A positive relationship was noticed between plant height, leaf area, photosynthesis, biomass production, root mass and leaf area. Total biomass for the different kenaf accessions ranged from 26.26 to 93.06 g plant-^{1}(-1 needs to be superscripted). Stems accounted for the greatest proportion of dry mass (67.05%), followed by roots (21.15%). Dry mass accumulation in the stem was highest in accession 35, followed by accession 28. Using cluster analysis, the accessions were divided into two major groups, in which accessions 35 and 28 from the first group had the highest values of all measured parameters. The results of the study will aid in the selection of better accessions for growers to produce kenaf that is best suited to marginal sandy soil.

Keywords: Biomass; BRIS soil; growth; kenaf accessions; photosynthesis.
Abbreviations: BRIS–beach ridges interspersed with swales; CEC–cation exchange capacity; DAP–days after planting; MOP–muriate of potash; TSP–triple super phosphate.

Introduction

Kenaf (*Hibiscus cannabinus* L.) is an annual fibre crop and is considered to be a potential source of raw material for manufacturing paperboard products, and may also be a substitute for fibreglass and other synthetic fibres. As a fibrous crop, kenaf appears to have enormous potential to become a valuable biomass crop of the future (Alexopoulou et al., 2000). Kenaf also has high potential to be used as a raw material for boards with low density panels, suitable for both sound absorption and thermal resistance (Sellers et al., 1993). It has also been used as a raw material alternative to wood in pulp production and the paper industries (Ardente et al., 2008). The inner part of the plant (core) is applicable as an adsorbent animal bedding material (Lips et al., 2009). Since the plant is fast-growing, kenaf also has a good ability to sequester carbon and can produce a large quantity of biomass. Given its high adaptability to all kinds of soils, kenaf has the potential to be planted on problem soils that have a characteristically low productivity, and are poor in water-holding capacity and nutrient availability (Roslan et al., 2010). In Malaysia, where fertile land is scarce, the use of less fertile soils, such as BRIS soil, will be required for large scale production of kenaf. The soils on beach ridges in Malaysia are locally known as BRIS soil. This soil is characterized by a sandy texture and is found along the coastal plains of the Malaysian Peninsula and Borneo Island. The BRIS soils along the east coast of the Malaysian Peninsula and the coastal areas of Sabah cover about 200,000 ha in total, with 155,500 ha on the Peninsula and 40,500 ha in Sabah. These soils contain 82–99% sand particles, mainly quartz, and have a low CEC of about 9.53 cmol kg^{-1} soil and a pH ranging between 4.3 and 4.4 (Chen, 1985; Roslan et al., 2010). Plant growth and biomass production can be influenced by many physiological processes and environmental factors, but photosynthesis is the major basis for growth and biomass yield of crops. It is obvious that photosynthesis contributes about 90 % of total dry mass. Hence, plants having efficient photosynthetic mechanisms can produce high biomass. The basic index of plant photosynthetic activity is net photosynthesis (Wong et al., 1985; Knapp et al., 1993; Eamus, 1996). Information relating to photosynthesis of kenaf accessions is scanty and remains to be explored. A review of existing literature revealed that there is scarce information on growth, photosynthesis, biomass production and its allocation, particularly in low fertility sandy soils. Given the increase in utilization of its strong and long fibre, the mass production of kenaf can be of benefit to the wood and fibreboard industries throughout the world. Therefore, this study on its growth, photosynthesis, and biomass allocation is important in determination of the options for growing different accessions of kenaf on BRIS soil. We hypothesized that growth, photosynthesis and biomass allocation differ in their response to different kenaf accessions. Hence, the objective of this study was to determine the growth, photosynthesis and biomass allocation of different kenaf accessions planted on sandy soil.

Results and discussion

Growth indices and photosynthesis

The basal diameter and plant height showed significant differences between the different kenaf accessions (Table 2). Accession 35 had the highest basal diameter and plant height, followed by accession 28, and accession 27 had the lowest basal diameter and plant height. The variation in plant height of different kenaf accessions could be attributed to the variation in the rate of photosynthesis observed in the present study. Our results were in accordance with those of Agbaje et al. (2008), who report significant variation in plant height of different kenaf varieties, and found that Cuba 108 and Ifekan 400 were both taller in height than Ibadan local. Plant height extension and variation are attributable to variation in growing internodes, leaf addition on main-stem and branches, and expansion of the area of all leaves capable of growth and photosynthesis (Reddy et al., 1997, 2004; Gerik et al., 1998; Reddy and Matcha, 2010). Leaf number and leaf area varied significantly among kenaf accessions (Table 2). Of the accessions studied, the maximum leaf number and leaf area were observed in accession 35, and the minimum in accession 27. Leaf number, total leaf area and plant height are the major factors influencing photosynthesis of the plant and therefore biomass production (Reddy and Matcha, 2010). This finding supports our results which indicated a positive relationship between plant height and biomass production, and total leaf area and biomass production (Figs. 2 and 3). Significant variations in growth and biomass production were also observed in different cultivars of rapeseed (Afshari et al., 2011). Photosynthesis markedly differed among the kenaf accessions (Table 2). Accession 35 had the highest rate of photosynthesis, followed by accession 28; the lowest rate of photosynthesis was observed in accession 27. In the present study, it was observed that biomass production was positively related to rate of photosynthesis (Fig. 4). As net photosynthesis is closely related to growth and biomass production, this could be interpreted as evidence that accession 35 is more efficient in terms of growth and biomass yield in comparison with other kenaf accessions used in this study. Yaghoob et al. (2011) noticed significant variation in photosynthesis rate among different kenaf varieties, reporting that the variety KK60 had the highest amount of net photosynthesis. As net photosynthesis is a major factor influencing growth and biomass production, the differences in photosynthesis could be attributed to the variable outcome of growth and biomass production in kenaf accessions.

