FRUIT MATURITY UNIFORMITY AND EXTRACTABLE OIL YIELD OF JATROPHA (Jatropha curcas Linn)

JUPIKELY JAMES SILIP

THE GRADUATE SCHOOL
BOGOR AGRICULTURAL UNIVERSITY
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2011
STATEMENT OF RESEARCH ORIGINALITY

Hereby, I state that the dissertation entitled “Fruit Maturity Uniformity and Extractable Oil Yield of Jatropha (Jatropha curcas Linn)” is my own work, which has never previously been published in any university. All of incorporated originated from other published as well as unpublished papers are stated clearly in the text as well as in the references.

Bogor, June 2011

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F164088062
ABSTRACT

Jupikely James Silip. Fruit Maturity Uniformity and Extractable Oil Yield of Jatropha (*Jatropha curcas* Linn). Advised by ARMANSYAH H. TAMBUNAN (as chairman), ERLIZA HAMBALI, SUTRISNO and MEMEN SURAHMAN (as members).

The primary objective of this study was to determine the physiological occurrences during the life of the fruit on and off the jatropha tree. The work began with determining the reproductive characteristics followed by determining the fruits’ physicochemical characteristics during maturation, ripening and senescence on the tree. The effort was continued with determining the effect of selected postharvest handling practices on increase oil extraction yield, followed by determination of harvesting indicators and finally a study on ripening treatments for harvested mature green jatropha fruits. The study on reproductive characteristics showed wide variation among observed variables during the months of observation. The crop showed indeterminate reproductive characteristics and therefore it was expected that it would be difficult to schedule harvesting which could lead to high harvesting costs being incurred. To reduce the expected harvesting problems required, understanding the harvest characters and therefore monitoring changes in selected physicochemical characteristics during the life of jatropha fruit was performed. The extracted oil yield was significantly high from dry fresh fruit kernels. However, the extracted oil was not only different according to maturity stage but also affected by postharvest handling practices such as drying prior to extraction. Extracted oil from off-tree ripened fruits was significantly higher compared to the on-tree ripened fruit. The advantage of high oil accumulated in the kernels of off-tree ripened fruits was solely dependent on the harvester’s capabilities to determine the individual physiological mature fruits in the farm. However, this study recommended harvesting bunches instead of individual fruits for increased advantage in harvesting volume. The fruit bunch harvesting indicator was bunches with maximum 80% of fruits still green in color and others advanced in maturity as her yellow ripe or senescent fruits. The physiologically mature green fruits were subjected to various ripening enhancers. Treatment with calcium carbide showed that a minimum of three hours exposure to ripen and senescence was better. Field heat as a ripening enhancer also showed good potential. This study demonstrated that poor harvesting is not the major reason for not commercializing this non-edible biodiesel feedstock.

Keywords: *Jatropha*, ripening, maturity, extracted oil, harvesting, postharvest
JUPIKELY JAMES SILIP. Fruit Maturity Uniformity and Extractable Oil Yield of Jatropha (Jatropha curcas Linn). This study was advised by ARMANSYAH H. TAMBUNAN (as chairman), ERLIZA HAMBALI, SUTRISNO and MEMEN SURAHMAN (as members).

Poor harvesting has been the major limiting factor for commercialization of this crop, which has been highlighted in various publications (ERIA 2010, Biswas et al. 2006 and Heller 1996). Jatropha fruits mature heterogeneously which leads to laborious and time consuming harvesting because the harvesters have to select only the fruits that are of the right ripening index for processing. Furthermore, they concluded that 80% of seeds production costs was mainly on harvesting and postharvest handling. Mechanical harvesting of this crop was considered impossible due to its indeterminate flowering and growth habit. Today, jatropha fruits are still harvested by hand in small and plantation scale farms. Jatropha seeds in Myanmar’s eight million acres were reported to be rotting on the farm due to poor harvesting technology (Jim 2009). The indeterminate reproductive habit of this crop is thought to be responsible for this problem, but little information exists on these characteristics.

Crude jatropha oil (CJO) content has been related to harvesting time but the recommendations were inconsistent. Heller (1996), Wiesenhutter (2003), Archolis and Sumarsih (2007), Priyanto (2007) and Hambali et al. (2008) recommended that harvesting of fruits be done at 90 and 55 (Santoso 2008), 45 (Wanita and Hartono 2006), or 37 (Annarao et al. 2008) days after anthesis. The 90 days as an indication of harvest time by previous research was due to a claim that dry fruit results in high CJO. In contrast to the recommended 90 days as harvest time, Wanita and Hartono (2006) reported that high CJO was from fully yellow jatropha fruits or when bunch age is 45 days after anthesis. Santoso
also found that the kernel oil content was in agreement with Wanita and Hartono’s report. Inconsistencies in the recommendations indicate the importance of future study on this issue.

The primary objective of this study was to determine the physiological occurrences during the life of the fruit on and off the jatropha tree. The work began with determining the reproductive characteristics followed by determining the fruits’ physicochemical characteristics during maturation, ripening and senescence on the tree. The effort was continued with determining the effect of selected postharvest handling practices on increase oil extraction yield, followed by determination of harvesting indicators and finally a study on ripening treatments for harvested mature green jatropha fruits.

Study on the reproductive characteristics showed that all reproductive variables observed in this study had comparably high variability. Days required to reach recommended harvesting index varies, implying that harvesting visits to the same tree is should be done rapidly and in a short duration. Jatropha fruits are available throughout the year but there is high variation between observed trees. As a consequence the jatropha production prediction is difficult. In addition, the crop showed variation in sizes, which is expected to lead to difficulty in grading of harvested fruits for further handling practices. Rainfall was found to have a direct effect on fruit production. After the dry season and start of rain showed increase in the number of inflorescence, however increase in the number of branches does not affect the number of fruits and/or inflorescence. Thus, recommendation to prune to increase number of new branches is not advisable.

The frequency of total fruits per bunch in this study showed a positive relationship with total fruit production. Thus, this finding suggests future study to increase the frequency of more fruits per bunch as an approach to increase fruit production. With the high variation amongst the variables, this study suggests that jatropha should be classified as an indeterminate class of crop. As an indeterminate crop, the harvesting problem needs to be addressed by future studies to identify other important variables of the crop so that more solutions to the problem can be suggested.
All ten variables observed in the physicochemical study experienced changes when attached on the jatropha tree. Physical variables i.e. size, firmness, fresh weight and firmness showed differences between maturity stages. The physical variable data indicate benefits in removing the fruit coat prior to further handling practices such as transportation and storage because fruit coats implied increased weight and surface area. Trade of jatropha is suggested to be best with fresh fruits because maturity of harvested fruit can be judged with the naked eye. Recommended harvest index for jatropha is dry harvested fresh fruit because it has high chemically extracted oil yield. However, the recommendation requires future study because the efficiency of oil extraction yield was affected by several factors. The relationship between extracted oil yield and water content revealed the function of moisture content. Changes in the kernels’ soluble solid concentration during the life of the fruit indicated low oil synthesis during the ripe stage but increased during senescence. The pH value of kernels at any maturity stage was between pH six and seven indicating the presence of low ionic value in the sample. Percentage of free fatty acids at any maturity stage in this study was below two percent which indicates the benefit of only requiring esterification during biodiesel processing. Respiratory study indicated jatropha fruits as climacteric fruits with up surge in production of carbon dioxide during off-tree fruit ripening. This study suggests future studies on the effect of several handling practices such as the effect of drying prior to oil extraction and extracted oil yield from off-tree ripe and senesced fruits. The handling practices may influence the oil extraction yield.

This study has also confirmed several effects of postharvest handling practices on oil extraction yield. Chemical extraction methods showed high extracted oil yield but the mechanical extraction method revealed the expected increase extraction efficiency with the modified hydraulic presser, specific handling practices were recommended. Prior to extraction, samples should be crushed as crushed kernels resulted in higher extracted oil yield compared with n-crushed or using seed samples. Preheating temperatures, preheating time and
pressing duration was best at 50°C, 10 minutes and longer time to press, respectively. Significant high chemically extracted oil yield was recorded from off-tree ripened fruit compared with the on-tree ripened sample. The new finding implies requires further investigation. The success of this new finding depends on the success in harvesting physiologically mature green fruits.

The study has identified individual and fruit bunch harvesting indicators for jatropha. Individual fruit character of mature green with trace of yellow was recommended as the individual harvesting indicator. Fruit bunch harvesting indicator was those bunches that has maximum 80% of fruits that were still green in color while the others were advancing in maturity as either yellow ripe or senescent. The trend of harvestable fruit production throughout the year confirms three big harvesting times in a year. Those are in March, August and December. However, the data on fall fruit during delay in harvesting suggests that the harvesting times should be repeated within 6 and 17 days to avoid fall fruits. Increase in fall fruits percentage was a function of time and was best described as a logarithmic trend ($R^2=0.94$). The fall trend showed a plateau after about two months of observation indicating occurrences of multiple dry fruit bunches in the same branch. The occurrence was easily observed during the dry season. The extracted oil yield from up to five different levels of dry fruit bunches from the same branch was found to be almost uniform at about 55% except for the samples from the second from bottom of the branch which has about 60% yield. However, the extracted oil yield from fall fruits was found to be significantly low at only about 40%. The disadvantage of fall fruit in this study suggests that the harvesting visits could be prolonged if 100% mature green fruits can ripen off the tree. Thus, the potential of several ripening enhancers to the harvested mature green jatropha fruit was also tested in this study.

