Songklanakarin J. Sci. Technol.
34 (1), 9-15, Jan. - Feb. 2012

SONGKLANAKARIN JOURNAL OF SCIENCE AND TECHNOLOGY
http://www.sjst.psu.ac.th

*Original Article*

# Determination of vibration properties of *Jatropha curcas* for mechanical harvesting operations

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Received 29 July 2011; Accepted 8 December 2011

**Abstract**

Jatropha curcas has been considered as a potential feedstock for biodiesel production. Today, Jatropha curcas plant has been widely planted for its fruits in order to produce biodiesel. Jatropha curcas is a species of Euphorbiaceae. The plant is a perennial shrub, which can grow approximately five to eight meters in height and it can be grown anywhere and either from seed or cutting. It seems that jatropha has a great potential to replace the fuel derived from petroleum as well as oil palm. Unfortunately, the cost of jatropha production for biodiesel is still high, especially the labor costs for harvesting. Presently, jatropha fruits are mainly harvested by hand. However, this current harvesting method is costly, as the cost of labor constitutes about 80% of the total production costs. The harvesting of the jatropha fruits is a difficult process due to the ripening characteristics of the jatropha fruits. Earlier harvesting machinery has been modified for use in jatropha, but was found unsuitable. This study involves designing and developing a branch shaker harvester. The research project aimed at alleviating problem of high production cost during harvesting by finding the vibration frequency and force needed to dislodge only the ripe jatropha fruits.

**Keywords:** *Jatropha curcas*, cost reducing, mechanical harvesting, frequency, force

## 1. Introduction

*Jatropha curcas* is a multipurpose tree of Central America and Mexico origin with a long history of cultivation in tropical America, Africa, and Asia (Martı′nez-Herrera *et al.*, 2006). The genus *Jatropha* belongs to tribe Joanneasiae of Crotonoideae in the *Euphorbiaceae* family and contains approximately 175 succulents, shrubs, and trees. The genus *Jatropha* was derived from the Greek words *Jatros* (doctor) and *trophe* (food). It can grow eight to ten meters in favorable conditions and the life span of the plant is more than 50 years (Heller, 1996). It is traditionally used in the form as a living fence to prevent animals from grazing crops. Jatropha, which is a hardy shrub and traditionally known in many subtropical and semi-arid regions for its medical properties, has been planted extensively in spite of the world's demand on biodiesel stocks. The oil from jatropha is regarded as a potential fuel substitute. Plant based fuels are biodegradable, non-toxic and possesses low emission profiles (Narayana Reddy and Ramesh, 2006). It has become more attractive because of its environmental benefits and renewable resource. Petroleum based fuels (diesel) is a hydrocarbon with 8-10 carbon atoms per molecule, but jatropha oil has 16-18 carbon atoms (Wood, 2005). Thus, the jatropha oil is much more viscous than diesel and has a lower ignition quality.

Jatropha produce 1,600 liters of oil per hectare (Heller, 1996). The cake, which remains after the oil is pressed out, can be used for fertilizer and even used for animal feed after treatment, while the seed husks can be used as fuel in generators (Staubmann *et al.,* 1997). The seeds however are

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toxic to human and animals except the Mexico variety (Makkar *et al.,* 1998). Being rich in nitrogen, the seed cake is an excellent source of plant nutrients. A by-product in processing for biodiesel is glycerine, which can be turned into soap, candle and cosmetics and all parts of jatropha have been used in traditional medicine and for veterinary purpose (Duke, 1983).

Further research is required to produce other jatropha products, including biodiesel at a more competitive price. The cost of operation is probably considered a major factor in determining whether or not there will be an economically successful investment. According to Kececioglu (1975) and Sivapragasam and Mansor (2008), manual harvesting of jatropha fruits accounts for 60% to 80% of the total production costs. For cost reduction, mechanical harvesting can be a reasonable solution. Currently, jatropha as well as many other fruits are still picked entirely by hand, which is time consuming, costly, and requires a tremendous number of labors. By adopting technology in such agriculture activity makes the operation cost lower, while increasing the operation rate for farm mechanization efficiency (Razali *et al*., 2008 and Hudzari *et al*., 2011a). The aim of this research is focused on reducing the production costs in harvesting operation with the objectives of this research is to determine the most effective vibration characteristics (frequency and force) to detach the jatropha's ripe fruits.

