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Research Article
Planting Density Effects on Feed and Fibre Yield of Two Kenaf (*Hibiscus cannabinus* L.) Varieties in Malaysia

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Abstract
Background and Objective: Kenaf (*Hibiscus cannabinus* L.) has been identified as a viable alternative crop to replace tobacco in Malaysian agriculture. Since 2001 V36 kenaf variety has long been planted and currently a new variety MHC123 is being evaluated. The study was conducted to determine the effects of planting density and harvesting age on yield and quality of MHC123 compared to V36 kenaf varieties. **Methodology:** The study was conducted at MARDI Serdang Selangor and planting was carried out on 4th-6th April, 2013. The treatments of planting density, harvest age and variety were arranged in a split-split plot design with 4 replications. Harvest age was set as the main plot, planting density as a sub plot and variety as a sub-sub plot. Data were analyzed using SAS software. **Results:** The MHC123 had higher ($p<0.05$) CP content (18%) at planting density of 666,700 plants ha^{-1} while V36 with 20.6% CP at planting density of 500,000 plants ha^{-1}. The MHC123 and V36 varieties had lower ADF content at planting density of 666,700 plant ha^{-1} (30.7 and 30.8%, respectively) compared to the other planting densities. Planting density of 444,400 plants ha^{-1} produced the highest fibre production for MHC123 and V36 where both varieties were higher in dry matter yield, bast yield and core yield compared with other planting densities. Across both varieties, dry matter yield was highest ($p<0.05$) at the lowest planting density of 444,400 plants ha^{-1} at 12.7 t ha^{-1}, followed by decreased dry matter yield of 11.5, 11.2 and 10.3 t ha^{-1} for planting density of 500,000, 571,500 and 666 700 plants ha^{-1}, respectively. **Conclusion:** The MHC123 is superior to V36 variety in leaf yield, stem yield, leaf to stem ratio, leaf area index, number of days to flowering and bast yield. For kenaf forage production the suitable planting density for MHC123 variety is 666,700 plants ha^{-1}.

Key words: Kenaf, plant population, fibre, animal feed, fibre analysis, nutritive values

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Kenaf has a potential to be commercialized in Malaysia but there are many challenges facing it. The limiting factor for commercialization of kenaf in Malaysia is lack of suitable variety to be cultivated under Malaysian condition. So far there is only one variety already introduced by MARDI which is V36. The existing variety has limitations in yield and newer varieties with higher yield and good quality especially for forage and fibre may boost production[1].

Various varieties of kenaf can be found in several countries like China, India and Bangladesh. Cultivar by environment interaction is an important issue to agronomist who transfer a new variety from one to another environment[2]. There are variable in plant growth rate, photosensitivity to day length, stem and leaf colour, leaf and seed shape and the suitability to the different environment. To produce enough biomass of high quality which can be converted to fibre and animal feed there is need to identify kenaf varieties with potential for high biomass yield and specific quality traits[3]. One of the potential varieties is MHC123.

The MHC123 exhibits good agronomic characteristics compared to V36. New varieties like MHC123 have to come with new agronomic practices because different varieties have different life spans. Normally for V36 it takes about 6-8 weeks to harvest for animal feed while for fibre it takes about 4 months[4]. For MHC123 the time to harvest which gives high dry matter yield with good quality may be different. Other factors such as planting density are also important and a combination of optimal planting density and appropriate harvest time are the key to maximixing kenaf yield and quality. Previous recommendation for cultivation were based solely on using existing farm equipment for kenaf production to minimize start-up cost and the lack of herbicide to control weeds in kenaf planted in narrow row. Practicing various planting densities may be useful in tailoring kenaf fibre production to its desired use. For example, the narrow row spacing in kenaf not only increases the total biomass yield, but also increases the bast fibre percentage of the stalks[5]. A better understanding on how the yield component (plant population, plant height, stalk and leaf yield, total biomass) are affected by agronomic practices and other factors needs to be studied especially in Malaysian condition.

In kenaf cultivation, the plant density should be adjusted according to the end product of the crop, harvesting system, fibre extraction procedures and application of the final product[6]. It is also based largely on local practices and water availability which vary by geography (soil type and rainfall pattern).

The optimum plant density to produce the maximum yields varies between varieties and it is not right to use a single optimum plant density for the crop. The recommended plant population density for V36 is between 600,000-650,000 plants ha^{-1} [6]. The optimum plant density for MHC123 has not yet been determined, thus this experiment was conducted to study the effect of plant density and harvesting age on the quality and yield of kenaf for animal feed and fibre and to determine the suitable plant density and harvesting age specific to the end product.

MATERIALS AND METHODS

The design of the experiment was split-split plot with 3 harvest ages (8, 12 and 16 weeks after planting) as the main plot, 4 planting densities (444,400 plants ha^{-1} (45$\times$5 cm) (D1), 500,000 plants ha^{-1} (40$\times$5 cm) (D2), 571,400 plants ha^{-1} (35$\times$5 cm) (D3) and 666,700 plants ha^{-1} (30$\times$5 cm) (D4)) as sub-plot and 2 varieties (MHC123 (V1) and V36 (V2) as sub sub-plot. In total there were 24 treatment combinations with 4 replications. Each sub sub-plot measured 2$\times$3 m. Kenaf was harvested at 8 and12 weeks after planting (WAP) for forage production while the 16 WAP for fibre production. The whole duration of the present study was 8 months. Kenaf seeds were obtained from MARDI Serdang for MHC123 and National Kenaf and Tobacco Board for V36. The experiment was conducted at MARDI Research Station in Serdang and the level of the research work conducted was at the national level. Planting of seeds was at depth 2.0-2.5 cm by using the manual method and hand thinning was carried out to ensure that the population density as assigned by the treatments was achieved 2 weeks after planting. Plots were fertilized with 300 kg NPK green (15:15:15) prior to planting. A subsequent application of 300 kg NPK blue (12:12:17+TE) was made 6 weeks after planting. Irrigation was applied soon after planting because of the dry weather and to ensure sufficient moisture was received at the critical stage for kenaf establishment. Irrigation was not carried out whenever it rained. *Glufosinate ammonium* 200 g L^{-1} (Basta) was applied to control weeds. *Imidacloprid* 200 g L^{-1} (Confidor) and *Deltamethrin* (Decis) were applied to control leaf hoppers and cotton stainers.

Measurements

Yield

Dry matter yield: Above ground dry matter yield was measured from four random samples taken from each plot using a 2$\times$1 m^2 quadrat. Samples were harvested manually from each plot and were weighed and dried in the dehumidifier dryer at 60°C until constant weight.