This study demonstrates the effectiveness of CaC$_2$ and direct sunlight exposure as ripening enhancers for harvested mature green fruits. Treatment with any of the enhancers will hasten ripening and senescence. Minimum three hours but not more than six hours exposure to CaC$_2$ is recommended to get best ripening and avoid ripening disorder. There is no limit on sunlight exposure duration as no ripening disorder was observed during the experiment. In addition, treatment
with sunlight exposure ensured 100% senescent fruits at final day of observation. Harvesting time and packaging conditions was confirmed to affect the rate of ripening, senescence and germination percentage. Fruits harvested during 07:00 to 1000 hours and ventilated packaging showed slightly slower rates of ripening and senescence compared to samples harvested after 10:00 AM local time. Germination was also shown to be higher in the sample harvested during 07:00 to 10:00 hours. The occurrence of germination suggests minimum delay in processing of harvested fruit of five days or when all fruits are ripe.
RINGKASAN

JUPIKELY JAMES SILIP. Keseragaman Matang Buah dan Hasil Ekstrasi Minyak Jarak Pagar (*Jatropha curcas* Linn). Dibawah bimbingan ARMANSYAH H. TAMBUNAN (ketua), ERLIZA HAMBALI, SUTRISNO dan NEMEN SURAHMAN (ahli).


yang berasal dari buah yang dipanen saat tersebut menghasilkan CJO tinggi.


Tujuan utama dari penelitian ini adalah untuk menentukan fisiologi buah yang masih segar pada pohon maupun yang sudah dipanen. Penelitian diawali dengan menentukan karakteristik reproduksi, kemudian menentukan karakteristik fisik kimia buah selama proses tua dan pematangan di pohon. Kemudian dilanjutkan dengan menentukan pengaruh penanganan pascapanen untuk meningkatkan minyak hasil ekstraksi, selanjutnya penentuan indikator panen, dan akhirnya pengkajian tentang penanganan buah jatropha hijau yang matang.

Hasil penelitian tentang karakteristik reproduksi menunjukkan bahwa semua variabel reproduksi yang diamati dalam penelitian ini mempunyai variabilitas tinggi. Jumlah hari yang direkomendasikan untuk mencapai kematangan yang siap panen bervariasi, hal ini menggambarkan bahwa pemanenan pada satu pohon yang sama harus dilakukan dengan cepat dan dalam jangka waktu pendek. Pohon jatropha dapat berbuah sepanjang tahun tetapi jumlah buah yang dihasilkan dari pohon ke pohon yang diamati bervariasi tinggi.

Dengan demikian, maka sulit untuk memprediksi hasil tanaman jarak. Selain itu, variasi ukuran tanaman yang berbeda akan menimbulkan kesulitan dalam pengklasakan buah yang dipanen untuk diproses lebih lanjut. Curah hujan juga terbukti memiliki pengaruh langsung terhadap produksi buah. Setelah musim susut dan dengan datangnya musim penghujan maka tanaman mulai mempertajam peningkatan jumlah bunganya, walau demikian bertambahnya jumlah cabang tidak mempengaruhi jumlah buah maupun bunga. Dengan demikian, rekomendasi untuk memangkas pohon agar banyak tumbuh cabang baru tidak dianjurkan. Penelitian juga menunjukkan adanya hubungan positif antara rekuensi total buah per tandan dengan produksi buah total. Dengan demikian, hasil penelitian merekomendasikan untuk diadakan penelitian lanjut...
tentang metode frekuensi perbanyakan buah per tandan sebagai langkah awal untuk meningkatkan produksi buah. Dengan varibel variasi tinggi, penelitian ini menyarankan agar memasukkan tanaman jatropha kedalam tanaman dengan tipe reproduksi tidak terbatas (indeterminate). Sebagai tanaman dengan tipe ini, perlu diadakan kajian lebih lanjut untuk mendapatkan varibel penting sebagai solusi masalah pemanenan.

Sepuluh variabel yang diamati dalam kajian fisikokimia yang diterapkan pada pohon jatropha semuanya mengalami perubahan. Variabel fisik yang diterapkan adalah, ukuran batang, kekokohan batang, berat segar dan kekokohan menunjukkan adanya perbedaan pada tahap kematangan. Data variabel fisik menunjukkan adanya manfaat penghilangan kulit buah sebelum penanganan biji lanjut, seperti transportasi dan penyimpanan, karena kulit buah menambah berat dan luas permukaan. Sebagai komoditas perdagangan, disarankan agar buah yang dipanen dipakai standar karena kematangan buah yang dipanen dapat dilihat dengan mata telanjang. Fitur indeks panen untuk buah jatropha adalah buah segar karena pada keadaan ini buah jatropha menghasilkan minyak yang bila diekstraksi secara kimiai. Namun, rekomendasi tersebut perlu mengkajian lebih lanjut karena efisiensi hasil ekstraksi minyak dipengaruhi oleh beberapa faktor. Hubungan antara minyak hasil ekstraksi dan kadar air mengungkapkan fungsi dari kadar air. Perubahan konsentrasi padatan terlarut pada kernels dalam perkembangan buah mengindikasikan adanya sintesa minyak yang rendah dalam tahap perkembangan namun meningkat dalam proses pematangan. pH kernel pada angka 6 (enam) dan 7 (tujuh) menunjukkan adanya nilai ion yang rendah dalam sampel. Persentase asam lemak bebas pada setiap tahap kematangan dalam penelitian ini berada di bawah dua persen dengan demikian hanya diperlukan proses esterifikasi untuk pengolahan biodiesel. Kajian pirasi buah jatropha, sebagai sebagai buah klimakterik, menunjukkan adanya lonjakan produksi karbon dioksida selama proses pematangan buah yang sudah betik. Penelitian ini merekomendasikan untuk diadakan penelitian lebih lanjut tentang pengaruh beberapa cara penanganan buah jatropha, seperti pengaruh dagingan sebelum ekstraksi minyak dan diekstraksi buah matang hasil meraman. Praktek penanganan dapat mempengaruhi hasil ekstraksi minyak.

Penelitian ini telah menemukan indikator panen untuk tandan individu dan buah jatropha. Karakter buah hijau matang secara individual dengan jejak kuning direkomendasikan sebagai indikator panen. Indikator pemanenan tandan buah adalah tandan yang 80% (delapan puluh persen) buahnya masih hijau tetapi buah lainnya sudah mulai matang atau sudah matang. Trend buah-buahan yang bisa dipanen sepanjang tahun menegaskan bahwa pohon bisa dipanen besar tiga kali dalam setahun. Masa panen tersebut adalah, bulan Maret, Agustus dan Desember. Namun, dari data buah yang gugur selama penundaan masa panen menunjukkan bahwa pemanenan harus diulang pada hari ke-6 dan ke-17 untuk menghindari buah gugur. Peningkatan persentase gugur buah adalah fungsi dari waktu yang terbaik yang digambarkan sebagai trend logaritma ($R^2 = 0.94$). Kecenderungan buah yang gugur di dataran tinggi setelah sekitar dua bulan pengamatan menunjukkan adanya beberapa tandan buah kering di cabang yang sama. Kondisi itu mudah diamati selama musim kemarau. Hasil minyak yang diekstraksi dari 5 (lima) tingkat tandan yang berada dari suatu cabang yang
sama juga menunjukkan adanya keseragaman sekitar 55% (limapuluh lima persent), kecuali untuk buah yang berasal dari tandan kedua dari bawah suatu cabang yang menghasilkan sekitar 60% (enam puluh persen). Namun, hasil minyak yang diekstraksi dari buah yang gugur secara signifikan menunjukkan 40% (empat puluh persen) lebih rendah. Kerugian dari buah yang gugur dalam penelitian ini merekomendasikan untuk memperpanjang masa pemanenan agar 100% (seratus persen) buah yang tua diperam supaya masak. Dengan demikian, berikut dalam perangkat ini akan membahas potensi percepatan pemasakan buah jatropa hijau yang sudah tua yang dipanen.

Hasil penelitian ini menunjukkan adanya efektivitas CaC\(^2\) dan ekspos di bawah matahari langsung buah jarak hijau matang yang dipanen sebagai percepatan pematangan. Penanganan dengan salah satu bahan percepatan pematangan dan penuaan. Untuk mendapatkan hasil pemeraman yang baik serta menghindari gangguan dalam proses pematangan dianjurkan agar buah jarak diperam dengan menggunakan CaC\(^2\) minimum tiga jam dan maksimum enam jam. Tidak ada pembatasan durasi eksposur dibawah sinar matahari karena tidak ada gangguan proses pematangan yang diamati selama percobaan. Selain itu, ekspos biji jarak dibawah sinar matahari memastikan bahwa biji matang 100% (seratus persent) pada hari terakhir pengamatan. Waktu panen dan kondisi kemasan benar-benar mempengaruhi laju pematangan, dan persentase perkecambahan. Buah yang dipanen antara pukul 07:00 sampai 10:00, dan dibungkus dengan kemasan berventilasi menunjukkan adanya kelambatan pematangannya dibandingkan dengan buah yang dipanen setelah 10:00 waktu setempat. Perkecambahan juga terbukti lebih tinggi pada sampel yang panen antara pukul 7:00-10:00. Terjadinya perkecambahan memberikan kemungkinan untuk toleransi keterlambatan minimal selama lima hari atau ketika semua buah-mahatang.
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FRUIT MATURITY UNIFORMITY AND EXTRACTABLE OIL YIELD OF JATROPHA
(Jatropha curcas Linn)

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A Dissertation
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Bogor, June 2011
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CURRICULUM VITAE

Jupikely James Silip (author) was born on May 4th, 1975 at Luanti Baru Village in the District of Keningau, Sabah, Malaysia. He is the third son of Mr. Silip Philip Baniat and Mrs. Lasanim Bida Parantis. The author completed his primary school education at SK Sodomon, Keningau in 1987 and secondary school at SM Bingkor, Keningau in 1992. He completed three years of general agricultural courses in 1996 where he was the top student and best academic achiever at Institut Pertanian Sabah, Timbang Menggaris. He also served as Farm Manager for 14 months at Livestock Evergreen Sdn. Bhd. before continuing his studies pursuing a Diploma in Animal Health and Production at Faculty of Veterinary Sciences, Universiti Pertanian Malaysia, which he completed in 1999. He completed his first degree of Bachelor of Bio-industry Science at the Faculty Agriculture at the same University in 2001. He received a PASCA scholarship to continue his studies and completed his Master in Agriculture Science at the same Faculty in 2003. In September 2008, the author registered as a PhD student in the Agriculture Engineering Program at the School of Postgraduate, Bogor Agricultural University which he completed in June 2011.