Biomass production

All the kenaf accessions exhibited variability in biomass accumulation (Table 3). The root, stem, leaf and total biomass were observed to be highest in accession 35 followed by accession 28, and accession 27 had the lowest values of these parameters. Plant biomass production is positively related to plant height, leaf area and photosynthetic

Table 1. Number, name and country of origin of kenaf accessions used in the present study.

Number of accessions	Name of accessions	Country of origin
1	K482-109	France
2	V36	China
3	E41	United States
4	A63-478	Philippines
5	7-1X	United States
6	15	United States
7	N.S.002	Thailand
8	A62-427	Sudan
9	KK60	Thailand
10	Cuba2032	Cuba
11	K465/118	France
12	Everglade71	United States
13	NSDB63-1	Philippines
14	Tainung2	Taiwan
15	Elsalvador	El Salvador
16	BG53-14	Egypt
17	BG53-31	United States
18	Ghanamixed 07	Ghana
19	K465/117	France
20	117	United States
21	1X51	Indonesia
22	BG52-38	Cuba
23	G29	Guatemala
24	Guatemala 4	Guatemala
25	75-52	Tanzania
26	BG61-20	United States
27	BG53-42	United States
28	HW1-from-kirlin	China
29	Cuba797	Cuba
30	G46	Guatemala
31	75-71	Tanzania
32	Gregg	Iran
33	G7	Guatemala
34	Tainung	Thailand
35	C75	Bangladesh
36	113	United States
37	FDW-75-33	Australia
38	FDW-75-82	United States
39	Mahmur	Zambia
40	CQ3205	Australia

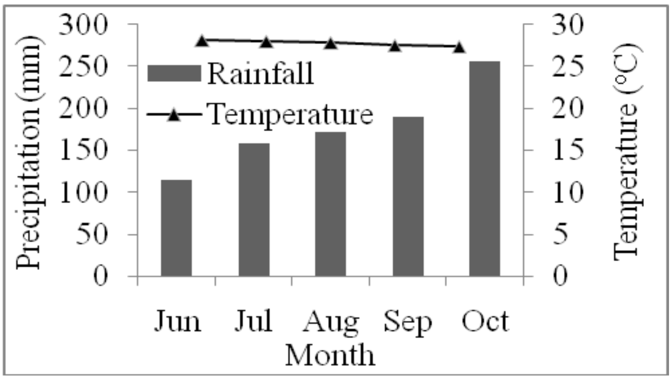

Fig 1. Monthly total precipitation (mm) and monthly mean temperature (^{o}C) for the experimental site during the experimental period.

Table 2. Basal diameter, plant height, leaf number, leaf area and photosynthesis of different kenaf accessions.