Plant growth measurement

Plant height, stem diameter, leaf area index and number of days to flowering: Plant height was measured with steel ruler from ground level to the highest shoot. Plant diameter was measured 2 cm above the soil using a digital calliper Mitutoyo every 2 weeks until harvest. Measurements were taken on 10 randomly marked plant from each plot. The leaf area index (LAI) was measured using a plant canopy analyzer LAI-2000 (LI-COR Inc). This was measured weekly until designated harvest. The measurement was done by taking one reading above and four reading below the canopy in each plot. Two readings were recorded for each plot. Leaf area index was calculated from values of leaf area of all green leaves per unit soil surface. Number of days to flowering was quantified from planting date to the day when first flower, 50% flower and 100% flower of the marked plants bloomed with white yellowish petal.

Forage quality

Leaf yield, stem yield, leaf to stem ratio, acid detergent fibre (ADF) and crude protein (CP): Kenaf was sampled using a 0.3×0.3 m quadrat (four replicates for each sampling) on 8 and 12 WAP. For leaf yield, stem yield and leaf to stem ratio harvested plants were cut at ground level and fresh weight was recorded. Leaves were removed from the stalks and were weighed separately, before and after the samples were oven dried at 50°C until constant weight. The data were recorded. Leaf to stem ratio of the plant is the ratio of stem to leaf biomass. For acid detergent fibre (ADF) and crude protein (CP), the plants were harvested at ground level. The plants were oven dried at 50°C until constant weight. Dried samples were ground through 1 mm screen and analyzed for CP and ADF content using Near Infrared Reflectance Spectrophotometer (NIRS) (Brand FOSS, model No. N6500).

Fibre quality

Bast yield, core yield and bast and core ratio: Kenaf was sampled using a 0.3×0.3 m^2 quadrat (four samples for each plot) on 16 and 20 WAP. The bark (containing bast fibre) was peeled from each stalk section manually and both components (bast and core) were oven dried at 60°C until no further weight loss was observed. Weights were recorded before and after the drying process. Bast and core ratio represent the percentage by weight of bast compared with the total stalk weight.

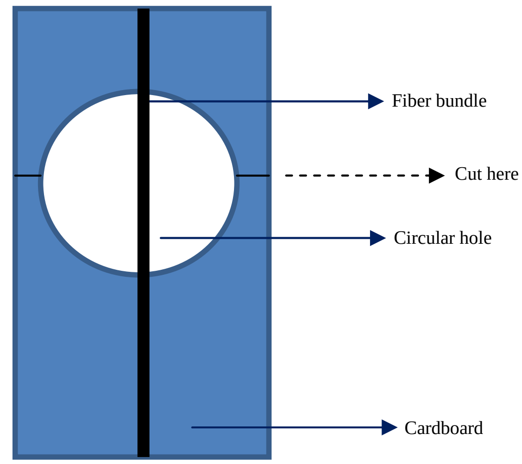

Fig. 1: Mounting card of fibre test piece
Source: Khan *et al.*[7]

Tensile strength test: A random sample of five plants were harvested from each plot and the bark was peeled manually by hand from each stalk to separate the bast and core. The bast section was soaked in water in a fibre tank until the fibres were separated from each other. The process is called the retting process. The retting process takes about 30 days to be completed. The fibres then were oven dried at 60°C until constant weight. These fibres were used for the tensile and water absorption test.

Fibre bundle test was performed using an Instron machine 3366 with a crosshead speed of 5 mm min^{-1}. The kenaf fibre samples were glued at rectangular cardboard with a dimension of 30×70 mm. The same weights of fibre were used for each sample. In this trial weight of each sample was 0.0120 g. The cardboard contained a circular hole right at the centre with a diameter of 20 mm. A detailed illustration of the sample is illustrated in Fig. 1.

Water absorption: Bundles of kenaf fibre were immersed into distilled water which was kept in a covered bottle at room temperature. The moisture content was calculated using Eq. 1. A fixed amount of fibre was weighed before and after immersing into water. The weight was taken using an electronic balance after removing the kenaf fibre from the water and wiping them dry. Weighing was done every day until a constant weight was achieved:

$$\text{Moisture (\%)} = \frac{W_t - W_0}{W_0} \times 100 \quad (1)$$

Where:
W_t = Weight after immersion
W_o = Weight before immersion

Data analysis: Data on the effect of densities, harvest age and varieties were analyzed by analysis of variance (ANOVA) (Type III) using SAS software analysis of variance (ANOVA) version 9.2 (SAS Institute, Inc, Cary, North Carolina). The differences among means were compared by Duncan's New Multiple Range test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Yield and yield component

Dry matter yield: Analysis of variance on dry matter yield indicated significant difference ($p<0.05$) among harvest age, density and variety, but there were no significant interactions between all the factors studied (Table 1). Thus, the result will focus on main effects of each factor.

Harvest age at 16 WAP gave significantly ($p<0.05$) higher dry matter yield followed by harvest age at 12 and 8 WAP with 13.90, 11.53 and 8.85 t ha^{-1}, respectively. The planting density that gave the highest dry matter yield of 12.73 t ha^{-1} was at 444,400 plants ha^{-1} while plant density of 500,000, 571,400 and 666,700 plants ha^{-1} gave almost similar value of 11.48, 10.33 and 11.17 t ha^{-1}, respectively. In contrast, Bitzer and Bruening[8] and Wilson and Joyner[9] showed higher density resulted in higher dry matter yield but there were variations between soil types. The current study showed the opposite: lower density gave higher dry matter yield. Increasing density does not necessarily result in increased yield because higher densities may result in greater competition to get light and nutrient between plants and increased plant mortality.

A large number of research works have been carried out worldwide in order to determine the appropriate plant population that results in maximization of the crop yield. Plant density between 99,000-932,000 plants ha^{-1} have been tested for several kenaf varieties[10]. In most of these finding, it is reported that plant density between 150,000-350,000 plants ha^{-1} gave higher yields[11-15] while in Sudan, Salih[16] reported that for maximum yield the optimum plant density between 250,000-500,000 plants ha^{-1}.

Nik Ablah[1] reported that kenaf planted in mineral soil, (MARDI Jeram Pasu) had lower dry matter yield at 12.64 t ha^{-1} with the population density of 443,055 plants ha^{-1} with 40 cm between rows in comparison with kenaf planted in bris soil (MARDI Telong) at 880,952 plants at distance of 35 cm inter row spacing with 27.94 t ha^{-1}. The plant density required to achieve maximum dry matter yields in this study were similar to those reported by Nik Ablah[1] at Jeram Pasu as the soil characteristic are almost similar (mineral soil) with the current study area (Serdang). In this experiment the input of nutrient were distributed at same rate for all planting density. This may be one of the reason low yields was found at higher density because lack of nutrient for kenaf growth was likely to occur at higher plant densities. At lower fertility, high plant density increased stem number but decreased stem weight[6]. The N fertilization increased stem number, while P and K fertilization increased stem weight. Thus, with increased plant density, single applications of N, P or K and an N-P-K combination significantly increased yield[17]. Kenaf requirements for nitrogen are high, up to 30 kg N per tonne of stem which means that nitrogen will have significant influence on harvest yields[6].