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CHAPTER 1
INTRODUCTION

Background of the Research

Oil security is a major issue in the world today. For the very first time the price of crude oil reached up to USD145 a barrel due to limited production sources and increase in demand for fossil fuel. Hence, many investors, policy makers and scientists are involved in an urgent search for renewable energy. In many countries, biofuel is now the focus of this search for renewable energy, after wind energy, microhydro energy, solar energy and geothermal energies. As a consequence, today, there is high demand for biofuel materials. Palm, coconut, sunflower, rapeseed and jatropha oils are the materials available in today’s market as biofuel feedstock. *Jatropha curcas* Linn has been given priority because the other sources listed above are also food materials. It was forecasted that each year for the next 5 to 7 years approximately 2 million hectares of jatropha will be planted around the world (GEXSI 2008). Biofuel technology based on jatropha requires further investment, supported by a broad body of information from various researches. As jatropha is considered a new and developing crop to the plant science community, there has been a great deal of research on it.

Poor harvesting has been the major limiting factor for commercialization of this crop, which has been highlighted in various publications (ERIA 2010, Biswas *et al.* 2006 and Heller 1996). Jatropha fruits mature heterogeneously which leads to laborious and time consuming harvesting because the harvesters have to select only the fruits that are of the right ripening index for processing. Further the fruits have to be harvested manually at regular intervals. Sivapragasam and Puteh (2008) reported that the amount of harvested jatropha fruits was only about 100 g.minute$^{-1}$ or about 6 g.hr$^{-1}$. Furthermore, they concluded that 80% of seeds production costs was mainly in harvesting and postharvest handling. Mechanical harvesting of this crop was considered impossible due to its indeterminate flowering and growth habit. Today,
Jatropha fruits are still harvested by hand in small and plantation scale farms. Jatropha seeds in Myanmar’s eight million acres were reported to be rotting on the farm due to poor harvesting technology (Jim 2009). The indeterminate reproductive habit of this crop is thought to be responsible for this problem, but little information exists on these characteristics.

Crude jatropha oil (CJO) content has been related to harvesting time but the recommendations were inconsistent. Heller (1996), Wiesenhutter (2003), Nurcholis and Sumarsih (2007), Priyanto (2007) and Hambali et al. (2008) recommended that harvesting of fruits be done at 90 and 55 (Santoso 2008), 45 (Wanita and Hartono 2006), or 37 (Annarao et al. 2008) days after anthesis. The 90 days as an indication of harvest time by previous research was due to a claim that dry fruit results in high CJO. In contrast to the recommended 90 days as harvesting time, Wanita and Hartono (2006) reported that high CJO was from fully yellow jatropha fruits or when bunch age was 45 days after anthesis. The seed oil was reported to be 10.93, 26.98, 29.38, 22.83, and 23.68% in green, green with yellow, fully yellow, yellow with black and black fruits colors respectively. Santoso (2008) also found that the kernel oil content was in agreement with Wanita and Hartono’s report. Inconsistencies in the recommendations indicate the importance of future study on this issue.

Multiple harvesting requirements being a main contributor to high harvesting costs could be due to the recommendation to harvest individual dry or yellow fruits. To increase the harvestable volume, harvesting fruits bunches has been recommended. It was recommended that fruit bunches are ready to be harvested when 50% (Hambali et al. 2008), 60 - 70% (Nurcholis and Sumarsih 2007) and 75% (Priyanto 2007) of the fruits in a single bunch are ripe. If fruit bunches’ characteristics are to serve as a harvesting indicator then the next problem would be to solve the problem posed by variations in the fruits’ ripening stage after harvest, especially the green fruits. The harvested fruits that are yet to reach the required ripening stage for high oil extraction rate might require postharvest handling such as ripening treatments with external ethylene gas treatment. However, no such treatments are available for jatropha at this time. It is important to note that there are...
physiological and biochemical ripening differences between the fruits that ripen on (in situ) and off the tree. According to Wills et al. (1998) the development and maturation of fruits is complete only when it is attached to the plant, but ripening and senescence may proceed on or off the plant.

Contrary recommendations on harvesting time based on days after anthesis was also thought to be due to this indeterminate growth habit of the crop. Long term solutions could be the breeding of varieties whose growth habits are determinate with uniform fruit maturity. These traits can make harvest scheduling possible for maximum economic yield. Unfortunately, the breeding of new varieties is costly and time consuming and, therefore, near-term solutions are also needed during domestication of local accession. One of the solutions involves harvest and postharvest treatments. Physiologically mature fruits could be ripened off the tree with similar oil extraction quantity like those that ripen on the tree. However, scarce information is available in the literature, related to postharvest handling of this crop.

Since poor harvesting efficiency has been attributed to the indeterminate growth habit and contrary recommendations on the harvesting time and indicators, this research was designed to determine selected reproductive characteristics followed by determining physicochemical occurrences during the life of the fruit on and off the tree. To further understand the extracted oil yield, effects of selected postharvest handling practices on oil yield was determined. Ripening characteristics of various individual fruits and fruits bunches was determined to recommend harvesting indicators. The final work carried out involved determining the effect of various ripening enhancers on the ripening percentage of harvested green fruits. This research is thought to be useful from the economic perspective of jatropha industries because all the possibilities explored will contribute to reduction in harvesting costs.
Objectives of the Research

Two main objectives of this research were to determine the physiological occurrences during ripening on and off the tree and improve ripening uniformity off the tree.

Four specific objectives were:

1. To characterize jatropha productive heterogeneity,
2. To determine physicochemical characteristics based on fruit color,
3. To determine harvesting indicators of individual and fruits bunches and
4. To improve ripening uniformity of harvested mature green fruits off tree through postharvest approach.

Benefits of the Research

Since poor harvesting efficiency has been related to the indeterminate growth habit and lack of harvest and postharvest physiology information, therefore, the results of this research would be shed light into how to increase harvesting efficiency and reduce harvesting costs. The technologies developed would be desirable from the economic perspective of jatropha industries.

Boundaries of the Research

The study was limited to a specific jatropha accession, specific targets of reproductive characteristics, specific target of fruit maturity, specific target of physicochemical character and within a specific time frame.

a. Jatropha accession: Luanti accession from Luanti Baru Village, Keningau, Sabah, Malaysia become the main samples for this study but several different accessions were used for study on the fruit maturity uniformity according to different
accession. Two other specific accession namely Tanzania and IP1 were used for preliminary experiment and respiration study.

b. Targeted reproductive characters: uniformity of fruit maturity, number of active and non-active branches, number of buds, number of inflorescences, fruit production, total number of bunches, frequency of fruits per bunch and days required to reach specific stage of development.

c. Targeted fruit maturity: immature fruits or young fruits, mature green fruits, ripe or yellow fruits, senescence wet black fruits and senescence dry fruits.

d. Targeted physicochemical characters: ripening percentage, size, soluble solid concentration, free fatty acids, crude jatropha oil, pH value, water content, carbon dioxide concentration, color, weight loss and firmness.

e. Time frame: Two years of data collection. 2009 and 2010.
CHAPTER 2

LITERATURE REVIEW

Reproductive Characteristics of Jatropha

*Jatropha curcas* L. belongs to the family Eupropiaceae (Jongschaap *et al.* 2007). There are approximately 170 known species of the plant around the world. Jatropha originated from Mexico and Central America, but has spread all over the world (Van Marwijk *et al.* 2007). Names used can also vary by region or country. In Indonesia and Malaysia it is called “jarak pagar”. Jatropha is a multipurpose species with many attributes and considerable potential (Kumar and Sharma 2008). All parts of the jatropha have been used in traditional medicine and for veterinary purposes for long time (Duke 1985a and Duke 1986b). The oil has been used as a purgative to treat skin diseases and to soothe pain such as that caused by rheumatism. Its leaves have been used against coughs or as antiseptic after birth (Heller 1996). A substance that is responsible for wound healing and has anti-inflammatory properties has also been isolated and characterized from this plant (Nath and Dutta 1991). Various extracts from Jatropha seeds and leaves showed molluscicidal, insecticidal and fungicidal properties (Nwosu and Okafor 1995 and Liu *et al.* 1997).

Presence of phorbol ester which is toxic and carcinogens in jatropha has been the major constraint for human and animal consumption (Goel *et al.* 2007). Due to the toxicity of the plant and oil, some special precautions need to be exercised during the processing of the jatropha seed and oils. Many researchers have attempted various chemical and physical treatments to extract or inactivate phorbol esters so that the protein-rich seed meals could be used as a feed resource. However, not much progress has been reported so far (ERIA 2010). Various parts of this plant can be used for numerous purposes but more attention is given to its potential as a biodiesel feedstock. The oil can be directly used in diesel engines, blended with fossil diesel and/or other fossil fuels or the oil can be transesterified into jatropha (m)ethyl esters that can be used in conventional diesel engines or diesel engines with adapted parameters (Acthen *et al.* 2008).
Morphological structure and function

Jatropha is a small tree or large shrub, 5-7 m tall and with favorable conditions it can attain a height of 8 to 10 m, with soft wood and a life expectancy of up to 50 years. The plant shows articulated growth, with a morphological discontinuity at each increment. The branches contain latex. The plant develops a deep taproot and initially four shallow lateral roots (Heller 1996). The leaves are smooth, 4-6 lobed, 10-15 cm in length and width and sheds during dry season.