Accessions	Basal diameter (mm)	Plant height (cm)	Leaf number	Leaf area (cm^2 $plant^{-1}$)	Photosynthesis (μmol $m^{-2}s^{-1}$)
1	$16.13\pm 0.64^{a-g}$	$227.57\pm19.76^{a-f}$	$77.54\pm2.39^{b-h}$	$1292.82\pm14.11^{g-i}$	15.98 ± 0.25^{fg}
2	$15.70\pm1.51^{a-i}$	$221.27\pm25.92^{a-i}$	$76.35\pm2.20^{c-l}$	1251.22 ± 23.04^{jk}	$15.77\pm0.25^{g-i}$
3	$14.68\pm1.32^{c-l}$	$201.87\pm40.65^{c-l}$	$73.66\pm2.11^{j-s}$	1146.22 ± 41.09^{pq}	$14.88\pm0.17^{o-q}$
4	$15.74\pm1.48^{a-i}$	$222.53\pm22.22^{a-i}$	$76.65\pm1.90^{c-l}$	1266.16 ± 21.62^{ij}	15.83 ± 0.19^{gh}
5	$16.56\pm0.57^{a-d}$	$237.23\pm17.07^{a-c}$	$79.38\pm1.83^{a-d}$	1385.22 ± 40.10^{cd}	$16.71\pm0.14^{a-c}$
6	$14.26\pm1.19^{f-m}$	$194.03\pm38.68^{e-m}$	$72.56\pm1.71^{m-w}$	$1094.35\pm27.96^{s-u}$	$14.64\pm0.23^{q-s}$
7	$16.01\pm1.84^{a-h}$	$222.77\pm16.72^{a-h}$	$77.22\pm1.93^{b-e}$	1287.67 ± 27.21^{hi}	15.94 ± 0.27^{fg}
8	$15.67\pm3.08^{a-j}$	$220.40 \pm16.01^{a-i}$	$75.96\pm2.51^{e-o}$	1242.24 ± 29.01^{jk}	$15.72\pm0.23^{g-j}$
9	$12.70\pm2.06^{l-n}$	$184.27\pm17.95^{h-m}$	$70.36\pm2.80^{s-x}$	$1065.55\pm20.89^{u-x}$	13.82 ± 0.21^{wx}
10	$16.48\pm1.04^{a-d}$	$232.73\pm 43.61^{a-e}$	$78.58\pm2.35^{a-f}$	1342.45 ± 44.99^{ef}	16.55 ± 0.32^{cd}
11	$15.64\pm2.37^{a-j}$	$218.30\pm46.63^{a-j}$	$75.24\pm2.07^{f-q}$	1196.22 ± 29.01^{lm}	$15.55\pm0.33^{i-k}$
12	$14.47\pm0.92^{d-m}$	$194.97\pm23.99^{d-m}$	$72.74\pm2.21^{m-v}$	1097.72 ± 50.61^{st}	$14.71\pm0.33^{p-s}$
13	$14.75\pm1.60^{c-k}$	$206.80\pm14.96^{c-k}$	$73.88\pm2.30^{j-s}$	$1156.23\pm31.02^{o-q}$	$14.96\pm0.29^{n-p}$
14	$14.65\pm0.36^{c-l}$	$201.43\pm7.56^{c-l}$	$73.35\pm2.37^{k-t}$	1133.65 ± 35.09^{qr}	14.84 ± 0.21^{pq}
15	$16.61\pm0.53^{a-d}$	$237.30 \pm29.28^{a-c}$	$79.65\pm2.31^{a-e}$	1392.46 ± 55.22^{cd}	$16.75\pm0.16^{a-c}$
16	$16.49\pm0.84^{a-d}$	$233.97\pm21.93^{a-d}$	$78.92\pm2.60^{a-f}$	1366.64 ± 26.79^{de}	16.62 ± 0.20^{bc}
17	17.18 ± 1.72^{ab}	247.90 ± 21.06^{ab}	80.25 ± 2.3^{ab}	1435.16 ± 41.40^{ab}	16.84 ± 0.07^{ab}
18	$13.40\pm1.62^{j-n}$	$184.33\pm32.96^{h-m}$	$70.85\pm2.33^{r-x}$	$1072.28\pm38.04^{v-x}$	13.94 ± 0.18^{vw}
19	$13.75\pm0.26^{i-m}$	$187.27\pm9.09^{h-m}$	$71.54\pm1.98^{p-w}$	$1078.23\pm33.42^{t-w}$	14.16 ± 0.40^{uv}
20	$14.48\pm0.10^{d-m}$	$197.07\pm21.38^{d-l}$	$72.94\pm2.18^{l-u}$	1115.54 ± 50.09^{rs}	$14.76\pm0.27^{p-r}$
21	$15.02\pm1.24^{b-j}$	$208.47\pm31.04^{b-j}$	$74.16\pm2.01^{k-s}$	$1165.55\pm31.90^{n-p}$	$15.15\pm0.41^{m-o}$
22	$13.88\pm0.08^{g-m}$	$187.77\pm7.01^{h-m}$	$71.71\pm2.20^{p-w}$	$1082.27\pm35.01^{t-w}$	14.33 ± 0.29^{tu}
23	12.28 ± 0.51^{mn}	$168.27\pm11.80^{k-m}$	$69.12\pm2.00^{v-x}$	1044.45 ± 30.09^{x}	13.66 ± 0.25^{xy}
24	$15.21\pm0.21^{a-j}$	$214.03\pm31.64^{a-j}$	$74.75\pm2.20^{g-r}$	1187.75 ± 23.40^{mn}	$15.37\pm0.31^{k-m}$
25	$12.45\pm0.61^{l-n}$	$178.77\pm10.78^{j-m}$	$69.46\pm1.89^{u-x}$	1055.66 ± 36.91^{wx}	$13.72\pm0.24^{w-y}$
26	$12.46\pm1.16^{l-n}$	$182.80\pm18.37^{i-m}$	$69.79\pm2.00^{t-x}$	1061.23 ± 32.01^{xy}	$13.78\pm0.26^{w-y}$
27	11.57 ± 0.26^{n}	157.13 ± 15.93^{m}	67.72 ± 2.04^{x}	994.82 ± 29.50^{y}	13.15 ± 0.31^{z}
28	17.40 ± 0.35^{a}	249.83 ± 11.84^{a}	81.15 ± 2.50^{ab}	$1452. 86\pm43.38^{a}$	16.88 ± 0.05^{ab}
29	$15.65\pm0.67^{a-j}$	$218.57\pm13.22^{a-i}$	$75.62\pm1.91^{e-o}$	1225.12 ± 35.33^{kl}	$15.66\pm0.21^{h-j}$
30	$16.95\pm0.60^{a-c}$	$238.20\pm26.62^{a-c}$	$79.88\pm1.93^{a-d}$	1412.22 ± 50.07^{bc}	$16.78\pm0.14^{a-c}$
31	$16.45\pm2.01^{a-d}$	$230.63\pm13.67^{a-f}$	$78.15\pm2.03^{a-f}$	1321.23 ± 41.06^{fg}	16.34 ± 0.30^{de}
32	$16.19\pm0.06^{a-f}$	$227.77\pm15.52^{a-f}$	$77.87\pm1.64^{a-g}$	1311.23 ± 44.99^{gh}	16.12 ± 0.41^{ef}
33	$15.03\pm0.73^{b-j}$	$213.87\pm25.45^{a-j}$	$74.45\pm1.99^{g-s}$	$1177.22\pm27.99^{m-o}$	$15.22\pm0.25^{l-n}$
34	$15.26\pm1.20^{a-j}$	$215.53\pm13.10^{a-j}$	$74.93\pm2.01^{f-r}$	1192.33 ± 41.09^{mn}	$15.46\pm0.27^{j-l}$
35	17.44 ± 1.06^{a}	251.73 ± 6.31^{a}	81.55 ± 2.07^{a}	1455.62 ± 41.86^{a}	16.92 ± 0.10^{a}
36	12.26 ± 0.58^{mn}	165.67 ± 34.65^{lm}	68.57 ± 2.01^{wx}	1042.35 ± 30.09^{x}	13.52 ± 0.19^{y}
37	$15.85\pm0.54^{a-h}$	$222.67\pm15.87^{a-i}$	$76.94\pm1.98^{c-k}$	1282.15 ± 26.30^{hi}	$15.88\pm0.23^{f-h}$
38	$14.08\pm1.08^{f-m}$	$191.10\pm15.60^{f-m}$	$72.27\pm1.99^{p-w}$	$1092.82\pm30.39^{s-u}$	$14.52\pm0.30^{r-t}$
39	$13.92\pm1.64^{f-m}$	$190.27\pm39.39^{g-m}$	$71.92\pm1.64^{p-w}$	$1087.74\pm24.48^{s-v}$	14.45 ± 0.31^{st}
40	$13.55\pm0.70^{i-m}$	$184.40\pm6.15^{h-m}$	$71.16\pm2.05^{q-w}$	$1076.62\pm34.79^{u-w}$	13.97 ± 0.25^{vw}

Data are expressed as mean values ± SD, dash between letters means 'to.' Means with the same superscripted letters are not significantly different at $P \leq 0.05$.