Table 1: Mean dry matter yield of MHC123 and V36 at three harvest age and four planting density

Treatments	Dry matter yields (t ha^{-1})
Harvest age (H)	
8 week after planting	8.85^{c}
12 week after planting	11.53^{b}
16 week after planting	13.90^{a}
Density (D)	
444,400 plants ha^{-1}	12.73^{a}
500,000 plants ha^{-1}	11.48^{b}
571,400 plants ha^{-1}	10.33^{c}
666,700 plants ha^{-1}	11.17^{bc}
Variety (V)	
MHC123	12.65^{a}
V36	10.21^{b}
Significance level	
Harvest age	**
Density	**
Variety	**
Interaction	
D×V	ns
H×D	ns
H×V	ns
H×D×V	ns

Yield followed by the same letter are not significantly different among harvest age, density and variety,**$p<0.05$, ns: Non-significant

The total dry matter yield was significantly higher in MHC123 compared to V36 with 12.65 and 10.21 t ha^{-1}, respectively (Table 1). Biomass and growth vary considerably according to the maturity type of the kenaf varieties. Biomass of the intermediate flowering varieties (V36) gradually declined after flowering until the end of reproductive period. In contrast with the intermediate varieties, the late flowering ones (MHC123) exhibited a higher biomass. Alexopolou *et al.*[18] also reported that the kenaf variety produced a higher biomass before the beginning of the anthesis stage.

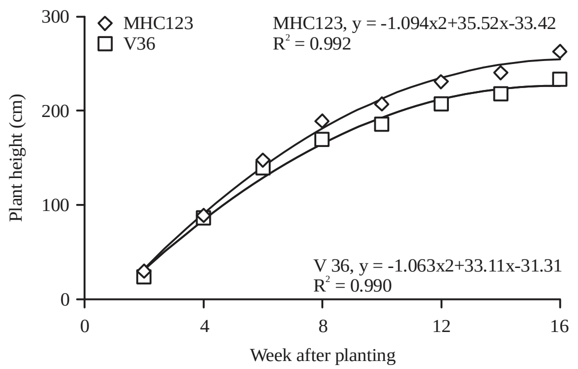

Fig. 2: Increment of plant height of the two kenaf varieties

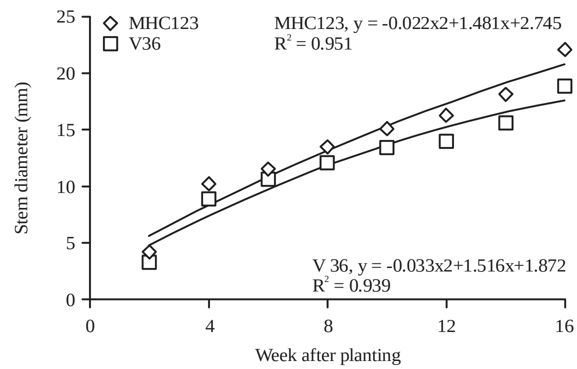

Fig. 3: Increment of stem diameter of the two kenaf varieties at four harvest age

Table 2: Mean plant height and stem diameter for MHC123 and V36 at four plant density and bi-weekly interval

Treatments	Plant height (cm)	Stem diameter (mm)
Density (D)		
444,400 plants ha^{-1}	172.1^a	14.1^a
500,000 plants ha^{-1}	167.3^b	13.3^b
571,400 plants ha^{-1}	163.5^c	12.7^c
666,700 plants ha^{-1}	162.8^c	11.8^d
Significance level	**	**
Variety (V)		
MHC123	174.8^a	13.8^a
V36	157.5^b	12.1^b
Significance level	**	**
Week (W)		
W2	27.1^h	3.7^h
W4	85.0^g	9.5^g
W6	145.1^f	11.0^f
W8	180.7^e	12.8^e
W10	196.7^d	14.3^d
W12	219.3^c	15.1^c
W14	229.3^b	16.8^b
W16	248.4^a	20.5^a
Significance level	**	**
Interaction		
D×W	ns	**
D×V	ns	**
W×V	**	**
D×V×W	ns	ns

**p<0.01, ns: Not significant

Plant growth measurements

Plant height and stem diameter: Analysis of variance for plant height indicated significant differences (p<0.01) among density, variety and week (Table 2). Interaction was significant (p<0.01) between week and variety while other interactions were not significant. In terms of density, the highest plant height was obtained at plant density of 444,400 plants ha^{-1} (172.1 cm), followed by plant density of 500,000 plants ha^{-1} (167.3 cm) and the lowest at plant density of 571,400 and 666,700 plants ha^{-1} which gave similar value with 163.5 cm and 162.8 cm, respectively.

Figure 2 showed the quadratic response from week 2 until 16 WAP, MHC123 was taller than V36 and reached 262.97 cm while V36 reached 233.76 cm at final harvest. The taller plants found at plant density of 444,400 plants ha^{-1}and of MHC123, may be related to the higher dry matter yield compared to other densities. It was postulated that, when the plant populations were increased the plant height and the basal stem diameter were significantly decreased, while the achieved yields were decreased[19]. Increasing plant density will increase competition between plants not only to get nutrient but also sunlight. Some of the plant may be shaded by other plants and receive a little sunlight thus they cannot grow higher and stem diameter becomes small as described by Axelopolou *et al.*[19], plants in stands that are too dense tend to be short, spindly and week-stemmed, while in stands too sparse many branches are being producing that are too heavy.

Analysis of variance for stem diameter indicated significant differences (p<0.05) among density, variety and week. Significant interaction was found between week and density, week and variety and variety and density (Table 2).

The interaction of varieties and weeks of harvest is shown in Fig. 3-5. Figure 6 is mean leaf area index at every 2 weeks until harvest. Quadratic responses of stem diameter with increasing age of planting were observed for both varieties from 2-16 week after planting (WAP) and stem diameter reached 22.06 mm for MHC123 and 18.85 mm for V36 at final harvest (Fig. 4). At every week MHC123 has higher stem diameter compared to V36 and the differences were greater at later harvests, indicating that growth rate of MHC123 was maintained longer than that of V36.