The flowering in jatropha produces more male than female flowers. The inflorescence of this plant is axillary paniculate polychasial cymes, monoecious and flowers are unisexual, while occasionally hermaphrodite flowers occur (Dehgan and Webster 1979). A flower is formed terminally, individually with female flowers usually being slightly larger. Ten stamens are arranged in two distinct wholes of five each in a single column in androecium, and in close proximity to each other. The ratio of male and female flowers range from 13:1 to 29:1 (Raju and Ezradanam 2002 and Raju and Ezradanam 2002b ), female flower (about 10-20%) and male flowers are more numerous (about 80-90%) and decrease with the age of the plant (Aker 1997). Number of flowers (male plus female) per inflorescence is around 65.5 to 158.7, significantly different according to jatropha ecotypes (Santoso 2008).

This information indicates that a huge amount of flowers will not guarantee an increasing number of fruits if there are more male than female flowers. On the other hand the female flower is not guaranteed to become a fruit. According to Sir Hartati et al. (2009) the fruit set is influenced by climatic conditions. They found that heavy rain will significantly reduce the percentage of fruit sets. In contrast, Abdelgadir et al. (2008) and Rianti et al. (2010) reported that the fruit set is significantly increased with introducing insect pollinators into the jatropha farm. The flowering was also reported to increase with a good watering system (Saefudin and Pranowo 2006).
**Fruit production characteristics**

Jatropha is a newly domesticated oil crop and has not as yet considered an industrial crop. The challenge in developing this crop as an industrial crop has been published in the final report of the global market study on jatropha (GEXSI 2008) recently by ERIA (2010). Jatropha has not as yet undergone a careful breeding program with systematic selection and improvement of suitable germplasm, which is why it can still be considered a wild plant that exhibits great variability in productivity between individuals (Achten et al. 2008). However, some countries like Indonesia have already advanced in the breeding program of this crop. Appendix 1 shows the production potential of selected jatropha varieties in Indonesia and Appendix 2 shows the contrary predictions on jatropha yield. The information indicates that jatropha yields forecasting seem scattered and this offers opportunities for more study in this area.

More recent news on jatropha breeding in Indonesia was reported at Lokakarya Jarak Pagar National IV at Malang, Surabaya last November 4, 2008. New varieties called IP-3A, IP-3M and IP-3P were reported to be able to produce eight to 10 tonnes of dry seeds in year 4 and 5 respectively. The report also identified various accessions that proved to give 57 – 77% higher production as compared to IP-1P. Methods to reduce the heterosis effect which could reach 93% were also reported to have been already established using tissue culture techniques.

Appendix 3 shows several variables used in the publication for yield measurement and prediction. The number of trees.ha$^{-1}$, branches.tree$^{-1}$, fruits.bunches$^{-1}$ and dry seed weight.fruit$^{-1}$ have been used as indication of future production capability of jatropha. It has been assumed that if each branch bears a flower and each tree has 48 productive branches and each bunch has 15 fruits with each fruit having 3 grams of dry seeds and a planting distance of 2 m x 2 m per hectare, then the production of dry seeds can be calculated as around 5,500 kg/hectare (Santoso 2008). The reality is that not all branches are productive. According to Raden (2008) not all branches will inflorescence, as the percentage of flowering branches is around 59 – 3%. He also reported that the number of fruits.bunches$^{-1}$ was around 6.3 to 8.1. On
the other hand, there are many other factors influencing productivity such as fertilizer, watering system, insect pollinators and use of plant growth regulators (Appendix 3).

The above mentioned variations among the variables are used to determine the yield of the crop. In general, extreme external factors such as earthquake and flooding or any natural disaster which definitely affects yield are impossible to predict but internal factors such as reproductive characteristics of specific crops will further improve prediction of the harvested volume. Deep knowledge of the crop’s character could also increase human control over any related intervention to the crop.

Crops in the class of indeterminate reproductive characteristics have been intensively studied by crop breeders to reduce its disadvantages. The fact with crops in this class of indeterminate reproductive characteristics is the difficulty in harvesting schedules and therefore increased harvesting cost (Berti et al. 2008). Breeding is definitely the answer to solve this characteristic problem but the effort is really time consuming and costly. Short term solutions during domestication of local varieties is required and best agronomic management practices to promote production of this non-edible biodiesel feedstock has been documented but little is known about the best harvesting and postharvest handling practices for the jatropha crop (Gaur 2006; Achten et al. 2008 and GAXSI 2008).

Poor harvesting has been reported in relation to its indeterminate characteristics (Berti et al. 2008) but little is known about this aspect in jatropha (ERIA 2010). The importance of information on the reproductive characteristics in relation to production prediction has been mentioned earlier. Findings by Raden (2008) in this regard are very important. He reported that not all branches will inflorescence and the rate was only around 59 – 93%. He also reported that the most frequent number of fruits per bunch was in the range of 6 – 8. Ginwal et al. (2004) reported a positive relationship between the number of branches, number of fruits per branch and amount of oil yield. In details, Santos (2008) reported 50 morphological, growth and development characteristics of seven jatropha ecotypes in Indonesia. Appendix 4 shows selected morphological characters of seven selected jatropha
ecotypes in Indonesia reported by Santoso. He concluded in his study that the differences amongst variables were relatively low at only 27%.

Based on Santoso’s (2008) report, it was obvious that the differences were important from the harvesting perspective due to the high differences in irrespective ecotypes to start flowering and also readiness of fruit to be harvested (Appendix 4). Some ecotypes were reported to start flowering as early as 105 days after planting while some only started when they reached 163 days. While within fruits’ readiness to be harvested, some were reported ready when reaching 55 days after anthesis, others took as longer up to 59 days. The differences are important in harvesting scheduling because not all fruits will ripen on the same day. However the available data could not show ripening uniformity per tree or within bunches.

It is important to note that the agro-climate has been reported to have a significant effect on growth, development and production potential of any crop. Frey (1981) and Wiley (1981) reported that jatropha planted by seed will undergo natural cross breeding within different ecotypes and will adapt with new agro-climates. However, according to Ginwal et al. (2004) the cross pollination occurring within different jatropha accession has no significant effect on their morphological characteristics. However, the agro-climate was reported to influence the oil content of jatropha kernels. Jones and Miller (1991) and Santoso (2008) reported significant high jatropha kernel oil content in dry land compared to jatropha planted in areas with high amount of rain. Low oil content in sunflower seeds were also reported in areas with low temperature and short days as compared with areas with long days and high temperature (Leon et al. 2003).

Besides the agro-climate, good agricultural practices were also reported to have a significant effect on oil content. Leon et al. (2003) and Santoso (2008) reported that the differences in the oil content with different ecotypes were found to be not significantly different when good agricultural practices were applied. On the other hand Aguirrezabal et al. (2003) reported the significant effects of planting distance on seed production and oil yield of sunflower.
Physicochemical Changes during the Life of the Jatropha Fruit

Plants and plant parts progress through a dynamic series of genetically controlled development processes terminating in their eventual senescence and death (Kays 1991). There is great interest to understand physicochemical changes occurring during jatropha fruit maturation, ripening and senescence because it could lead to understanding the harvesting perspective such as harvesting time, harvesting schedule and harvesting cost.

Initiation of flowering and the end of anthesis are the starting points of fruit development. The plants and plant parts development is the combination of both growth (an irreversible increase in size or volume accompanied by a biosynthesis of new protoplasmic constituents) and differentiation (qualitative changes in the cells) and can be viewed at either whole plant or individual organ level (Kays 1991). Ripening can generally be defined as the summation of changes in tissue metabolism rendering the fruit organ attractive for consumption by organisms that assist in seed release and dispersal (Adams-Phillips et al. 2004).

As jatropha fruits develop, they display changes in size, weight, colour and oil content. Like other plant, the jatropha fruit development and ripening involves a combination of biochemical and physiological events. The jatropha tree will start to bear flowers at the age of 4–5 months in the farm (Nurcholis and Sumarsih 2007; Priyanto 2007; Rijssenbeek and De Jongh 2006; Hariyadi 2005 and Heller 2000). Recently, Annarao et al. (2008) reported that the fresh weight of immature young seeds range from 32.4 mg to 1061 mg. Percentage moisture decreased as the seed matured. Increase in fresh weight from day 12 to 22 was nearly ten times (32.4 – 317 mg) while it was only three times from day 22 (317 mg) to 32 (1061 mg). The seed weight was reported to decrease when the fruit ripened (yellowish in colour) from green colour or age of 37 to 42 days. They also chronologically divided it into two classes of jatropha seed development. These are early development stage (12 – 22 days after anthesis) and maturation stage (27 – 42 days). They observed a significant difference in linoleic, linolenic and sterols in the two stages of Jatropha seed development.
**Changes on colour**

The colours of agricultural products contribute more to the assessment of quality than any other single factor (Kays 1991). Consumers tend to associate colour with flavour, safety, storage time, nutrition and level of satisfaction due to the fact that it correlates well with physical, chemical and sensory evaluations of product quality (Pedreschi et al. 2007). Therefore, this factor has been used in many agricultural products as prediction of harvesting time. Wanita and Hartono (2006) used the jatropha fruits’ colour as references for their study on changes in crude jatropha oil (CJO) quantity. Wanita and Hartono (2006) used five fruit colour changes in their study. The fruit colours they used are green, green with yellow colour, fully yellow colour, yellow with black colour and black colour. Instead of using colour changes, Santoso (2008) used stages of fruit maturity in his similar study. The five stages were immature or 25 days after anthesis, near mature or 35 days after anthesis, mature or 45 days after anthesis, ripe or 55 days after anthesis and over ripe or 65 days after anthesis. The different methods of observing the CJO during maturity and ripening shows a need for future work in the development of the ripening index on this plant.