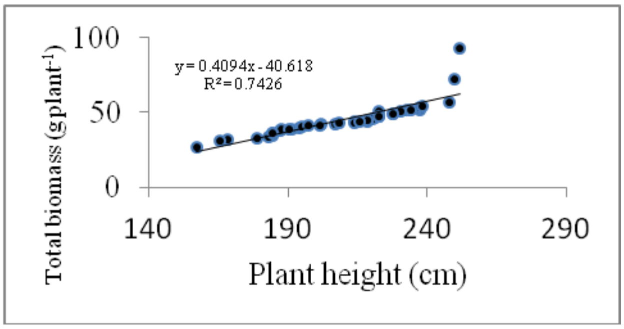

Fig 2. Relationship between plant height and total biomass of different kenaf accessions.

ability (Malik, et al., 2007; Li et al., 2009). In our study, the highest total biomass in accession 35 could be attributed to its values for plant height, leaf area and photosynthesis, which were also the highest (Table 3). On the other hand, the lowest total biomass of accession 27 could be due to the shorter plant height, and smaller leaf area. This is because the reduction in leaf area limits photosynthesis and further decreases biomass production (Li et al., 2009), consistent with the positive correlation between total leaf area and biomass production, and photosynthesis and biomass production (Figs. 3 and 4). It is reported that the function of leaf photosynthesis is to supply the carbohydrate necessary for growth and biomass production of the crop. In addition, root growth depends on the supply of carbohydrate from the above ground parts (Ogbonnaya et al., 1998), and therefore the smallest leaf area could be expected to produce the

Table 3. Root, stem, leaf and total biomass of different kenaf accessions.

Accessions	Root dry mass (g plant^{-1})	Stem dry mass (g plant^{-1})	Leaf dry mass (g plant^{-1})	Total biomass (g plant^{-1})
1	10.80 ± 1.33^{bc}	32.35 ± 0.42^{g}	6.01 ± 0.48^{ef}	49.16 ± 1.37^{gh}
2	$9.84\pm3.59^{c-g}$	31.34 ± 0.16^{h}	$5.57\pm0.32^{f-h}$	46.75 ± 4.03^{ij}
3	$10.17\pm0.13^{b-f}$	26.75 ± 1.02^{op}	$5.20\pm0.59^{f-k}$	$42.12\pm0.63^{m-o}$
4	$10.12\pm0.87^{b-f}$	32.47 ± 0.75^{g}	$4.58\pm0.13^{j-n}$	47.17 ± 0.26^{i}
5	10.96 ± 1.13^{bc}	35.92 ± 0.74^{de}	$5.17\pm0.27^{f-k}$	52.05 ± 1.59^{ef}
6	$7.24\pm0.63^{k-l}$	28.48 ± 0.27^{l}	$4.09\pm0.46^{l-o}$	$39.81\pm1.06^{p-r}$
7	$8.70\pm0.32^{e-j}$	$35.21\pm0.17^{d-f}$	6.75 ± 0.56^{de}	50.66 ± 0.32^{fg}
8	10.64 ± 0.09^{bc}	29.74 ± 0.64^{jk}	$5.58\pm0.35^{f-h}$	$45.96\pm0.55^{i-k}$
9	$8.21\pm0.32^{g-l}$	23.50 ± 0.30^{r}	2.79 ± 0.29^{p}	34.50 ± 0.82^{st}
10	11.97 ± 1.37^{b}	33.25 ± 0.20^{g}	6.72 ± 1.14^{de}	51.94 ± 0.62^{ef}
11	$7.90\pm0.89^{h-l}$	31.35 ± 0.35^{h}	$4.98\pm0.31^{g-k}$	$44.23\pm0.63^{k-m}$
12	$7.31\pm0.64^{k-l}$	$28.13\pm0.49^{l-n}$	$4.94\pm0.45^{g-l}$	$40.38\pm1.20^{o-r}$
13	$7.99\pm0.53^{g-l}$	28.57 ± 0.26^{l}	$5.60\pm0.92^{f-h}$	$42.17\pm1.37^{m-o}$
14	$7.68\pm0.55^{h-l}$	28.41 ± 0.40^{l}	$5.60\pm0.29^{f-h}$	$41.69\pm0.72^{n-p}$
15	$10.35\pm0.86^{b-d}$	35.76 ± 0.58^{de}	7.40 ± 0.38^{cd}	53.51 ± 0.38^{de}
16	$8.01\pm0.48^{g-l}$	38.29 ± 0.16^{c}	5.62 ± 0.26^{fg}	51.92 ± 0.41^{ef}
17	14.89 ± 0.55^{a}	34.37 ± 1.30^{f}	7.69 ± 0.31^{c}	56.96 ± 1.12^{c}
18	$8.48\pm2.67^{e-k}$	22.73 ± 0.67^{rs}	$4.88\pm0.35^{g-l}$	36.09 ± 2.93^{s}
19	$7.66\pm1.39^{h-l}$	26.01 ± 0.36^{pq}	$4.62\pm0.41^{i-n}$	38.29 ± 0.75^{r}
20	$7.54\pm0.14^{h-l}$	28.21 ± 0.48^{lm}	$5.17\pm0.74^{f-k}$	$40.92\pm1.10^{o-q}$
21	$7.72\pm0.65^{h-l}$	30.04 ± 0.73^{ij}	$5.49\pm0.31^{f-h}$	$43.26\pm0.54^{l-n}$
22	$8.36\pm0.48^{e-k}$	25.48 ± 0.34^{q}	$4.53\pm0.37^{j-n}$	38.37 ± 0.57^{r}
23	$7.45\pm0.65^{h-l}$	20.63 ± 0.08^{u}	$3.87\pm0.24^{m-o}$	31.95 ± 0.78^{u}
24	$8.40\pm0.24^{e-k}$	31.02 ± 0.94^{h}	$4.79\pm0.67^{g-l}$	$44.21\pm1.28^{k-m}$
25	$7.00\pm0.60^{k-l}$	21.82 ± 0.40^{t}	3.78 ± 0.11^{no}	32.61 ± 0.31^{tu}
26	6.73 ± 0.94^{kl}	22.53 ± 0.47^{st}	$4.70\pm0.06^{h-m}$	33.96 ± 1.25^{t}
27	6.35 ± 0.26^{l}	16.98 ± 0.36^{v}	2.93 ± 0.34^{p}	26.26 ± 0.95^{v}
28	15.69 ± 0.46^{a}	47.84 ± 0.40^{b}	8.96 ± 0.47^{b}	72.49 ± 0.47^{b}
29	10.69 ± 0.59^{bc}	29.05 ± 0.70^{kl}	$5.17\pm0.38^{f-k}$	$44.91\pm1.17^{j-l}$
30	10.88 ± 0.16^{bc}	36.13 ± 0.06^{d}	7.16 ± 0.52^{cd}	54.17 ± 0.64^{d}
31	$10.16\pm0.24^{b-f}$	35.14 ± 0.20^{ef}	5.68 ± 0.22^{fg}	50.98 ± 0.50^{fg}
32	$9.31\pm0.79^{c-h}$	35.04 ± 0.75^{ef}	$4.99\pm0.52^{g-k}$	49.34 ± 0.51^{gh}
33	$8.32\pm0.37^{f-k}$	30.67 ± 0.26^{hi}	$4.36\pm0.55^{k-n}$	$43.35\pm1.15^{l-n}$
34	$10.20\pm0.10^{b-e}$	28.71 ± 0.17^{l}	$5.31\pm0.26^{f-j}$	$44.22\pm0.31^{k-m}$
35	15.88 ± 0.05^{a}	66.50 ± 0.28^{a}	10.68 ± 0.10^{a}	93.06 ± 0.34^{a}
36	$6.82\pm0.75^{k-l}$	20.68 ± 0.21^{u}	3.49 ± 0.35^{op}	30.99 ± 0.89^{u}
37	$9.16\pm0.58^{c-i}$	33.27 ± 0.31^{g}	$5.32\pm0.41^{f-j}$	47.75 ± 0.42^{hi}
38	$7.25\pm0.56^{k-l}$	$27.39\pm0.45^{m-o}$	$4.38\pm0.18^{k-n}$	39.02 ± 1.07^{qr}
39	$7.67\pm0.25^{h-l}$	27.25 ± 0.71^{no}	3.77 ± 0.36^{no}	38.69 ± 0.56^{r}
40	$7.57\pm0.88^{h-l}$	25.28 ± 0.32^{q}	3.47 ± 0.40^{op}	36.32 ± 1.54^{s}