## 2. Materials and Methods

The first step in this research is to develop a prototype harvester machine for jatropha tree (Figure 1). When the prototype machine is completed, it will be tested by using the vibration method in order to test the best frequency level and the force that can be use to harvest only for the matured fruits without detaching the unripe fruits or drop the leaves and causing damage to the tree.

The fruits on a bunch are green, yellow, and black in color. The ideal fruit for best raw oil production is yellow, while the black fruits are acceptable. Green fruit is unripe and not acceptable for this experiment. Before the data collections of frequency and force value were carried out, several measurements were taken. The measurements are diameter of the branches attached to the shaker, the length of fruit stalk and the distance of fruit stalk from the main branches. The data of those measurements were used to evaluate the frequency and force values. The shaker was placed on the tree limb at the fruit bunch stalk which normally consists of unripe, ripe, and overripe fruits. Vibration was imposed at the fruit bunch stalk until all the ripe fruits wholly detach. Frequency and force, which can detach all the ripe fruits was recorded using a tachometer. Twelve treatments were used in this study, which involved different combinations of shaking point and amplitude of the shaker. Four positions were used in the experiment; on the fruit stalk, 5 cm, 10 cm, and 15 cm distance from fruit stalk (Figure 2). Three different amplitudes that were used in the shaker are 2.5 cm, 3.5 cm, and 5.5 cm. Ten replicates were made for each treatment (Table 1).

An experiment was conducted in a randomized complete block design (RCBD). The data obtained were subjected to analysis of variance (Statistical Analysis System) and the mean values of each treatment were compared by

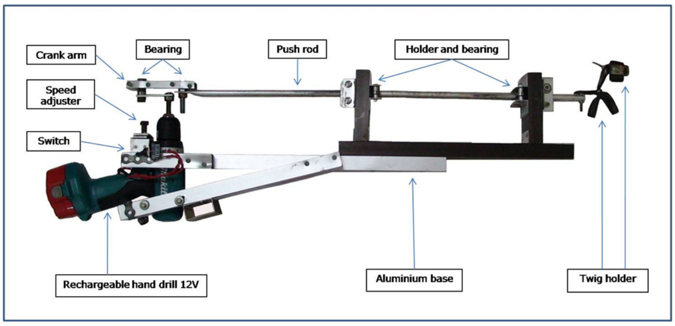


Figure 1. Prototype harvester machine for jatropha tree.

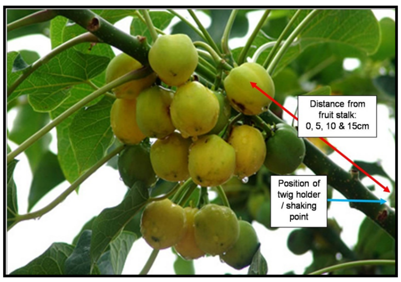


Figure 2. Shaker position on the fruit bearing twig.

Table 1. Treatment was used in this study.

| Treatment No. | Combination of Treatment | Replication |
|---|---|---|
| 1 | Position 1 (at the fruit stalk), Amplitude 2.5cm | |
| 2 | Position 2 (5cm from stalk), Amplitude 2.5cm | |
| 3 | Position 3 (10cm from stalk), Amplitude 2.5cm | |
| 4 | Position 4 (15cm from stalk), Amplitude 2.5cm | |
| 5 | Position 1 (at the fruit stalk), Amplitude 3.5cm | |
| 6 | Position 2 (5cm from stalk), Amplitude 3.5cm | 10 |
| 7 | Position 3 (10cm from stalk), Amplitude 3.5cm | replications |
| 8 | Position 4 (15cm from stalk), Amplitude 3.5cm | |
| 9 | Position 1 (at the fruit stalk), Amplitude 5.5cm | |
| 10 | Position 2 (5cm from stalk), Amplitude 5.5cm | |
| 11 | Position 3 (10cm from stalk), Amplitude 5.5cm | |
| 12 | Position 4 (15cm from stalk), Amplitude 5.5cm | |

*Duncan'*s multiple range test (DMRT) in order to compare the significant difference of each combination of positions and amplitudes. The experiment was carried out at the National Kenaf and Tobacco Board (NKTB) research plantation, Merang, Terengganu, Malaysia.