Colour is a function of light striking a product, the differential reflection of certain wavelengths, and the visual perception of those wavelengths perceived due to the presence of pigments within products (Kays 1991). The change of colour in skin and/or pulp or flesh of horticultural products is due to the change of colour pigments (Wills et al. 1998). In most fruits, the loss of chlorophyll is accompanied by the unmasking or biosynthesis of carotenoid pigments (Gross 1987). Carotenoid is present in green fruit tissues prior to maturation and there are two patterns of carotenoid biosynthesis. The first pattern of carotenoid biosynthesis takes place in the chloroplast and is an integral part of the development (Gross 1987). It is closely linked to the biosynthesis of chloroplast components but masked by the presence of chlorophyll. During ripening the green colour turns to yellow as chlorophyll gradually degrades, unmasking the colour of previously available carotenoid pigments. The degreening of lemon is due to this pattern (Gross 1987).
Changes in texture

Texture is associated with a softening of parts of fruits such as the flesh or skin during ripening. Therefore, texture is an important physical attribute that has always been associated with ripening. Kays (1991) reported that once the softening processes are initiated, the rate of textural changes is a function of the type of fruit and the condition under which the product is held. The researcher further explained that the texture of fruits is affected by the composition of their cell walls and cellular constituents and their degree of hydration. Seymour et al. (1993) also agreed with the statement by a previous author that in general, texture changes during ripening of most fruits is thought to be largely the result of cell wall degradation.

Cell wall and meddle lamella are composed of cellulose, hemicellulose, pectin and protein. Hydrolysis of these cell wall component monomers yields a cross-section of compounds (Williams and Bevenue 1954). This monomer could be a soluble solid concentration or group of acids. Agrawal et al. (2002), Mercado-Silva et al. (1998), El Buluk et al. (1997) and Gupta et al. (1979) reported that soluble solid concentration (SSC) in many fruits increased during ripening and decreased in overripe fruits. The high sugar during ripening was due to hydrolysis of starch into sugar by phosphorylase enzymes in the fruits, or sugar was being synthesized in the leaves and transported into the fruit (Spayd and Morris 1981). The increase of SSC could also be due to the decrease in titratable acidity when organic acids were converted into sugars or being utilized during respiration (Wills et al. 1989 and Belitz and Grosch 1987).

Major changes in acidic pectin are also observed during ripening (Tucker and Grosch 1987) and esterification were also reported to occur. They found that the percentage of the esterification was about 75% in green tomato but decreases to about 50% during ripening. The above reports indicate the importance of determining textural characters during maturity and ripening. However, there was no report on the textural characters of jatropha fruit during maturity and ripening. However, rupture force, hardness and toughness of yellow stage jatropha fruit, nut and kernels has been reported by Sirisomboon et al. (2007). They reported that the rupture force, hardness
and toughness of the jatropha fruit, nut and kernels were 135.39, 146.63 and 67.72 N respectively. The report showed that high energy was required to rupture jatropha nut or shells. Firmness of horticultural products can be measured by compression or puncture with various probes at different force or deformation levels, depending on the purpose of the measurement (Abbott 1999).

Changes on soluble solid concentration

Soluble solids concentration (SSC) in many fruits are normally increased during ripening and decreased in overripe fruit (Agrawal et al. 2002; Mercado-Silva et al. 1998; El Buluk et al. 1997 and Gupta et al. 1979). The high sugar during ripening is due to hydrolysis of starch into sugar by phosphorylase enzymes in the fruits, or sugar being synthesized in the leaves and transported into the fruit (Spayd and Morris 1981). The increase of SSC could also be due to the decrease in titratable acidity when organic acids are converted into sugars or being utilized during respiration (Wills et al. 1989 and Belitz and Grosch 1987).

Plant cells require sugars to synthesize lipids. Degradation of six-carbon via glycolysis is said to be the first one involved in the oil biosynthesis (Salas et al. 2000). The degradation occurs in plastid, which can yield acetyl-CoA. Acetyl-CoA is the initial substrate for synthesis of the carbon backbone of all fatty acids (Conde et al. 2008). The alternative major possibility consists of acetyl-CoA production via mitochondrial pyruvate dehydrogenase, followed by the cleavage of this precursor to acetic acid and the latter’s transportation to the plastid, where it is reactivated to acetyl-CoA (Salas et al. 2000). However the relative contribution of the pathway of oil biosynthesis has not been studied so far in oil fruits (Salas et al. 2000). Information on the availability of the sugar processor for oil biosynthesis in Jatropha fruit is very scarce.

There are two sources of carbohydrates for fruit growth and lipid biosynthesis in oil fruits. The major one is provided by sugars translocated in the phloem from leaves to the sites of storage. The second is formed by photosynthesis in the fruits
themselves. Previous reports by Wanita and Hartono (2006) and Annarao et al. (2008) indicated that the jatropha fruit changes its own colour from green to yellow during development and ripening. In olives, Sanchez and Harwood (2002) confirmed that both fruit photosynthesis and photoassimilates contribute to lipid biosynthesis. It is very important to note that if sugar plays an important role in inducing the production of acetyl-CoA then there could be huge acetyl-CoA production during ripening. Wanita and Hartono (2006) and Annarao et al. (2008) previously indicated high oil content in ripe jatropha fruit. However, no information was available on the sugar and acetyl-CoA content during development and ripening of this fruit.

**Changes in free fatty acids**

The importance of free fatty acid (FFA) content in crude plant oil to get fatty acid methyl esters (FAME) by transesterification was reported by Joelianingsih et al. (2007). They found that high FFA in the biodiesel feedstock will reduce the quality of FAME. However, the paper did not state the minimal level of FFA in the CJO to get high quality FAME because they believed that the conditions can be manipulated to get high quality FAME by regulating the reaction temperature using their innovated bubble column reactor. On the other hand other researchers found that FFA of more than 5% in a feedstock by using alkali-catalyzed reaction will only form soap and water (Van Gerpen and Knothe 2005).

The above information showed the importance of FFA in biodiesel feedstock. Extracted CJO’s for black dried fruits is reported to contain 0.18 – 3.40 % (kgkg⁻¹) FFA (Gubtiz et al. 1999; Forson et al. 2004; Kandpal and Madan 1995 and Reddy and Ramesh 2006). Annarao et al. (2008) reported the percentage contribution of fatty acids in different stages of the jatropha seeds development. Free fatty acids ranged from 63.4 to 74.2% at ages of 12 to 22 days after anthesis and thereafter showed a sharp decline to only around 2.0 to 3.5% at ages of 32 and 37 days after anthesis. FFA in CJO was higher compared to crude palm oil (CPO) and net coconut
oil (NCO) (Berchmans and Hirata 2008). The FFA in CJO, CPO and NCO were 14.9%, 6.1% and 1.2% respectively.

High FFA cited by Berchmans and Hirata (2008) of 14.9%, contradicts the report by Annarao et al. (2008). The sample of CJO used by Berchmans and Hirata (2008) could be unripe. According to Annarao et al. (2008) the production of 74.2 to 83.3 % FFA is when the fruit enters 17 to 22 days after fertilization (days after anthesis). Another possibility of high FFA in the sample of Berchmans and Hirata (2008) could be due to a fact that their CJO sample was stored for a long time prior to analysis. Without proper handling and storage, the process causes various chemical reactions such as hydrolysis, polymerization and oxidation. Therefore, the physical and chemical properties of their sample during handling and storage might contribute to the high FFA content.

A lot of research has already been conducted to characterize vegetable oil quality during handling and storage (Leung et al. 2006; Monyem and Van Gerpen 2001; Oversen et al. 1998). The percentage of FFA has been found to increase due to the hydrolysis of triglycerides in the presence of moisture and oxidation. The oxidation of the unsaturated fatty acid component in the CJO might occur easily and it could lead to degradation of the oil (Canakci 2007). The reason for auto oxidation is due to the presence of double bonds in the chains of unsaturated fatty acid compounds.

**Respiration trends**

Respiration can be described as the oxidative breakdown of the more complex materials normally present in cells, such as starch, sugar and organic acid, into simpler molecules, such as carbon dioxide and water, with the concurrent production of energy and other molecules which can be used by the cell for synthetic reaction (Wills et al. 1989). Respiration requires the synthesis of novel proteins and mRNA, as well as new pigments (Seymour et al. 1993). These anabolic processes require both energy and a supply of carbon skeleton building blocks. These are supplied in
fruits, just as in other tissues of respiration. Therefore, the respiration rate of the produce is an excellent indicator of the metabolic activity of the tissue. However, no information is available on the jatropha’s respiration patterns during ripening.

In general, fruits can be classified as either climacteric or non-climacteric on the basis of their respiration pattern during ripening. The classification of fruit into climacteric and non-climacteric is considered an over-simplification (Obando et al. 2007). Climacteric ripening is characterized by an upsurge in the respiration rate accompanying an autocatalytic ethylene production peak during ripening (Kays and Paul 2004). It is interesting to note that climacteric fruits, such as banana and papaya tend to ripen rapidly which has led to the regulation of respiration as a possible target of biochemical manipulation of shelf life. In contrast, non-climacteric fruits such as pineapple, orange and star fruit simply exhibit a gradual decline in their respiration during ripening.