Data are expressed as mean values ± SD, dash between letters means 'to.' Means with the same superscripted letters are not significantly different at $P \leq 0.05$.

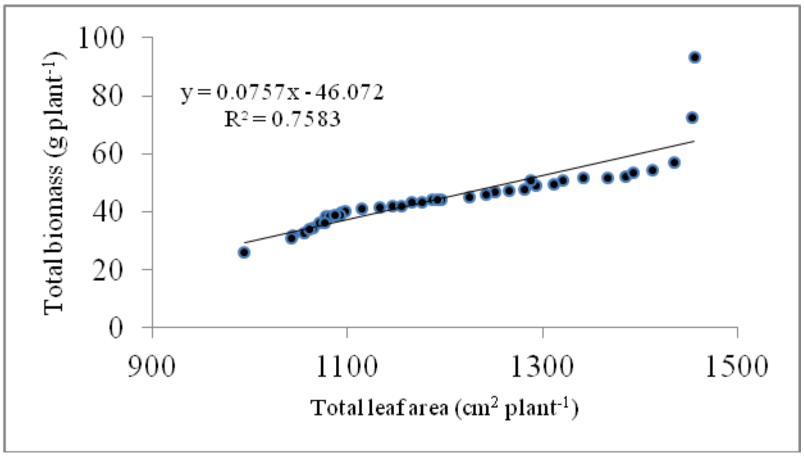

Fig 3. Relationship between total leaf area and total biomass of different kenaf accessions.

minimum root growth in accession 27. This was observed from the positive relationship between root mass and total leaf area in our study (Fig. 5).

Biomass allocation

There was significant difference in biomass allocation among different kenaf accessions (Table 3). Mean comparisons of the kenaf accessions showed that stems accumulated more biomass than leaves and roots across the kenaf accessions. Accession 35 had the highest stem biomass (66.50g), followed by accession 28. Accession 27 contained the lowest stem biomass (16.98g). Alexopoulou et al. (2000) report similar findings, observing the highest biomass allocation in the kenaf stem. Promkhambut et al. (2011) observed significant differences in biomass production of different sorghum cultivars. They found that cv. Wray produced significantly higher stem dry mass than cv. SP1. The commercial product of kenaf is its stem (Danalatos and Archontoulis, 2010). Higher stem mass is an important consideration for the production of higher stalk yield. In selecting varieties to be used for fibre production, higher stalk yields are the major consideration, as they are the source of bast and core fibres (Webber and Bledsoe, 2002; Danalatos and Archontoulis, 2010). The maximum root biomass allocation (15.88 g) was obtained from accession 35, followed by the root mass (15.69 g) of accession 28, while the minimum value of root mass was from accession 27. The highest root mass produced by accession 35 could be attributed to the elevated supply of carbohydrate from the above ground parts, which resulted from the enhancement of photosynthesis due to the higher total leaf area (Ogbonnaya et al., 1998; Li, et.al., 2009). Based on the mean values of plant parts for the different kenaf accessions, the highest amount of biomass was allocated to stems (67.05%), followed by that found in roots (21.15%) (Table 4). Regarding the ratio of stem biomass to total biomass, there was an obvious distinction between kenaf accessions, with the maximum value (71.46%) being found in accession 35 and the minimum value (58.29%) in accession 17. The percentage of stem mass is an important consideration in selecting cultivars to be grown for kenaf fibre production. The majority of the breeding programmes in the US have developed cultivars that are more suited to producing greater percentages of stalk biomass (Webber and Bledsoe, 1993). For example, Webber and Bledsoe (1993) report that the kenaf cultivar, Tainung 2, produced greater stalk biomass in five cultivars. Above ground plant mass showed significant differences among kenaf accessions (Table 4). Regarding yield per unit area, the percentage of total above ground plant mass is crucial for evaluating kenaf cultivars (Webber and Bledsoe, 2002). In our study, accession 35 had the highest above ground plant biomass (82.94%), which was statistically identical to above ground biomass produced by accession 28 (82.76%), and accession 30 had the lowest value (72.86%) of above ground plant mass.