Figure 4 showed quadratic response of stem diameter to increasing age of harvest for all the densities tested. Stem diameter was highest at the lowest density and decreased with increasing plant density. The differences among plant densities were also greater at later harvests indicating that the

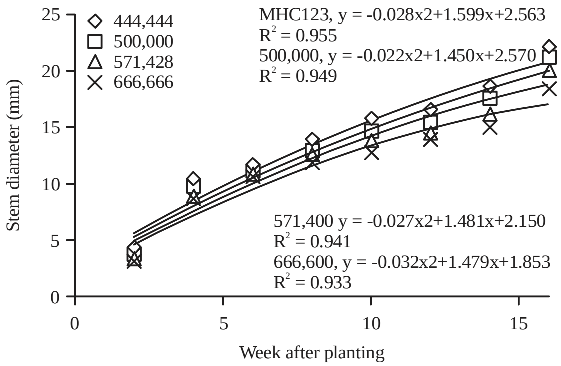

Fig. 4: Increment of stem diameter of two kenaf varieties at four plant densities

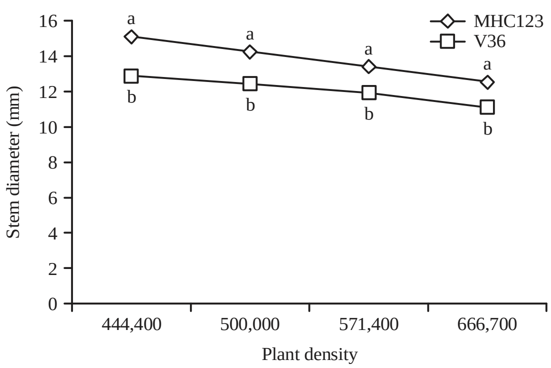

Fig. 5: Interaction between density and variety on stem diameter

Mean with different letter for each density was significantly different at p<0.01

Table 3: Number of days to flowering for MHC123 and V36 at four plant densities

Treatments	1st flowering	50% flowering	100% flowering
Density (D)			
444,400 plants ha^{-1}	54.5	74.8	101.3
500,000 plants ha^{-1}	55.5	74.3	100.5
571,400 plants ha^{-1}	55.8	75.1	100.8
666,700 plants ha^{-1}	54.3	74.3	100.6
Significance level	ns	ns	ns
Variety (V)			
MHC123	62.4^{a}	80.9^{a}	111.0^{a}
V36	47.5^{b}	68.3^{b}	90.6^{b}
Significance level	**	**	**
Interaction			
D×V	ns	ns	ns

**p<0.01, ns: Non-significant

growth rate of plants at lower density was sustained longer than at higher densities. Wider stem diameter at lower density could be because of greater individual space for kenaf. Bigger stem could be one of the reasons that the dry matter yield was highest at the lowest density of 444,400 plants ha^{-1}. Alexopoulou *et al.*[20] described that in the plots with high populations lower branching was reported and the stem diameter was smaller and the plants were more sensitive to lodging after the flowering initiation.

Figure 5 showed the interaction between density and variety on stem diameter. The MHC123 has significantly (p<0.05) bigger stem diameter compared to V36 at all densities but larger differences occurred at the lowest density (444,400 plants ha^{-1}). Kenaf has an indeterminate type of growth, which is rather rapid until the first flowers appear and there after the growth rate significantly decreases. The MHC123 was classified as late flowering variety while V36 is an intermediate flowering variety. The MHC123 took longer time to initiate flowering and most of its photosynthate are used mainly for its prolific vegetative growth. Such postulation is supported by Alexopolou *et al.*[18], who found that the late maturing varieties grew taller and exhibited a higher growth rate and developed larger stem diameters as compared to the early/intermediate maturing ones. The reduction in growth (height, stem diameter and biomass) was particularly marked in intermediate flowering variety since a substantial growth portion of its energy was allocated for reproductive growth[17,18,21].

Days to flowering: All four densities did not show significant difference (p>0.05) in number of days to flowering (Table 3). Number of days to flowering for first flowering ranged from 54-55 days, 50% flowering range from 74-75 days and 100% flowering range from 100-101 days.

In terms of variety, MHC123 was significantly later in flowering compared with V36. The MHC123 started first flowering after 62 DAP and 50% flowering after 81 DAP followed by 100% flowering at 111 DAP. The V36 had first flowering after 48 DAP and 50% flowering after 68 DAP followed by 100% flowering after 91 DAP. In most research work, it was reported that the early/intermediate varieties were less productive than the late ones due to the shorter vegetative phase (45 days shorter). Adamson *et al.*[22] found that the early varieties (PI 329195, PI 323129, PI 343139, PI 343142 and PI 343150) gave significant lower yields (7.64 vs. 17.9 t ha^{-1}) compared to the late varieties (C-2032, Everglades 41). It is reported by Alexopoulou *et al.*[19] that there is a positive relation between kenaf productivity and the absence of the flower induction. The MHC123 has longer vegetative phase (62 days) compared with V36 (47 days) and it give benefit to the MHC123 to gain more dry matter.

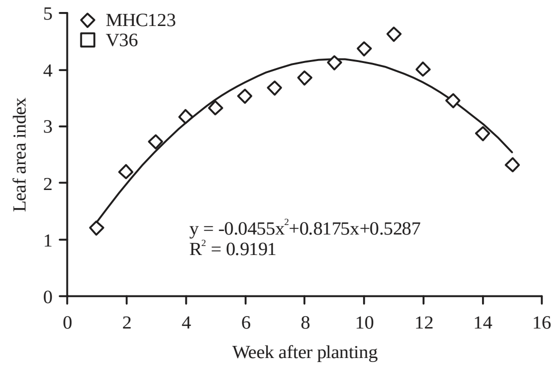

Fig. 6: Mean leaf area index at every 2 week until harvest date

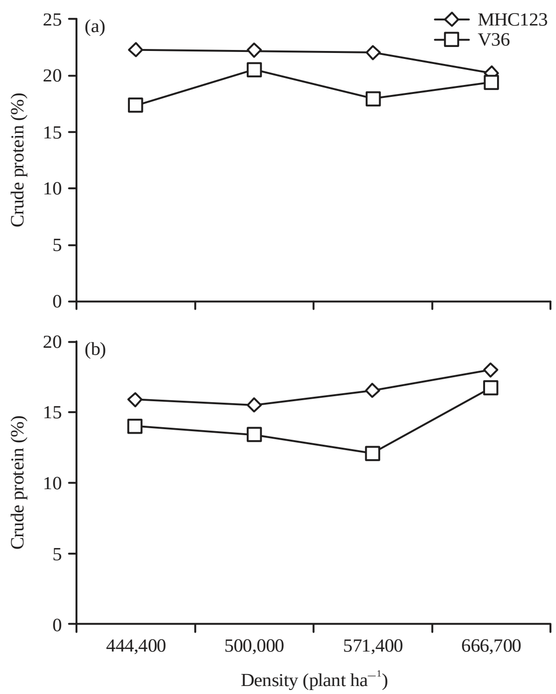

Fig. 7(a-b): Interaction between harvest age, variety and density on crude protein content at (a) 8 WAP and (b) 12 WAP

Leaf area index (LAI): The leaf area index (LAI) is an important parameter to determine light interception and transpiration in field crop. Leaf area index depends on temperature (day and night), nitrogen, water availability and plant density[23]. Values of LAI increased until maximum values were attained at or around flowering and they then subsequently decreased as leaves senesced[10]. Leaf area index of MHC123 and V36 at four densities is shown in Table 4. There were significant differences (p<0.01) between varieties but no significant difference was found among densities (p>0.05) where LAI ranged from 3.28-3.34. This finding was supported by Danalatous and Archountoulis[24], who reported that plant density kenaf had minimal effect on LAI.