## 3. Results and Discussion

### 3.1 Frequency measurement

The results obtained showed that treatment four which used an amplitude of 2.5 cm and a position on 15 cm distance from the fruit stalk requires the highest frequency value (299.0 rpm of mean) among all treatments. On the other hand, treatment eleven (5.5 cm amplitude and a 10 cm position from the fruit stalk) were identified as requiring the lowest frequency value. Table 2 shows the mean frequency value of each treatment. From the data collected, it was found that the lowest frequency to detach the jatropha's ripe fruit is 86 rpm and the highest 389 rpm.

Treatment four was identified as a treatment that requires the highest frequency value to detach the matured fruits due to the combination of the shortest amplitude (2.5 cm) and the longest shaking point (15 cm distance from fruit stalk). This explained why the treatment needs a high frequency value. An amplitude of 2.5 cm, which is used in combination of treatment four, is the shortest amplitude in this experiment compared to amplitude two (3.5 cm) and amplitude three (5.5 cm). The shorter the amplitude, the less vibration generated due to the lack of energy from the rotation (Tsatsarelis, 1987). Therefore, a higher frequency is required to produce a more energetic vibration to detach the fruits. The shaking point at the tree twig also influences the frequency value. A shaking point that is nearer to the main stem requires a higher frequency to make the shaking action that

Table 2. The means comparison of frequency of every treatment for matured fruits.

| No. | Treatments | Mean of Frequency (rpm) |
|---|---|---|
| | | Mean ± (S.E) |
| 1 | T4- Amplitude 1 (2.5cm), Position 4 (15cm) | 299.00 ± (11.5739) |
| 2 | T2- Amplitude 1 (2.5cm), Position 2 (5cm) | 294.80 ± (7.2000) |
| 3 | T1- Amplitude 1 (2.5cm), Position 1 (0cm) | 280.80 ± (12.4996) |
| 4 | T8- Amplitude 2 (3.5cm), Position 4 (15cm) | 227.30 ± (16.5455) |
| 5 | T3- Amplitude 1 (2.5cm), Position 3 (10cm) | 214.90 ± (14.2138) |
| 6 | T7- Amplitude 2 (3.5cm), Position 3 (10cm) | 192.80 ± (6.3207) |
| 7 | T5- Amplitude 2 (3.5cm), Position 1 (0cm) | 179.70 ± (9.7354) |
| 8 | T9- Amplitude 3 (5.5cm), Position 1 (0cm) | 176.20 ± (9.4865) |
| 9 | T10- Amplitude 3 (5.5cm), Position 2 (5cm) | 174.70 ± (8.6821) |
| 10 | T6- Amplitude 2 (3.5cm), Position 2 (5cm) | 169.80 ± (10.5586) |
| 11 | T12- Amplitude 3 (5.5cm), Position 4 (15cm) | 169.70 ± (9.4401) |
| 12 | T11- Amplitude 3 (5.5cm), Position 3 (10cm) | 160.00 ± (10.9777) |

subsequently will detach the fruit. Apart of different combinations of amplitude and shaking point, other factors, such as the diameter of twig, length of fruit stalk, distance of fruit from the main branches, ripening stage of fruit, and position of fruit in the fruit bunches were also influencing the frequency values needed to detach the fruit (Fridley and Adrian, 1960). According to Al-Jalil *et al*. (1999), fruit size also affects the detachment frequency and force.

Tree twigs that have a wider diameter require a higher frequency to shake it (Erdogan *et al*., 2003). This is because the twig that has a wider diameter has a stronger stationary level compared to a short diameter twig. The stronger the stationary level, the higher the frequencies required to move it (Weinrich, 1984). The length of fruit stalk also affects the frequency needed. The longer the fruit stalk, vibration in the fruit bunches will be more powerful because the fruit bunches are shaking with a longer distance of oscillation. Distances of fruits from the main stem also influence the frequency needed. Bunches of fruit located far from the main stem are easier to be shaken compared to bunches of fruits, which are located near to the main branch. The easier to shake the twig, the lower the frequencies used (Fridley, 1983). Different stages of fruit maturity are also become a factor where it is requires a different frequency value to drop the fruit at different maturity levels. The fully ripe fruit (matured) is easier to detach than a fruit that is not fully matured (premature) because the matured fruit stalk is weaker than premature fruit stalk (see Figure 3; Baker, 1986; Polat, 2007).