Cluster analysis

In the dendrogram (Fig. 6), the 40 kenaf accessions were divided into two major groups: group 1 included accessions 35 and 28. The members of this group had the highest basal diameter, plant height, leaf number, leaf area, photosynthesis, root, stem, leaf and total biomass production. Group 2 was divided into two subgroups; subgroup 2 was further divided into two sub-subgroups. The members of sub-subgroup 1 had medium values for the measured traits. The distinguishing features of plants in sub-subgroup 2 was that they were low in basal diameter, plant height, leaf number, leaf area, photosynthesis, root, stem, leaf and total biomass accumulation. The differential performance of the accessions in this study may be a function of environmental adaptation, in addition to a genetic component (Ogunbodede and Ajibade 2001).

Materials and methods

Description of the project site

The experiment was carried out in 2010 at Bachok, Kelantan, Malaysia, located at a latitude of 6.07 (6° 4' 0 N) and a longitude of 102.4 (102° 24' 0 E) and at an altitude of 42 m. Based on the revised Malaysian Soil Taxonomy (Paramananthan, 2010), the soil at this site belongs to the Baging series (*Arenic alorthods*) and is classified as Typic Udipsamment, which is equivalent to Haplic Arenosol in the FAO/UNESCO Soil Map of the World, Revised Legend (FAO, 1990). This soil, formed near the coast over marine sands, consists of a series of beach ridges with intervening swales (BRIS). The soil has the following characteristics: sandy texture, 97% sand; total nitrogen, 0.07%; organic C, 0.42%; base saturation, 61%; available P, 0.90 mg kg^{-1} soil; and pH(H_2O) 5.3 (Roslan et al., 2010). The land was ploughed and harrowed, and the seedbed prepared using hand hoes. A basal dressing with triple super phosphate (TSP) and a muriate of potash (MOP) were applied at a rate of 66 kg P ha^{-1} and 125 kg K ha^{-1}, respectively. Nitrogen, in the form of urea fertilizer, was applied at the rate of 300 kg ha^{-1} in three splits at 20-day intervals. Forty kenaf accessions from the tropical and subtropical regions of the world were used for this study (Table 1). Seeds of the kenaf accessions were sown at a spacing of 30 cm × 8 cm, totalling 416,666 plants per ha^{-1}. Each plot size in this trial was 5 m × 1.5 m. The experiment was conducted using a randomized complete block design with three replicates. Alachlor (Lasso), a pre-planting herbicide, was applied at the rate of 3.0 L ha^{-1} and Deltamethrin (Decis), an insecticide, was applied at the rate of 2.0 L ha^{-1} one month after planting to control insects. Some meteorological data of the experimental site are presented in Fig. 1.

Growth and biomass measurements

The plants were harvested at maturity. The basal diameter, plant height, and leaf numbers were determined on five plants in each replicate for each accession. The leaves, stems, and roots were separated and oven-dried at 65^{o}C for 48 h until a constant weight was obtained. Biomass allocation to above and below ground parts was then calculated based on the measurements of oven dry weights of the plant parts. The sampled plants were uprooted to determine the biomass of above and below ground parts.

Leaf area and photosynthesis measurements

Leaf area was measured using the Li-3100 leaf area meter (LiCOR, Inc., Lincoln, Nebraska, USA) for all treatments at harvest. Total leaf area was measured on five plants in each replicate. At 60 days after planting (DAP), net photosynthesis rates of the uppermost, expanded main stem leaves, which were the third from the main axis terminal, from five plants in each treatment were measured between 8:00 and 11:00 h

Table 4. Composition of dry mass (%) to total biomass in plant parts of different kenaf accessions.