Table 4: Mean leaf area index for MHC123 and V36 at four plant densities

Treatments	Leaf area index
Density (D)	
444,400 plants ha^{-1}	3.28
500,000 plants ha^{-1}	3.34
571,400 plants ha^{-1}	3.31
666,700 plants ha^{-1}	3.29
Significance level	ns
Variety (V)	
MHC123	3.58^a
V36	3.02^b
Significance level	**
Interaction	
D×V	ns
D×W	ns
V×W	ns
D×V×W	ns

**p<0.01, ns: Non-significant

Interaction among the factor of density, variety and week were not significant. Leaf area index increased weekly and reached a maximum LAI (4.2) at 8 WAP (Fig. 6) after which LAI decreased gradually until 2.32 at 15 WAP. The LAI increased at considerable high rate, from 4-8 WAP reaching values above 3.0 for about 8 week. Thereafter LAI decreases due to leaf ageing and senescence.

Variety MHC123 had significantly higher (p<0.01) LAI compared to V36 with 3.58 for MHC123 and 3.02 for V36. Higher LAI significantly increased the growth rate (more light intercepted and higher net assimilation rate) thus resulting in higher biomass production[25]. This is also one of the reason MHC123 has higher dry matter yield compared to V36. The MHC123 has higher LAI compared to V36 could be because of leaf shape. The leaf shape of MHC123 was divided while V36 was entire. The entire leaves gave less adequate canopy distribution at surface level.

Forage quality

Crude protein (CP) and acid detergent fibre(ADF) content: Crude protein content was significantly affected by harvest age (p<0.01), plant density (p<0.01) and variety (p<0.01) as shown in Table 5. There was a significant interaction (p<0.05) between harvest age, density and variety for crude protein content. Thus, the result will focus on interaction between harvest age, density and variety as shown in Fig. 7a-b.

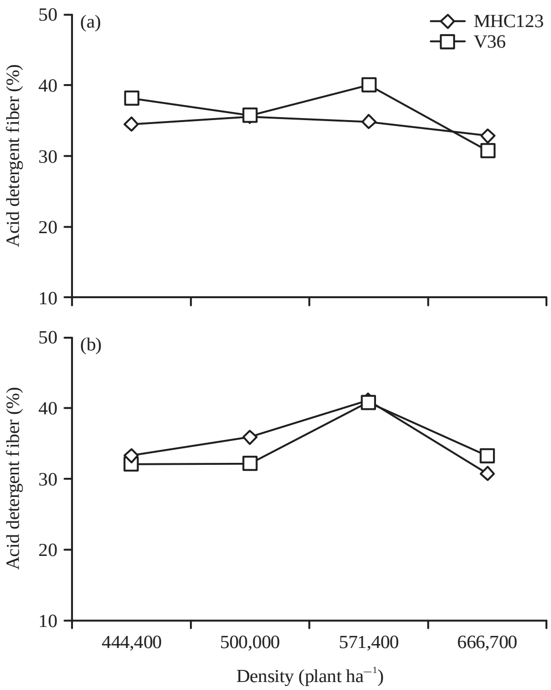

Fig. 8: Interaction between density and variety on acid detergent fibre content for harvest age at (a) 8 WAP and (b) 12 WAP

Table 5: Mean crude protein and acid detergent fibre content for MHC123 and V36 at two harvest age and four densities

Treatments	Crude protein (%)	Acid detergent fibre (%)
Harvest age (H)		
8 week after planting	20.30[a]	35.14
12 week after planting	15.26[b]	34.97
Significance level	**	ns
Density (D)		
444,400 plants ha^{-1}	18.65[a]	31.7[c]
500,000 plants ha^{-1}	17.2[c]	39.2[a]
571,400 plants ha^{-1}	18.0[ab]	34.8[b]
666,700 plants ha^{-1}	17.4[bc]	34.5[b]
Significance level	**	
Variety (V)		
MHC123	19.1[a]	34.9
V36	16.5[b]	35.3
Significance level	**	ns
Interaction		
D×V	**	ns
H×D	**	*
H×V	ns	ns
H×D×V	*	*

Harvesting age, planting density and variety followed by the same letter are not significantly different,**p<0.01, *p<0.05, ns: Non-significant

For the harvest age at 8 WAP, MHC123 was highest in CP content at the low planting density and CP content declined with increasing plant density. The MHC123 consistently gave higher CP content than V36 at all planting density. The MHC123 reached maximum CP content at density of 444,400 plants ha^{-1} with 22.3%. The V36 showed a different trend with fluctuation in CP content at the four densities. At lower density (444,400 plants ha^{-1}) the lowest (17.4%) CP content was obtained and the value increased to the highest CP content of 20.6% at density of 500,000 plants ha^{-1}. The CP content of V36 then dropped to 18% at density of 571,400 plants ha^{-1} and increased again at density of 666,700 plants ha^{-1} with 19.5%.

Harvest age at 12 WAP, showed a similar trend of higher CP content in MHC123 as compared with V36 at all four densities. The CP content in MHC123 showed a lower value at lower density with 15% at plant density of 444,400 and 500,000 plants ha^{-1} and increased gradually to 16% at planting density of 571,400 plants ha^{-1} then reaches at higher CP content (18%) at higher plant density (666,700 plants ha^{-1}). V36 decreased gradually from 14-13.4% and 12.1% at plant density of 444,400, 500,000 and 571,400 plants ha^{-1}, respectively but increased at higher plant density, 666,700 plants ha^{-1} with 16.7% of CP content. Plant density of 666,700 plant ha^{-1} resulted in higher CP due to higher leaf number and leaf yield compared to other densities. Kenaf leaf has high CP content as described by Webber[26], crude protein in leaves ranged from 21-34%, in stem 10-12% and whole plant 16-23%.