Ethylene is produced by most plant tissues at a relatively low level of around 0.05 µl h\(^{-1}\) g\(^{-1}\). Climacteric and non-climacteric fruit appear to differ in the control of ethylene synthesis. The biosynthesis of ethylene in climacteric fruit is said to be autocatalytic. Therefore, McMurchie et al. (1972) introduced two control systems for ethylene catalysis. System one, common to both climacteric and non-climacteric fruits is responsible for both basal ethylene production, where ethylene is produced when the tissue is wounded. System two is unique to climacteric fruit and is responsible for the autocatalytic production accompanying ripening in this fruits. Most plant tissue will respond to wounding with an increase in ethylene production (Seymore et al. 1993). In this respect both climacteric and non-climacteric fruit, at all stages of development, are no exception. Thus all fruit, if wounded, will respond with increase in ethylene synthesis.

The biochemical synthesis of ethylene was defined by the pioneering work leading to the definition of the YANG cycle. To summarize, the enzyme S-adenosyl-methionine (SAM) synthase catalyses adenosylation of the sulphur atom of catalysed. SAM is then metabolized to 5’-methylthioa-adenosine (MTA), which is incorporated into the methionine cycle to recover the catalyst atom and 1-aminocycloropane-1-
carboxylic acid (ACC), the first compound of the pathway committed to ethylene biosynthesis. The enzyme that catalysed this reaction is ACC synthase (ACS) and it is pyridoxal phosphate-dependent. Finally, in the presence of oxygen, ACC is converted to ethylene-forming enzymes by ACC oxidase (ACO), originally defined as the ethylene-forming enzyme (EFE). Genes encoding ACS and ACO were originally identified via elegant studies employing maturing fleshy fruit (Hamilton et al. 1990).

**Crude Jatropha Oil**

*Crude jatropha oil as fuel in a diesel engine*

The potential use of Jatropha oil as biodiesel feedstock has been well studied (Augustus et al. 2002; Pramanik 2003 and Reddy and Ramesh 2006). The oil is comparable to diesel fuel, but its density and viscosity are much higher (Namasivayam et al. 2007). Crude jatropha oil (CJO) is like other pure plant oil (PPO) and also known as unmodified oil or straight vegetable oil (SVO). However, PPO requires simple purifying processes such as degumming, filtration and deacidification before it can be directly used as bioenergy but SVO does not require this. PPO is simply different from biodiesel due to the fact that the oil has not undergone a transesterification reaction or any means or methods to enable its use in a common diesel engine without operational problems such as engine deposits.

The first known use of vegetable oil as fuel in a diesel engine was a demonstration of an engine built by the Otto Company designed to burn mineral oil, which was run on pure peanut oil at the 1900 World Fair (Mittelbach and Bernscheidt 2004). Late in his career, Rudolf Diesel investigated the use of vegetable oil to fuel engines of his design. In a 1912 presentation to the British Institute of Mechanical Engineers, he cited a number of efforts in this area and remarked, "The fact that fat oils from vegetable sources can be used may seem insignificant today, but such oils may perhaps become in course of time of the same importance as some natural mineral oils and their products are now."
Periodic petroleum shortages spurred research into vegetable oil as a diesel substitute during the 1930s and 1940s, and again in the 1970s and early 1980s when SVO enjoyed its highest level of scientific interest (Mittelbach and Remschmidt 2004). The 1970s also saw the formation of the first commercial enterprise to allow consumers to run SVO in their automobiles. In the 1990s Bougainville conflict, islanders cut off from oil supplies due to a blockade used coconut oil to fuel their vehicles. Academic research into straight vegetable oil fell off sharply in the 80s with falling petroleum prices and greater interest in biodiesel as an option that did not require extensive vehicle modifications.

PPO cannot be used directly in a conventional car engine due to several reasons. The viscosity of PPO is reported to be 2 to 10 times higher as compared with biodiesel or petrodiesel. This viscosity has impacts on injection and combustion. High viscosity leads to a high drag in the injection pump and thus causes high pressure and injection volumes, especially at low engine operating temperatures (Worgetter et al. 1998; Ryan et al. 1982; Fort and Plumberg 1982 and Walter and Derry 1982). Today, in many countries like in Germany general modification of their vehicles include a heater on the fuel line to help in the PPO flow. Volatility of PPO is low. Volatility of oils is important because it is related to storage and fire hazard and also defined as a measure of a temperature to which a fuel must be heated such that a mixture of vapor and air above the PPO can be ignited. Flesh point for PPO is more than 200°C while only 54°C and 93°C in petrodiesel and biodiesel respectively. PPO contains high density of around 900 – 930 kg m⁻³ which reduces its energy per volume compared to biodiesel or fossil diesel fuel. PPO has low oxidative stability compared to biodiesel or fossil fuel which shortens it storage shelf life. PPO also contains high water and sediments which can also contribute to lower combustion power. PPO also contains high polluting element such as sulphur which limits its use in some countries.

Some advantages of PPO were also reported (Mittelbach and Remschmidt 2004). PPO contains high cetane number (CN) compared to CN in biodiesel or fossil diesel fuel. This character implies an advantage of short delay in ignition. PPO needs
high temperature to be ignited compared to biodiesel or petrodiesel but from the perspective of storage and fire hazard, PPO is much safer. Preparation of PPO was also reported to not require costs for esterification / transesterification processes and therefore cost of production will definitely be lower.

Major compositions of jatropha fatty acid are C16:0=palmitic acid (14.54%), C18:0=stearic acid (6.30%), C18:1=oleic acid (42.02%) and C18:2=linoleic acid (35.38%). Other acids include capric acid, mysteric acid (C14:0), palmitoleic acid (C16:1), linolenic acid (C18:3), arachidic acid (C20:0), behenic acid (C22:0), cis-11-eicosenoic acid (C20:1) and cis-11,14-eicosadienoic acid (C20:2) (Foidl et al. 1996; Augustus et al. 2002; Akintayo 2004; Azam et al. 2005; Martinez-Herrera et al. 2006; Berchmans and Hirata 2008; Annarao et al. 2008 and Achten et al. 2008).

The fatty acid composition makes each PPO different with different potentials as biodiesel fuel. For example biodiesel density which has effect on heating values and fuel consumption definitely will be different with different compositions of fatty acids. According to Achten (2008) and Mittelbach and Remschmidt (2004) the density between C16:0, C18:0, C18:1 and C18:2 are significantly different. Beside differences in composition and density, the cetane number and kinematics viscosity of each fatty acid were also reported to be different (Appendix 5).

**Extracting crude jatropha oil**

Several methods can be used to obtain oil from jatropha seeds or kernels and each of the methods give different oil yields. In general, there are two methods of jatropha oil extraction: (i) mechanical extraction and (ii) chemical extraction. For chemical extraction only ground jatropha kernels are used as feed but mechanical expeller or presses can be fed either whole seeds or kernels or a mix of both, but common practice is to use whole seeds. There are many types or models of pressing machines commercially available and promoted claim high oil recovery. Good expeller or presses should not only consider oil recovery (quantity) but also the oil quality. The most important thing that should be considered in designing the pressing
Machine for high oil recovery and oil quality are: (i) capability of improving the oil output rate at low energy input, (ii) capability of controlling the processing temperature automatically, (iii) capability of filtering and (iv) capability of controlling cake size and thickness (Achten et al. 2008).

A good pressing machine should have the capability to extract whole oil in the seed within a short time, at big volume but at low energy. Engine drive screw press and some models called double screw press reported capability to extract around 75–80% of oil from jatropha seeds, while the manual ram press only achieved 60–65%. Presser machine designer and engineering should consider the machine capability to control the processing temperature. As the raw material is pressed, friction causes it to heat up due to high pressure and can sometimes increase raw material and oil temperature to about 60–99°C. The temperature created is not good to protect certain properties of the oil being extracted. In jatropha, phosphorus content has been reported to be directly affected by the temperature. Low temperature during oil pressing was reported to contain less phosphorus than when using high temperature (Cvengros et al. 1999).

Filtering is normally performed after degumming of CJO. However, a good expeller machine should be able to combine filtering to increase its functionality. This filtering function is important in the PPO processing to reduce total contaminants which cause blockage of fuel filters and injection pumps. Pressed cake formed from pressing can be directly converted into a specific size and thickness with expeller machine. This combined innovation will increase the cake quality which normally still contains oil and is known as bio-bricket. The materials used to do the hard work in the expeller machine must have the capability to not be reactive with oil properties. The materials used should be fully stainless steel and not iron or zinc which can react with oil properties such as the free fatty acids. In my opinion future expeller machines should also consider a combination with solvents to extract whole oils from raw materials.

Jatropha seed or kernel condition before extraction was also reported to have a significant effect on oil recovery. Oil extraction was reported to range from 70–80%
Achten et al. (2008). Pretreatment of seeds such as cooking increased oil yields of screw press by up to 81% after single press and 91% after dual press (Beerens 2007). Drying has been recommended prior to extraction of jatropha kernels (Tobin and Fulford 2005). The presence of water in the sample before extraction was reported to significantly affect oil recovery. A moisture content of 6% was reported to be the optimum for hydraulic pressing of sunflower seeds (Sing et al. 1984). Further reduction in moisture content (4.1%) was not beneficial and resulted in more sediment in the screw pressed uncooked crambe seed (Vergas-Lopez et al. 1999). This trend could be attributed to the high moisture content which increases plasticity and thereby reduces the level of compression, resulting in poor oil recovery. The high moisture content also acted as a lubricant in the barrel; resulting in insufficient friction during pressing (Ruber 1992).