Accessions	Root	Stem	Leaf	Above ground
1	$21.94 \pm 2.14^{c-j}$	$65.84 \pm 2.71^{g-k}$	$12.21 \pm 0.66^{b-h}$	$78.06 \pm 2.14^{d-l}$
2	$20.72 \pm 5.84^{e-n}$	$67.34 \pm 5.45^{d-i}$	$11.93 \pm 0.49^{b-k}$	$79.27 \pm 5.84^{a-j}$
3	$24.48 \pm 0.56^{a-e}$	$63.19 \pm 1.07^{k-m}$	$12.31 \pm 1.61^{b-h}$	$75.51 \pm 0.56^{j-n}$
4	$22.23 \pm 1.70^{c-j}$	71.34 ± 2.49^{ab}	6.42 ± 1.22^{n}	$77.77 \pm 1.70^{e-l}$
5	$21.02 \pm 1.62^{d-l}$	$69.02 \pm 0.89^{a-f}$	$9.95 \pm 0.73^{k-m}$	$78.97 \pm 1.62^{b-k}$
6	$18.84 \pm 1.16^{i-n}$	$70.98 \pm 1.91^{a-c}$	$10.16 \pm 0.80^{i-l}$	$81.15 \pm 1.16^{a-f}$
7	$17.96 \pm 0.55^{k-n}$	$70.44 \pm 0.85^{a-d}$	$11.59 \pm 0.33^{e-l}$	$82.04 \pm 0.55^{a-d}$
8	26.37 ± 0.50^{ab}	$62.00 \pm 0.83^{l-n}$	$11.62 \pm 0.71^{d-l}$	73.62 ± 0.50^{mn}
9	$23.92 \pm 2.63^{a-f}$	$69.51 \pm 2.40^{a-e}$	6.56 ± 0.55^{n}	$76.07 \pm 2.63^{i-n}$
10	$21.78 \pm 4.63^{c-k}$	$65.03 \pm 2.50^{h-l}$	$13.17 \pm 2.59^{b-f}$	$78.21 \pm 4.63^{d-l}$
11	$17.84 \pm 1.77^{l-n}$	$70.88 \pm 1.70^{a-c}$	$11.26 \pm 0.70^{f-m}$	$82.15 \pm 1.77^{a-c}$
12	$18.08 \pm 1.27^{k-n}$	$69.69 \pm 1.65^{a-e}$	$12.21 \pm 0.77^{b-h}$	$81.91 \pm 1.27^{a-d}$
13	$18.95 \pm 1.08^{i-n}$	$67.79 \pm 1.62^{c-i}$	$13.25 \pm 1.77^{b-f}$	$81.04 \pm 1.08^{a-f}$
14	$20.32 \pm 0.95^{f-n}$	$66.54 \pm 0.22^{g-j}$	$13.13 \pm 0.83^{b-f}$	$79.67 \pm 0.95^{a-i}$
15	$20.81 \pm 1.45^{e-n}$	$65.61 \pm 1.53^{g-k}$	$13.57 \pm 0.67^{b-}$e	$79.18 \pm 1.45^{a-j}$
16	$23.45 \pm 0.64^{b-h}$	59.85 ± 0.16^{no}	16.69 ± 0.63^{a}	$76.54 \pm 0.64^{g-m}$
17	$25.26 \pm 1.05^{a-c}$	58.29 ± 1.54^{o}	16.44 ± 0.49^{a}	$74.73 \pm 1.05^{l-n}$
18	$23.23 \pm 5.40^{b-h}$	$63.15 \pm 3.69^{k-m}$	$13.62 \pm 1.72^{b-d}$	$76.77 \pm 5.40^{g-m}$
19	$19.96 \pm 3.30^{g-n}$	$67.94 \pm 2.03^{b-i}$	$12.09 \pm 1.34^{b-j}$	$80.04 \pm 3.30^{a-h}$
20	$18.44 \pm 0.97^{j-n}$	$68.93 \pm 0.60^{a-g}$	$12.62 \pm 1.50^{b-g}$	$81.55 \pm 0.97^{a-e}$
21	$17.83 \pm 1.34^{l-n}$	$69.46 \pm 1.87^{a-d}$	$12.70 \pm 0.72^{b-g}$	$82.16 \pm 1.34^{a-c}$
22	$21.75 \pm 0.92^{c-k}$	$66.38 \pm 1.73^{g-k}$	$11.85 \pm 0.89^{c-k}$	$78.22 \pm 0.92^{d-l}$
23	$23.28 \pm 1.50^{b-h}$	$64.60 \pm 1.70^{i-l}$	$12.11 \pm 0.57^{b-i}$	$76.71 \pm 1.50^{g-m}$
24	$19.01 \pm 1.10^{i-n}$	$70.16 \pm 0.54^{a-d}$	$10.82 \pm 1.21^{g-m}$	$80.98 \pm 1.10^{a-f}$
25	$19.85 \pm 0.50^{g-n}$	$68.29 \pm 0.35^{a-h}$	$11.84 \pm 0.46^{c-k}$	$80.14 \pm 0.50^{a-h}$
26	$19.77 \pm 2.08^{h-n}$	$66.38 \pm 1.70^{g-k}$	13.84 ± 0.39^{b}	$80.22 \pm 2.08^{a-f}$
27	$21.57 \pm 0.91^{c-l}$	$64.74 \pm 0.80^{i-l}$	13.68 ± 1.43^{bc}	$78.43 \pm 0.91^{c-l}$
28	17.23 ± 1.40^{mn}	71.40 ± 2.05^{a}	$11.36 \pm 0.96^{f-m}$	82.76 ± 1.40^{ab}
29	$23.62 \pm 0.70^{a-g}$	$64.95 \pm 0.98^{h-l}$	$11.41 \pm 0.46^{f-m}$	$76.37 \pm 0.70^{h-n}$
30	27.14 ± 1.20^{a}	61.33 ± 0.51^{mn}	$11.52 \pm 0.89^{f-l}$	72.86 ± 1.20^{n}
31	$22.28 \pm 0.34^{c-i}$	$67.31 \pm 0.15^{d-i}$	$10.40 \pm 0.28^{h-m}$	$77.71 \pm 0.34^{f-l}$
32	$18.87 \pm 0.33^{i-n}$	$71.01 \pm 0.98^{a-c}$	$10.11 \pm 0.79^{j-l}$	$81.12 \pm 0.33^{a-f}$
33	$24.94 \pm 0.42^{a-c}$	$62.00 \pm 1.38^{l-n}$	$13.05 \pm 1.25^{b-f}$	$75.05 \pm 0.42^{l-n}$
34	$24.76 \pm 0.39^{a-d}$	$63.48 \pm 0.14^{k-m}$	$11.74 \pm 0.50^{c-k}$	$75.23 \pm 0.39^{k-n}$
35	17.05 ± 0.66^{n}	71.46 ± 0.74^{a}	$11.47 \pm 0.43^{f-m}$	82.94 ± 0.66^{a}
36	$21.64 \pm 0.46^{c-l}$	$65.99 \pm 0.57^{g-k}$	$12.35 \pm 0.10^{b-h}$	$78.35 \pm 0.46^{c-l}$
37	$18.41 \pm 1.07^{j-n}$	$70.89 \pm 1.17^{a-c}$	$10.69 \pm 0.76^{g-m}$	$81.58 \pm 1.07^{a-e}$
38	$20.62 \pm 1.28^{f-n}$	$68.43 \pm 0.98^{a-g}$	$10.95 \pm 0.47^{g-m}$	$79.38 \pm 1.28^{a-i}$
39	$19.83 \pm 0.82^{g-n}$	$70.42 \pm 1.43^{a-d}$	9.74 ± 0.87^{lm}	$80.16 \pm 0.82^{a-h}$
40	$20.80 \pm 1.53^{e-n}$	$69.66 \pm 2.23^{a-e}$	9.53 ± 0.70^{m}	$79.19 \pm 1.53^{a-j}$