The CP content was highest at 8 WAP for both varieties and the CP content declined at 12 WAP. However, CP content for MHC123 at harvest age at 12 WAP was still acceptable because the value of CP content was consider high as reported by Liang *et al.*[27] with 20% CP at 6-8 WAP for KhonKaen.

Acid detergent fibre content showed significant difference (p<0.01) among plant density but there was no difference among harvest age and between varieties (Table 5). There was significant interaction (p<0.05) between harvest age, density and variety as shown in Fig. 8.

Acid detergent fibre content was recorded lower at higher plant density (666,700 plant ha^{-1}) probably because of stem diameter at higher density were small, the fibrous part of the stem are not all matured and cellulose and lignin are not yet well developed. The leaf biomass percentage and percent crude protein decrease while percent acid detergent fibre increases as the kenaf plant increases in height and maturity[28]. It is mainly because the lower leaves senesce, producing mature plants without leaves on the lower part of the plant stalk as occurred to the kenaf at density of 666,700 plant ha^{-1}.

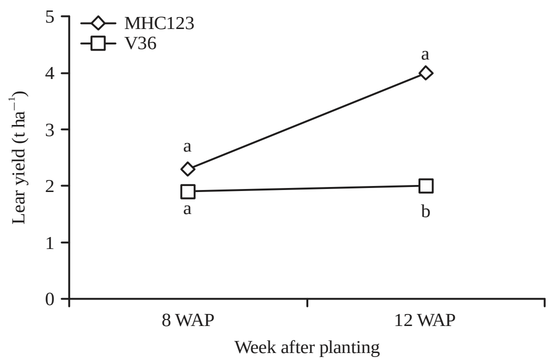

Fig. 9: Interaction between harvest age and variety on leaf yield

Means with the same letter for each harvest age are not significantly different at p<0.01

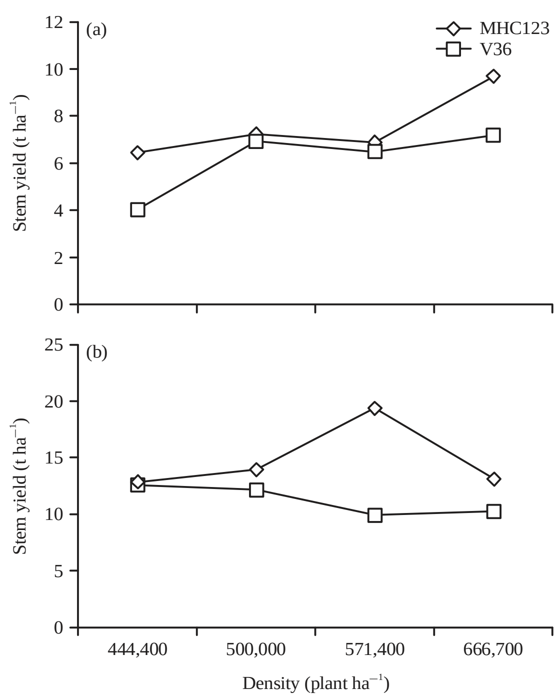

Fig. 10(a-b): Interaction between density and variety on stem yield of harvest age at (a) 8 WAP and (b) 12 WAP

Leaf yield, stem yield, leaf number and leaf to stem ratio: Analyses of variance for leaf yield indicated significant difference (p<0.05) among harvest age and between varieties but no significant difference among plant densities. The interaction (p<0.01) was significant between harvest age and variety while all other interactions were not significant (Table 6).

Figure 9 showed the interaction between harvest age and variety on leaf yield. The MHC123 and V36 were not significantly different in leaf yield at 8 WAP with range

Table 6: Mean leaf yield, stem yield, leaf number and leaf to stem ratio of MHC123 and V36 at two harvest age and four plant densities

Treatments	Leaf yield (t ha^{-1})	Stem yield (t ha^{-1})	Leaf number	Leaf to stem ratio
Harvest age (H)				
8 week after planting	2.1^{b}	6.9^{b}	65.5^{b}	0.3^{a}
12 week after planting	3.0^{a}	13.1^{a}	94.2^{a}	0.2^{b}
Significance level	**	**	**	**
Density (D)				
444,400 plants ha^{-1}	3.4	11.4	78.1	0.3
500,000 plants ha^{-1}	3.2	13.2	72.4	0.3
571,400 plants ha^{-1}	3.1	10.6	76.4	0.3
666,700 plants ha^{-1}	2.8	9.6	92.4	0.3
Significance level	ns	ns	ns	ns
Variety (V)				
MHC123	3.1^{a}	11.2^{a}	96.8^{a}	0.3^{a}
V36	1.9^{b}	8.7^{b}	62.7^{b}	0.2^{b}
Significance level	**	**	**	**
Interaction				
D×V	ns	ns	**	ns
H×D	ns	*	**	**
H x V	**	ns	**	**
H x D x V	ns	**	ns	*

Harvesting age, planting density and variety followed by the same letter are not significantly different, *p<0.05, **p<0.01 ns: Non-significant

1.9-2.3 t ha^{-1} while at 12 WAP, leaf yield of MHC123 (4 t ha^{-1}) was significantly higher (p<0.01) than V36 (2 t ha^{-1}). Leaf yield of MHC123 increased drastically while V36 hardly increased from 8-12 WA.

Analyses of variance for stem yield also indicated significant difference (p<0.05) for harvest age and variety but not for density (Table 6) meanwhile there are significant interaction between harvest age, density and variety (p<0.01) (Fig. 10). Harvest age at 8 WAP indicated higher stem yield at all densities for MHC123 compared with V36. Stem yield of MHC123 and V36 increased from plant density at 444,400 plant ha^{-1} to plant density at 500,000 plants ha $^{-1}$ with 6.45-7.22 t ha^{-1} for MHC123 and 4.05-6.95 t ha^{-1} for V36. At plant density of 571,400 plants ha^{-1} stem yield of MHC123 and V36 slightly decreased at 6.9 and 6.52 t ha^{-1}, respectively and rise again at higher stem yield of MHC123 (9.65 t ha^{-1}) and V36 (7.2 t ha^{-1}) at plant density of 666,700 plants ha^{-1}.