Another factor that was affecting the frequency value to detach the fruit is position of fruit on the fruit bunch. Since jatropha fruits do not become mature at the same time, there are different levels of maturity in bunches of a fruit stalk. Ripe fruits that are located in the middle or slit in immature fruits require a higher vibration for detachment. This is because a fruit is flanked by other fruits and the shaking was just a little. It does not directly impact on the vibration imposed. The ripe fruit that is located at the outside of fruit bunches is easily to be detached because it is not flanked by the other fruits. A small amount of vibration energy is enough to detach the fruit because the fruit is vibrating with the same vibration rate of vibration imposed and is directly impacted.

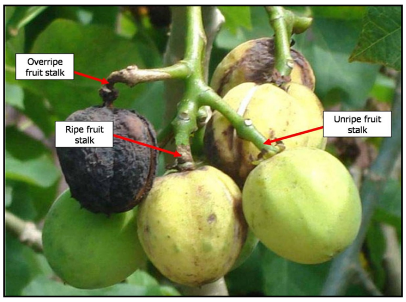


Figure 3. The characteristic of stalks of unripe and ripe fruit.

The treatment with the lowest frequency is the treatment eleven, which is imposed with 5.5 cm of amplitude and a shaking point of 10 cm distance from the fruit stalk. A 5.5 cm amplitude is the longest amplitude that has been used in the experiment. The use of the longest amplitude would produce energetic vibrations even at low frequencies. Benjamin (2010) stated in his book that the longer the amplitude used, the stronger the vibration generated. Therefore, the use of longer amplitudes will save more energy.

### 3.1.1 Analysis of frequency measurement results

A significant level of 1% was chosen for data calculation. The ANOVA table (Table 3) shows the comparison of the frequency value of ripe fruits compared to unripe fruits. The results obtained showed that the frequency used to detach a ripe fruit has a strongly significant difference at $P \leq 0.01$ compared to the frequency used to detach the unripe fruit; see maturity level (ML) results in the ANOVA table. Ripe fruits are easier to be detached and need lower frequency than the unripe fruits, which was agreed by Baker (1986).

The use of three amplitude sizes (2.5 cm, 3.5 cm, and 5.5 cm) shows a significant difference at $P \leq 0.01$ in frequency needed to detach the jatropha's fruit. The longer amplitude will produce a more powerful rotation and was subsequently changed to a more powerful shake. The more energetic rotation, the less frequency needed to detach the fruit (Benjamin, 2010). The data of the shaking point that is used in this study also showed significant difference at $P \leq 0.01$ whereby the Pr>F showed a value of less than 0.01. This data confirmed that shaking points on the fruit stalk, 5 cm, 10 cm and 15 cm distance from the fruit stalk, require a different frequency to

Table 3. ANOVA analysis of frequency for ripe and unripe fruit.

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| ML | 1 | 325606.6667 | 325606.6667 | 280.50** | <.0001 |
| amp | 2 | 666258.2333 | 333129.1167 | 286.98** | <.0001 |
| post | 3 | 32897.3667 | 10965.7889 | 9.45** | <.0001 |
| ML*amp*post | 17 | 68081.2667 | 4004.7804 | 3.45** | <.0001 |
| Error | 216 | 250735.200 | 1160.811 | | |
| Total | 239 | 1343578.733 | | | |

** = significant different at $P \leq 0.01$

detach the fruits. The results obtained also showed that the maturity level, amplitude applied and shaking point on the twigs mutually interact with the frequency required to detach the fruit (Pr>F is less than 0.01).

There is a certain frequency range that can detach the ripe and unripe fruit. It is common sense that the ripe fruits require less frequency to detach the fruits compared to the unripe fruits. The frequency range to detach the ripe fruit is from 160.00 rpm to 299.00 rpm whereas the frequency range to detach the unripe fruit is between 218.00 rpm to 397.30 rpm. The overlap of frequency value to detach the ripe and unripe fruit is around 218.70 rpm to 299.00 rpm. This means that when using this frequency range both ripe and unripe fruits can be detached. The results showed that the frequency range which can be used to detach only the matured jatropha fruit is in the range of 160.00 rpm to 217.00 rpm. However, it might be possible that some ripe fruits will not detach in this range. The use of frequencies higher than this range will start to detach the ripe fruits together with unripe fruits.