Ginwal et al. (2004) had also reported a positive relationship between jatropha fresh weights with oil extraction yield. Sudrajat et al. (2006) reported his study on the effect of boiling jatropha seed prior to extraction. They found that the treatment increased oil extraction yield. Sirisomboon and Kitchaiya (2009) reported that high heat treatment prior to extraction will increase oil extraction yield but also increase acid value and oleic acid content. Drying is a process to remove sample moisture content up to a specific level to reduce the rate of deterioration due to biological or chemical (Hall 1957) processes. In general, the characteristic of moisture release during drying was documented in detail by Henderson et al. (1997). According to Brooker et al. (1992) the drying efficiency was not only dependent on the drying temperature and relative humidity in the drier but also depends on the natural water content of the sample.

Understanding the jatropha seed physical and chemical characteristics could indirectly help to maximize CJO yield during processing, especially at extraction stage. We know that at extraction stage we can decide to either use jatropha seeds, kernels only or a mix. This information also showed many disadvantages of shells. Despite the low crude fat percentage it also contributed to increase in biomass which should be considered for logistic disadvantages such as transportation and storage.
The shells contributed to 35\% of the jatropha seed. Shells also increased bulk density, about similar to the density of kernels, and increased surface area by about half that of the kernels (Appendix 6).

Shells could also considerably reduce oil yield during extraction of oil in the jatropha seed. This is due to the fact that the shells are harder compared to the kernels. The information showed that the shells are 2 – 3 times harder than the kernels (Appendix 6). This characteristic also contributed to increase in energy used to rupture the seeds. On the other hand, the shells also contained high neutral detergent fiber (NDF) which indicated high content of lignin, hemicelluloses and cellulose. This long chain hydrocarbon could be the property that contributes to lower power combustion in PPOs. Therefore, future study should identify the overall benefits of removing the shell before extraction.

The CJO content was also reported to change during storage at different packaging and storage temperature. Nugroho (2010) studied the effect of selected packaging materials and storage temperatures on oil content and oil quality of yellow ripe dried jatropha seed of Malimping accession. The researcher found that the fresh weight of the dried seeds packed with half-net and stored at room temperature increased after two, four and six weeks of storage. Increase in fresh weight was reported followed by reduction in oil content by about 30\% (d.b) at first day of storage to 26\% (d.b) after six weeks of storage. The oil content of seeds packed in polyethylene and stored in vacuum and/or cool storage was reported not to change significantly. He also reported that the iodine number (\% d.b) was also reduced during prolonged storage but the free fatty acid increased.

CJO changes during maturation, ripening and senescent

The CJO content changes during maturation, ripening and senescence. The oil content of the fruits was mostly reported either in seed or kernel basis. Heller (1996) reported that the fatty oil contained in the kernel was on average 52\% and 33\% on
whole seed basis. The report by Heller (1996) was not clear on the stage of fruit maturity of the sample used in his experiment. Wanita and Hartono (2006) reported that the CJIO content was different according to the day after anthesis. They reported that the oil extraction rate of jatropha seeds 35, 40, 45, 50 and 55 days after anthesis are 15.19%, 17.32%, 26.04%, 26.91% and 26.28% respectively. The five maturity stages referred to by Wanita and Hartono (2006) was characterized as green, green with yellow colour, fully yellow colour, yellow with black colour and black colour fruits respectively.

Santoso (2008) has also reported on his study on various jatropha accession fruits’ development and ripening. He studied five stages of fruit maturation and ripening. The five stages were immature or 25 days after anthesis, near mature or 35 days after anthesis, mature or 45 days after anthesis, ripe or 55 days after anthesis and over ripe or 65 days after anthesis fruits or dry fruits. He reported that kernel oil content closely followed the fruits’ development trend. Kernel oil was reported to be about 8%, 20%, 40%, 50% and 43% for each development stage respectively.

Another report on the oil percentage according to seed development was by Annarao et al. (2008). They reported that the percentage of oil content (hexane soluble) in seed samples ranged from 0.3% to 24.9% (on seed dry weight basis), lowest being at day 12 after anthesis and highest at 37 days after anthesis. They also reported that there was a slight decrease in oil percentage in dry mature seed at age of 42 days after anthesis. CJCO extracted for black dried fruits were reported to contain 88.20 – 97.30 % (kg kg\textsuperscript{-1} \times 100) TG (Gubtiz et al. 1999; Forson et al. 2004; Kandpal and Madan 1995 and Reddy and Ramesh 2006).

The maturity stage of the fruits at the moment of collection is reported to influence the fatty acid composition of the oil (Raina and Gaikwad 1987). Recently, Annarao et al. (2008) reported the percentage contribution of triglycerol ester at different stages of the jatropha seeds’ development. Triglyserol ester was reported to be distinctly low at the early stage of development with a range of 33.9 to 24.8%. However, it was reported to increase by nearly three times (93-98%) in mature fruit. The researcher suggested that the free fatty acid contributed predominantly to the
total lipids in the early stage whereas these were replaced by triglycerol esters at the mature stage. The researcher also reported that ratio of linoleic to linolenic acid increased at the early stage of fruit development while only linoleic was observed at the matured stage of development. They suggested that linolenic acid was primarily involved in initial seed development and gave away to linoleic acid as the seeds start to mature. Therefore, they suggested that development of seeds can be grouped into two classes: "early development stages" (12 to 22 days after anthesis) and "matured stage" (27 days and onward after anthesis).

Fatty acid synthesis starts with the carboxylation of acetyl-CoA carboxylase which contains a biotin prosthetic group. Acetyl-CoA carboxylase is strongly regulated and determines, in large part, the overall rate of fatty acid biosynthesis. The carboxyl transferase transfers the activated CO\(_2\) from biotin to actyl-CoA, yielding malonyl-CoA (Sanchez and Harwood 2002). The malonyl group is then transferred to acyl carrier protein. Fatty acid elongation from this malonyl acyl carrier protein proceeds through a series of reactions catalyzed by a complex of several individual enzymes, collectively named fatty acid synthase. The acyl carrier protein consists of 77 amino acids which are also considered fatty acid synthase. The acetyl-CoA and malonyl-acyl carrier protein then condensed to form 3-ketobutyril-acyl carrier protein and resulted in a two-carbon chain length extension forming a four-carbon unit. Decarboxylation of the malonyl moiety acts to drive the formation of a carbon-carbon bond between C-1 and acetyl-CoA “primer” and C-2 of melonyl group on acyl carrier protein. The next three steps in fatty acid synthesis reduce the keto group at C3 to a methylene group. The pathway of the fatty acid formation has been studied most extensively for the four world most important oilseed crops, the soya bean, oil palm, rapeseed and sunflower, but not in jatropha.

The biosynthesis of fatty acids was also reported to be transferred and accumulated into subcellular structures called oil bodies or oleosomes (Baud and Lepiniec 2010). It has also been known for over a decade that the lipid bodies of many seeds are surrounded by a specific class of protein termed oleosins. The size of the bodies was reported to vary from 0.5-1.0 µm diameter in seeds that have...
undergo desiccation and slight higher, ranging from 2-10 µm diameter, in non-desiccating seeds (Murphy et al. 2001). True oilseeds accumulate lipid bodies as one of their major storage reserves in amounts ranging from about 20% seed weight in soybean to 42% in rapeseed and as high as 76% in some of the large seeds nuts (Murphy 1996). However, the oil bodies were reported to be absent in lipid-rich tissue of many tropical oilseeds that do not undergo desiccation as a normal part of development. It is important to note that information on the oil bodies in Jatropha could provide alternatives which may be faster and easier to assess changes or trends of oil content of new varieties or suggestions for new handling practices. However, there is no information related to the oil body in jatropha.

**CJO quality and standard**

Quality standards are prerequisites for the commercial use of many fuel products. They serve as guidelines for the production processes and guarantee customers that they are buying high quality fuels, and provide authorities with approved tools for the assessment of safety, risk and environmental pollution (Prankl 2002). Moreover, engine and automobile manufacturers rely on fuel standards for releasing warranties for their vehicles to be operated on biodiesel. The groups that had facilitated this cooperative effort are American Society for Testing and Materials (ASTM), DIN (German), UNI (Italy), CSN (Czechia), EN (EU) and RSNI BB (Indonesia). Austria ONORM C 1190 in 1991 is considered the first biodiesel related standard in the world. Appendix 7 shows the major quality standards for PPO and biodiesel applied in Indonesia and Appendix 8 shows the fuel properties of CJO and Jatropha biodiesel.

The B100 standard suggests that the fuel must ignite in the engine, must release energy when it burns, must provide a large amount of energy per gallon, must not limit the operability of the engine at low temperature, must not contribute to corrosion, must not contain sediments that could plug orifices or cause wear, the fuels should not cause excessive pollution, the fuel properties should not deviate from the
design specifications and the fuel should be intrinsically safe (Mittelbach and Remschmidt 2004).

Standard density value of PPO is about 900 – 930 kg/m$^3$ but lower for biodiesel at only 850 – 890 kg/m$^3$ (Appendix 7). Based on the standard, the value of jatropha oil and its biodiesel showed that this standard is achievable. The value of PPO and biodiesel density value was reported to depend on their fatty acid composition as well as on their purity. Density was reported to increase with decreasing chain length and increasing number of double bonds, meaning that oil rich in unsaturated compounds had high density value. Unsaturated and saturated fatty acids in jatropha oil were reported to be 77.7% and 22.3% respectively (Acten et al. 2008). It is important to note that different densities have different impacts on heating value and fuel consumption because the amount of combustion in a chamber is determined volumetrically (Mittelbech and Remschmidt 2004).

Flash point value for both CJO and PPO was set at 210 but the biodiesel standard requires it to be 100 which is impossible to reach because its real flash point was reported to be 191 (Appendix 7 and 8). It is important to note that flash point is a measure of a flammability of fuels and thus an important parameter for assessing hazards during fuel transport and storage. These values were reported to rapidly decrease with increased amounts of residual alcohol and other low-boiling solvents.