Harvest age at 12 WAP also indicated higher stem yield of MHC123 compared with V36. The trend of stem yield for V36 and MHC123 was different at 8 WAP. The stem yield of MHC123 increased gradually from 12.8-13.98 t ha^{-1} for plants density at 444,400 and 500,000 plants ha^{-1}, respectively. Plant density at 571,400 plants ha^{-1} gave higher stem yield (19.4 t ha^{-1}) for MHC123 and at plant density of 666,700 plant ha^{-1} the stem yield decreased to 13.18 t ha^{-1}. For V36, the stem yield decreased from 12.63-12.23 t ha^{-1} to 9.98 t ha^{-1} for plant density at 444,400, 500,000 and

571,400 plants ha^{-1}. At higher plant density (666,700 plants ha^{-1}) the stem yield rise up to 10.33 t ha^{-1}. Stem yield for MHC123 and V36 was fluctuated between four planting density tested. Similar was reported by Alexopolou *et al.*[20] which they recorded the data of two plants populations (200,000 and 400,000 plants ha $^{-1}$ on stem yields in seven sites in south Europe (2003-2007). In three sites the stem yields were higher at low population, in two sites the opposite trend were occurred, while in two sites the yields were almost the same.

Leaf number showed significant difference (p<0.01) among harvest age and between varieties. Interaction between harvest age and variety, harvest age and density, density and variety were significant (p<0.01) (Table 6).

Figure 11 showed the interaction between harvest age and variety on leaf number/plot. There were no differences in leaf number between the two varieties at 8 WAP but leaf number increased at 12 WAP for MHC123. On the other hand, leaf number of V36 did not increase further at 12 WAP.

Figure 12 shows the interaction between density and variety on number of leaf/plot. The MHC123 significantly showed higher (p<0.05) differences compared with V36 at higher density (666,700 plants ha^{-1}) with 126.75 for MHC123 and 58 for V36. Meanwhile at lower density (444,400 plants ha^{-1}) leaf number of MHC123 was not significantly different from V36.

Figure 13 showed the interaction between density and harvest age on number of leaf/plot. Leaf number was significantly greater (p<0.01) at 12 WAP than at 8 WAP only at the highest plant density. At other plant densities there was no significant difference in leaf number between harvest ages.

The V36 reaches 50% flowering (mature) earlier than MHC123. As described before, once kenaf has reached their maturity the kenaf growth in terms of plant height, stem diameter also decreased which will reflect in the stem yield, leaf yield and leaf number. This is probably the reason leaf number and leaf yield significantly increased for MHC123 while it hardly increased for V36 from 8-12 WAP. Stem yield and leaf number of MHC123 was always higher at all densities compared to V36 due to MHC123 being more productive and has longer vegetative phase (2 months) to exhibit the higher stem growth and also leaf number. Higher plant density (666 700 plant ha^{-1}) resulted in higher leaf number due to the higher plant number.

Leaf to stem ratio was significantly different (p<0.01) between harvest age and between varieties while it was not significantly affected by plant density (Table 6). Interactions (P<0.05) occurred between harvest age, density and variety. The interaction between harvest age, density and variety is shown in Fig. 14a-b.

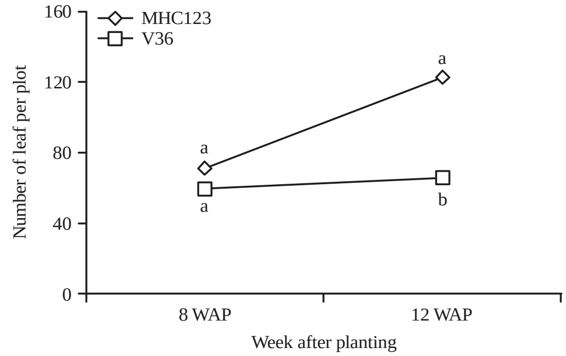

Fig. 11: Interaction between harvest age and variety on number of leaf per plot

Means with different letter for each harvest age was significantly different (p<0.01)

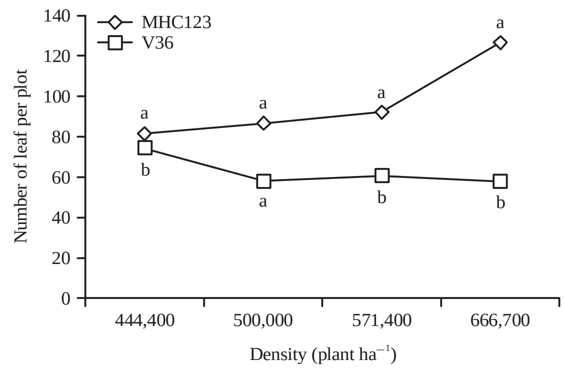

Fig. 12: Interaction between density and variety on number of leaf per plot

Means with different letter for each density was significantly different (p<0.01)

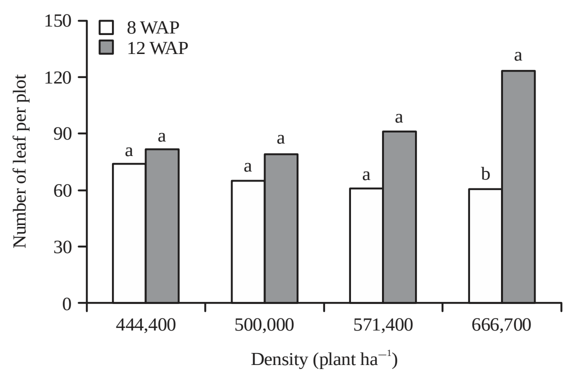

Fig. 13: Interaction between density and harvest age on number of leaf per plot

Means with same letter for each harvest age was not significantly different (p<0.01)

Harvest age at 8 WAP gave higher leaf to stem ratio for V36 (0.46) compared with MHC123 (0.32) at low density (444,400 plants ha^{-1}). At higher density leaf to stem ratio of

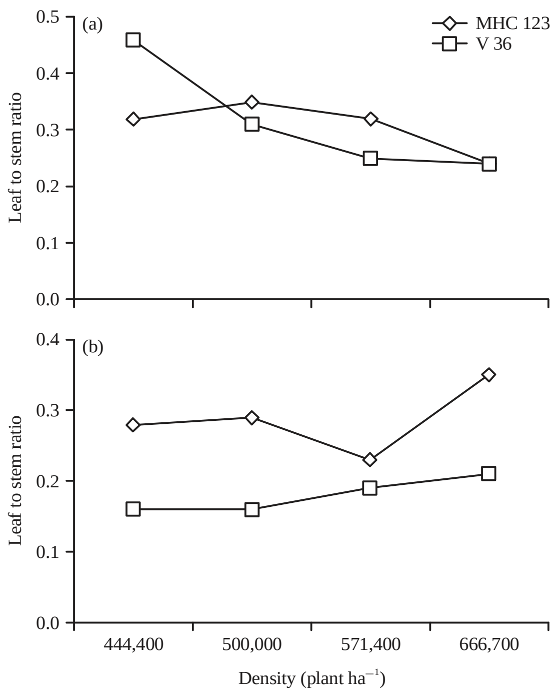

Fig. 14(a-b): Interaction between density and variety on leaf to stem ratio of harvest age at (a) 8 WAP and (b) 12 WAP