### 3.2 Force measurement

The force value to detach the matured jatropha fruits is commonly lower than the force value to detach the unripe fruits. The treatment one showed the highest value of force (2.5 cm amplitude and a shaking point at the fruit stalk) with the reading of the mean force of 1.946 kgF (1 kgF = 9.80665 N). The use of the shortest amplitude in the treatment one was the main factor to give the highest force reading. Benjamin (2010) stated that the use of the shorter amplitude produces a weak vibration. Thus, a larger force is needed to allow the vibrations to shake the twigs harder to detach the fruits. Treatment twelve (5.5 cm amplitude and 15 cm distance from fruit stalk to shake point) is the treatment which recorded the lowest force reading among all treatments by showing the mean force of 0.964 kgF. The 5.5 cm amplitude is the longest amplitude used in this experiment.

Therefore, the more powerful vibrations generated from this amplitude, the easier to detach the fruits even at a low force. The mean value of each treatment was shown in Table 4. The other factors such as twig diameter, length of fruit stalk, distance of fruit from the main branches, level of fruit maturity, position of fruit in the fruit bunches and fruit size are also affect the force required to detach the fruits.

#### 3.2.1 Analysis of the force measurement results

The force required to detach the ripe jatropha fruits shows a strongly significant different at $P \leq 0.01$ compared to the force needed to detach the unripe fruits. The ANOVA table (Table 5) shows the result analysis for the data recorded. Ripe fruit needs a lower force to be detached compared to unripe fruit.

Each of amplitude used in the treatment (2.5 cm, 3.5 cm, and 5.5 cm) requires different force values to detach the fruits. From the ANOVA table, it is shown that the force produced from the each amplitude that has been applied has a greatly significant difference at $P \leq 0.01$ whereby the value of Pr>F shows a lower value than 0.01. The value of force significantly decreases with the increase of the amplitude length. The point that attached the twig holder also shows a significant difference at $P \leq 0.01$. Each of points that are attached to the twig holder (at the fruit stalk, 5 cm, 10 cm and 15 cm distance from the fruit stalk) produce a different value of the force to detach the jatropha fruits. The maturity level, the amplitude that has been applied, and position of twig holder at the tree twig do not interact with each other on the force for fruit detachment. This means that the interactions of the three independent variables are not significant different at $P \leq 0.01$.

There is a certain range of force that will detach the

Table 4. Mean comparison of force of each treatment for matured fruits.

| No. | Treatments | Mean of Force (KgF) |
|---|---|---|
| | | Mean ± (S.E) |
| 1 | T1- Amplitude 1 (2.5cm), Position 1 (0cm) | 1.946 ± (0.10279) |
| 2 | T7- Amplitude 2 (3.5cm), Position 3 (10cm) | 1.688 ± (0.19581) |
| 3 | T3- Amplitude 1 (2.5cm), Position 3 (10cm) | 1.580 ± (0.20166) |
| 4 | T4- Amplitude 1 (2.5cm), Position 4 (15cm) | 1.466 ± (0.17133) |
| 5 | T5- Amplitude 2 (3.5cm), Position 1 (0cm) | 1.370 ± (0.28027) |
| 6 | T2- Amplitude 1 (2.5cm), Position 2 (5cm) | 1.360 ± (0.04909) |
| 7 | T6- Amplitude 2 (3.5cm), Position 2 (5cm) | 1.234 ± (0.02874) |
| 8 | T9- Amplitude 3 (5.5cm), Position 1 (0cm) | 1.194 ± (0.07366) |
| 9 | T8- Amplitude 2 (3.5cm), Position 4 (15cm) | 1.164 ± (0.17508) |
| 10 | T10- Amplitude 3 (5.5cm), Position 2 (5cm) | 1.132 ± (0.05276) |
| 11 | T11- Amplitude 3 (5.5cm), Position 3 (10cm) | 1.100 ± (0.18493) |
| 12 | T12- Amplitude 3 (5.5cm), Position 4 (15cm) | 0.964 ± (0.09703) |

Table 5. ANOVA analysis of force for ripe and unripe fruit.