Data are expressed as mean values ± SD, dash between letters means 'to.' Means with the same superscripted letters are not significantly different at $P \leq 0.05$.

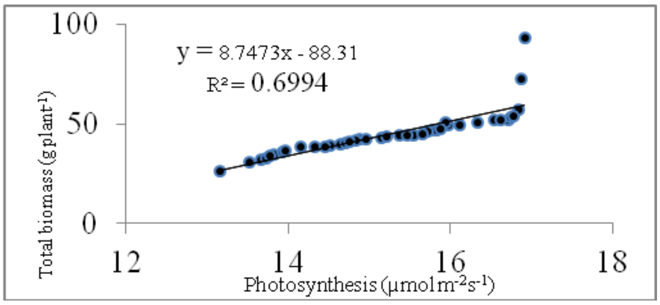

Fig 4. Relationship between photosynthesis and total biomass of different kenaf accessions.

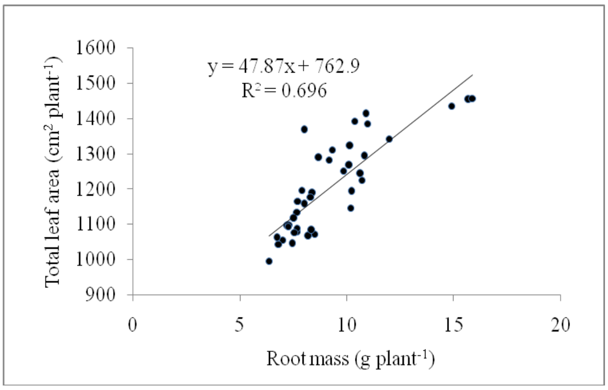

Fig 5. Relationship between root mass and total leaf area of different kenaf accessions

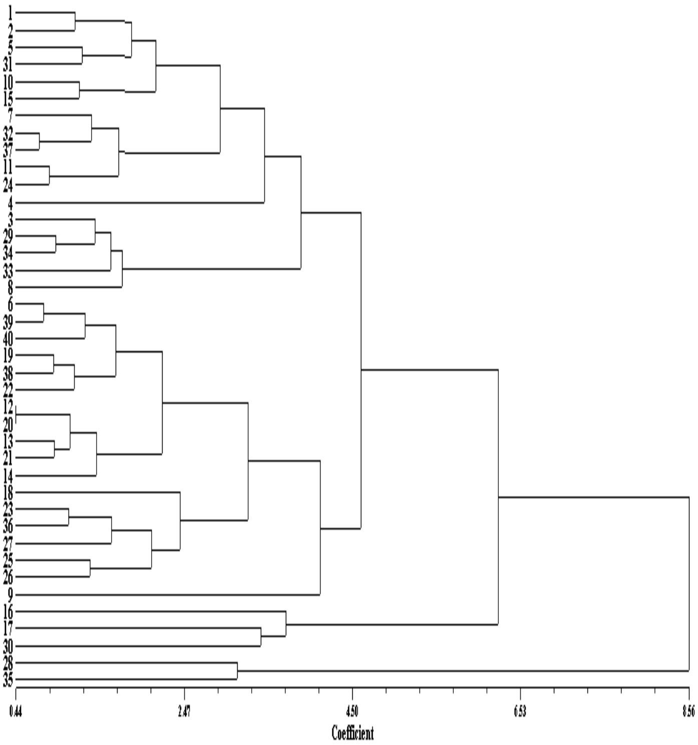

Fig 6. Dendrogram of 40 kenaf accessions based on growth, photosynthesis and biomass data, reflecting average distances among the accessions

using an open gas exchange system, LI-6400XT portable photosynthesis system (LiCOR Inc., Lincoln, Nebraska, USA).

Statistical analysis

Data on growth, photosynthesis, biomass production and its allocation were statistically analysed by using a randomized complete block design with three replicates according to SAS (SAS, 2007). Relationships between variables were determined using a Pearson's correlation coefficient test, and regression analysis was employed for those variables with significant correlations. Data analysis software NTSYSpc was used to produce a dendrogram using the UPGMA method. The significant differences between individual means were performed using Tukey's test.

Conclusion

Kenaf plant growth, photosynthesis, and biomass allocation into roots, stems and leaves varied significantly. Relationships between plant height, total leaf area, photosynthesis and biomass production, root mass and leaf area were all positive. Accession 35 produced the maximum biomass, followed by accession 28. Stems accumulated the highest (67.05%) biomass, followed by root (21.15%). The highest above ground plant mass of all the kenaf accessions was produced by accession 35, followed by accession 28. Among the clusters, accessions 35 and 28 of Group 1 were distinguished by the highest basal diameter, plant height, leaf number, leaf area, photosynthesis, root, stem, leaf, and total biomass. However, based on the growth, photosynthesis, biomass production and its allocation, kenaf accessions 35 and 28 performed better in comparison with all the accessions grown on sandy BRIS soil, and could therefore be the most important accessions that should be considered for cultivation on this sandy marginal soil.

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