Table 7: Mean bast yield, core yield and bast to core ratio of MHC123 and V36 for four plant densities

Treatments	Bast yield (t ha^{-1})	Core yield (t ha^{-1})	Bast to core ratio
Density (D)			
444,400 plants ha^{-1}	3.8^{a}	6.9^{a}	0.5
500,000 plants ha^{-1}	3.4^{ab}	6.6^{ab}	0.6
571,400 plants ha^{-1}	3.2^{bc}	5.7^{bc}	0.5
666,700 plants ha^{-1}	2.9^{c}	5.2^{c}	0.6
Significance level	**	**	ns
Variety (V)			
MHC123	4.0^{a}	7.4^{a}	0.5
V36	2.6^{b}	4.8^{b}	0.5
Significance level	**	**	ns
Interaction			
D×V	ns	ns	*

Planting density and variety followed by the different letter are significantly different, *p<0.05, **p<0.01, ns: Not significant

MHC123 and V36 were similar (0.24) while at density of 571,400 plants ha^{-1} MHC123 was higher in leaf to stem ratio compared with V36. Harvest age at 12 WAP showed greater leaf to stem ratio of MHC123 compared with V36 at all densities especially at higher density (666,600 plants ha^{-1}) with 0.35 for MHC123 and 0.21 for V36.

Fibre quality

Bast yield, core yield and bast to core ratio: Analysis of variance on bastand core yield indicated only significant difference (p<0.05) among plant densities and between varieties (Table 7) while the interactions were not significant. There was no significant interaction between density and variety. Thus the result will focus on the main effects. Increasing density resulted in lower bastand core yield. Density at 444,400 plants ha^{-1} gave significantly higher bast yield with 3.8 t ha^{-1} followed by density at 500,000 plants ha^{-1} with 3.4 t ha^{-1}, density at 571, 400 plants ha^{-1} with 3.2 t ha^{-1} and density at 666,700 plants ha^{-1} with 2.9 t ha^{-1}.

Highest core yield was obtained at lower density (444,400 plants ha^{-1}) with 6.9 t ha^{-1} followed by plant density of 500,000 plants ha^{-1} (6.6 t ha^{-1}), 571,400 plants ha^{-1} (5.7 t ha^{-1}) and 666,700 plants ha^{-1} (5.2 t ha^{-1}). Plants in stand that is too dense tend to have stalk that are thin and this lowers the bast and core yield.

The MHC123 also indicated significantly higher bast and core yield. Bast yield of MHC123 was 4.0 t ha^{-1} while V36 (2.6 t ha^{-1}). Core yield was recorded 7.4 t ha^{-1} for MHC123 and 4.8 t ha^{-1} for V36. The MHC123 was more productive compared with V36 with higher bast and core yield. The MHC123 has higher plant height and bigger stem diameter compared to V36, thus it will contribute to the higher bast and core yield.

Bast to core ratio were not significantly different among densities and varieties (Table 7). However, there was significant interaction (p<0.05) between density and variety as shown in Fig. 15. Plant density at 666,700 plants ha^{-1} gave highest bast to core ratio (0.59) compared with other densities for V36 while for MHC123 the density of 500,000 plants ha^{-1} gave highest bast to core ratio (0.62). Bast to core ratio is the ratio of dry fibre to dry core per plant and can be directly manipulated by plant population. Generally bast compositions are higher compared to core in higher density as evident from the study by Asfaliza *et al.*[29] where the ratio increases as the plant population increases. This was also shown for V36 where higher density gave higher bast to core ratio but for the MHC123 a different result was found, density seem not to have an effect on bast to core ratio. It was same as Baldwin and Graham[5] which they reported no effects are being reported among the bast to core ratio, plant populations and the row spacing.

Tensile strength and water absorption: Tensile strength of MHC123 and V36 at all densities was not significantly different (p>0.05) (Table 8). The tensile strength ranged from 71.8-100.7 and 76.1-85.3 MPa for the densities and varieties, respectively. Plant density did not give any effect to the tensile strength of the fibre for both varieties, MHC123 and V36.

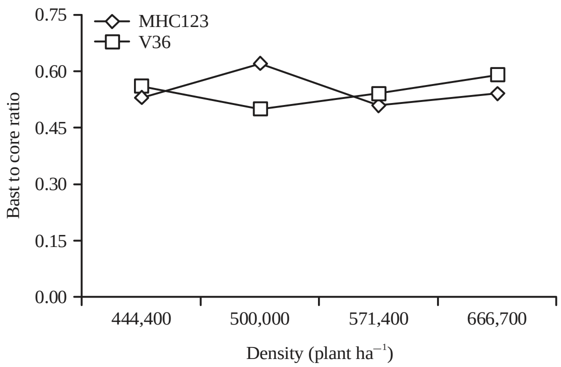

Fig. 15: Interaction between density and variety on bast to core ratio

Table 8: Mean tensile strength and water absorption of MHC123 and V36 for four plant densities

Treatments	Tensile strength (MPa)	Water absorption (%)
Density (D)		
444,400 plants ha^{-1}	71.8	206.1
500,000 plants ha^{-1}	100.7	200.1
571,400 plants ha^{-1}	69.9	200.7
666,700 plants ha^{-1}	80.5	194.7
Significance level	ns	ns
Variety (V)		
MHC123	85.3	193.3^{b}
V36	76.1	207.6^{a}
Significance level	ns	**
Interaction		
D×V	ns	ns

ns: Not significant, **p<0.01. Result were transform of square root

There was no significant effect of plant density on water absorption of kenaf but variety V36 had a higher water absorption percentage than MHC123 (Table 8). Fibre quality was determined by the ability of the fibre to absorb water, lower water absorption was better. Therefore, this result showed that MHC123 had better fibre quality compared with V36.

CONCLUSION

The MHC123 was found to be superior in dry matter yield, plant height, stem diameter, leaf area index, crude protein content, tensile strength, bast yield and core yield and lower in ADF content and water absorption compared to V36 variety. Recommendation of planting density depends on the final use of the kenaf materials, as for high dry matter and high fibre yields MHC123 and V36 varieties should be planted at plant density of 444, 400 plants ha^{-1} and for forage production a higher plant density of 666,700 plants ha^{-1}. For MHC123 variety harvesting at 12 weeks after planting would yield CP and ADF content of acceptable level as animal feed.

SIGNIFICANCE STATEMENT

This study discover and identified the specific effects of planting density on the animal feed and fibre yield of MHC123 kenaf in comparison to current V36 variety. Increases of 23.4% in animal feed yield and 28.7% in fibre yield were obtained from MHC123 compared to V36 variety. This can beneficial for kenaf growers to increase farm profit by planting the new variety MHC123.

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