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| ML | 1 | 6.72606750 | 6.72606750 | 55.10** | <.0001 |
| amp | 2 | 5.49067167 | 2.74533583 | 22.49** | <.0001 |
| post | 3 | 1.61591583 | 0.53863861 | 4.41** | 0.0060 |
| ML*amp*post | 17 | 1.63164417 | 0.09597907 | $0.79^{n.s}$ | 0.7045 |
| Error | 96 | 11.71920000 | 0.12207500 | | |
| Total | 119 | 27.18349917 | | | |

** = significant different at $P \leq 0.01$
$^{n.s}$ = not significant different at $P \leq 0.01$

ripe and unripe jatropha fruits. The ability to detach the ripe fruits is found in the force ranging from 0.964 kgF to 1.946 kgF while the range of force to detach the unripe fruits ranges from 1.290 kgF to 2.208 kgF. The overlapping force values to detach the ripe and unripe fruit are between 1.290 kgF to 1.946 kgF. Both maturity fruit level can be detached if the force in that range is applied to the tree. Forces to detach only the matured jatropha fruit are in the range of 0.964 kgF to 1.280 kgF, but there might be ripe fruits that will not be detached in this range depending on the factors mentioned previously. Forces that are higher than this range will start to detach both fruit levels.

### 3.3 Correlation between force and frequency

The graph in Figure 4 of force versus frequency shows the force and frequency range for the ripe fruit detachment (A area) and the force and frequency range of the unripe fruit detachment (C area). The force and frequency range that overlaps in order to detach the jatropha fruit is represented by B area.

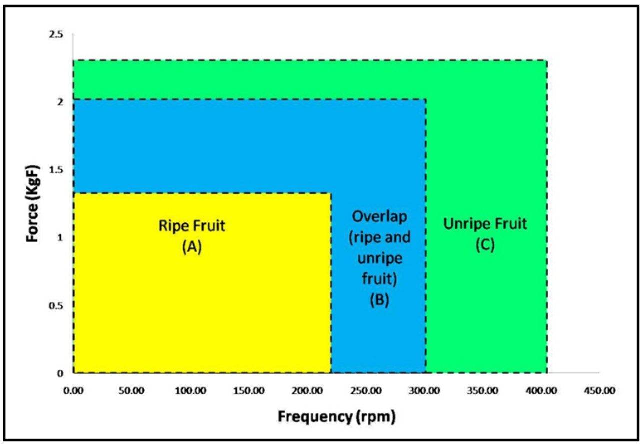


Figure 4. Force and frequency range to detach the ripe and unripe fruit are represented by specific areas.

The relationship between frequency and force trial which causes the fruit to be detached is not directly proportional. This is because the frequency and force is influenced by the physical characteristics of the tree such as the twig diameter size, the fruit maturity level, the distance of shaking point from the main branches, the length of fruit stalk, the position of fruits in fruit bunches, and the fruit size. Hudzari *et al.* (2011b) also found that the position of crop and lighting intensity which stand as the outside factors would affected on relationship between crop maturities prediction via it visual measurement.

## 4. Conclusion

The frequency and force values needed to detach the ripe fruits are different from the frequency and force values needed to detach the unripe fruits. Overall, the results show a highly significant difference in maturity level. This means that there are differences in the frequency and the force to detach the ripe and unripe fruits. The minimum frequency to detach the ripe fruits is 160 rpm and the maximum is 299 rpm. The lowest force required to detach the matured fruits is 0.964 kgF and the highest force is 1.946 kgF. The length of amplitude influences the frequency and force value. Longer amplitude uses a slower frequency and force to detach the fruits. This happened because longer amplitude provides more energy to shake the tree twig, even when the frequency and force is low. Shaking point also influences the frequency and force used, but it depends on the distance from the main stem. Other factors that influence the frequency and force value was diameter of twig, length of fruit stalk, length of fruit from the main branches, ripening stage of fruit and position of fruit in the fruit clusters. All those factors should be considered to determine the frequency and force value that should be used to detach the fruit.

## Acknowledgements

This research was funded by the Faculty of Agriculture and Biotechnology, University Sultan Zainal Abidin, Malaysia. Special thanks are due to National Kenaf and

Tobacco Board, Malaysia, for their permission to use their farm for carrying out this project.

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