The standard viscosity of PPO and biodiesel also show big differences. The CJO and PPO viscosity are similar at about 30 – 40 mm$^2$/s but much lower in biodiesel at only 2.3 – 6.0 mm$^2$/s (Appendix 7). However, the real viscosity value of jatropha oil and its biodiesel was reported to be 50 and 4.84 respectively (Appendix 8). The real readings indicated that jatropha biodiesel can fit with the standard requirements but not in CJO. Viscosity which is a measure of resistance to flow of liquid due to an internal friction on one part of a fluid moving to another, has long been known to affect the atomization of a fuel upon injection into the combustion chamber and thereby, ultimately the formation of engine deposits. Therefore, it was reported that the higher the viscosity value, the greater the tendency of the fuel to
cause such problems. This was the reason why CJO and PPO are not encouraged to be used as direct fuel in conventional car engines but advisable for biodiesel.

Standard, cetane number (CN) in PPO and biodiesel are 45 and a minimal of 51, respectively (Appendix 7). These values indicate that CN of CJO requirements are lower compared to biodiesel but slightly higher compared to CN of fossil diesel fuel. Differences in CN have been known to be due to differences in fatty acid ester cetane number. The fatty acid ester cetane number has been found to increase with increasing length of both the fatty acid chain and the ester group, while they are inversely related to the number of double bonds. CN has long been known as a measure of fuels’ ignition quality. This is why Knothe et al. (2005) implied that this parameter is considered as the prime indicator of fuel quality. Fuel with high CN will signify the need for short delays between fuel injection and ignition and thus ensures good cold start behavior and a smooth run of the engine. However, fuel with low CN tends to cause diesel knocking and increases gaseous and particulate exhaust emissions due to incomplete combustion.

Carbon residue serves as a measure of the tendency of a fuel sample to produce deposits on injector tips and inside the combustion chamber. The standard carbon residue in the CJO, PPO and biodiesel are about similar at around 0.3 and 0.4 while it has only minor relevance to fossil diesel fuel (Appendix 7 and 8). Unfortunately, it was reported that the amount of deposition reported was not only affected by different fuel samples but also due to the different types of combustion chamber, including the type of lubricant used in the engine.

The standard iodine value is a measure of total unsaturated fatty acids within a mixture of fatty acids. The limitation of unsaturated fatty acids is necessary due to the fact that heating higher unsaturated fatty acids results in polymerization of glycerides. This can lead to the formation of carbon residue or to deterioration of lubrication (Mittelbach 1996). The amount of iodine number in CJO, PPO and biodiesel are about similar at less than 120 g/100g (Appendix 7 and 8) while it was reported to be nil in fossil diesel fuel. Specifically, the iodine number in jatropha methyl ester is in the range of 92 – 112 and therefore considered lower than the UEN-EN 14214 and
On the other hand, palm oil biodiesel was reported to have lower iodine value of only around 45 – 62 due to the fact that palm oil is rich in ester of saturated acids such as palmatic (C16:0) and stearic (C18:0) acid.

Sulfur content standards for CJO and PPO are high at 20 mg/kg compared to only 0.01 mg/kg or less in biodiesel (Appendix 7 and 8). Fuel with high sulfur content has been associated with negative effects on human health and on the environment, which is the reason for the tightening of its use in many countries. In European biodiesel standard the limits for maximum sulfur content is 10 ppm. However, it scary to know that the amount of this toxic gas in fossil fuel diesel is high at around 500 ppm. Traditionally, biodiesel fuels have been praised as being sulfur-free and this was the main reason why many governments support biodiesel programs.

Total contamination is defined as the quota of insoluble material retained after filtration of a heated fuel over the standard 0.8 μm filter. The total contamination standards in CJO and PPO are 25 ppm but slightly lower with by 1 ppm difference with biodiesel (Appendix 7 and 8). It is known that total contamination tends to cause blockages of fuel filters and injection pumps. High concentration of soaps and sediments are mainly associated with these phenomena, leading to corresponding increased values of ash content as well.

Standard acid value in CJO and PPO are reported to be about 2 mg KOH/g but much lower in biodiesel at about 0.5 or less mg KOH/g (Appendix 7 and 8). However, there are some reports of a confusing nature on the calculation of acid value and saponification value due to the similar measurement methods and units used. The acid value of jatropha oil is around 38 mg KOH/g.

Standard oxidative stability requirements for PPO are slightly low, at only 5 h compared to 6 h in biodiesel (Appendix 7). No information is available at this moment on the real oxidative stability for CJO and jatropha biodiesel. However, Ramos et al. (2009) reported that all biodiesel from many vegetable oils including palm, olive, peanut, rape, soybean, sunflower, grape, sunflower, almond and cone in his study did not achieve the limit of six hours for oxidation stability. Stability of
Fatty compounds is influenced by factors such as presence of air, traces of metal, peroxides, light, or structural features of the compounds themselves, mainly the presence of double bonds (Bajpai and Tyagi 2006). The oxidation stability decreased with the increase in content of polysaturated methyl esters. Autoxidation of unsaturated fatty compounds proceeds at different rates depending on the number and position of double bonds. Relative rate of oxidation given in literature are 1h for methyl oleate, 41 h for methyl linoleate and 98 h for methyl linolenate (Knothe et al. 2005). Therefore, vegetables oils rich in linoleic and linolenic acids, such as soybean, sunflower and grape seed oil, including CJO, tend to give methyl ester fuels poor oxidation stability, whereas non polysaturated fuels, such as palm, olive and almond oil methyl ester, generally show improved stability.

The standard for phosphorus content is different for PPO and biodiesel. The requirements are 100 – 200, 10 – 50 and <10 mg/kg in PPO and biodiesel respectively (Appendix 7). The real amount of phosphorus in jatropha oil and biodiesel are 290 and 17.5 mg/kg respectively (Appendix 8). The transesterification process has been identified as an efficient means of lowering phosphorus content as well, with reductions from 100 ppm in the original samples to about 20 to 30 ppm in the ester product (Mittelbach 1996). Phosphorus content in fatty acid methyl esters mainly stems from phospholipids contained in the feedstock. Low temperature during oil pressing was reported to contain less phosphorus than when using high temperatures (Cvengros et al. 1999). Phosphorus can act as emulsifiers and thus impede phase separation during the transesterification process. Degumming and transesterification itself has been identified as an efficient means of lowering phosphorous content (Makkar et al. 2009). The material can also be removed by distillation of the final product.

Standard requirement for ash content in CJO and PPO as stated by BBPT Indonesia was similar to the corresponding value within the fossil diesel fuel, 0.01% (Appendix 7 and 8). On the other hand, no value for ash content standard for jatropha biodiesel specifically has yet been confirmed by the organization. The current European biodiesel quality standard limit sulfated ash to a maximum content of
0.02%, which is 0.01% higher as compared to the standard limit for fossil biodiesel fuel. Ash content describes the amount of inorganic contaminants, such as abrasive solids and catalyst residuals, and the concentration of soluble metal soaps contained in a fuel sample. This compound was reported to be oxidized during the combustion process, forming ash, which is connected with engine deposits.

Standard water content in PPO and biodiesel are 0.75, 0.75 and 0.7% respectively (Appendix 7). However, there is no information on the water content in hand for jatropha oil and jatropha biodiesel. Mittelbach and Remschmidt (2004) implied that high biodiesel quality must not contain water in concentrations higher than 500 ppm. However, the standard limit was reported to be impossible to reach due to the fact that fatty acid methyl ester has high polarity characteristics. Fatty acid methyl ester is hydroscopic and therefore reportedly can absorb water in concentrations of up to 1000 ppm during storage. High water content is not good because it can promote biological growth by which sludge and slime are formed and thus can cause blockage of fuel filters and fuel lines. In addition, high water content is also associated with hydrolytic reactions, partly converting fatty acid methyl esters into free fatty acids which are linked with filter blockages as well. Corrosion of chromium and zinc parts within the engine and injection system are also linked with this content.

**Harvesting System of Jatropha Fruits**

Harvesting is the most important part of agricultural activity. This is due to the fact that harvesting is an activity of detaching whole plants or plant parts from its original position or physiology. It is important to note that there are physiological and biochemical ripening differences between fruits on (in situ) and off the tree. According to Wills *et al.* (1989) the development and maturation of fruits is complete only when it is attached to the plant, but ripening and senescence may proceed on or off the plant. Therefore, good producers must have a good harvesting system for their
Crop. Good harvesting systems should have clear harvesting objectives, be well planned, note laborious considerations and know the best times to do the harvesting.

**Harvesting considerations**

The objective of harvesting in jatropha crops should be: (1) to harvest fruits which have high oil content in the kernels; (2) to transport the fruit into the operational house for processing as soon as possible; and (3) to keep the fruit in good condition before processing. This seed character has been the focus in many publications and it been the bench mark for harvesting time recommendations. Appendix 9 shows the contradictory recommendation on harvesting times for this crop based on the day after anthesis as the point of high oil content. Due to the contrary recommendations, future studies could confirm any of the recommendations.

The fact with jatropha fruit ripening is that mature and immature fruits exist on the same trees at the same time which make mechanical harvesting more difficult and leads to laborious and time consuming harvesting as farmers have to select only the ripe fruits or fruits have to be harvested manually at regular intervals (ERIA 2010; Blake 2008; Biswas et al. 2006 and Heller 1996). Harvesting fruit bunches has been the proposed alternative to increase harvesting efficiency. This idea could increase harvesting volume per worker per day or per area because the workers harvest whole bunches and not ripe fruits alone. However, this recommendation indicates a contrary recommendation. Priyanto (2007), recommended to harvest fruit bunches when 75% of the fruits are ripe. Nurchholis and Sumarsih (2007) suggested it when 60-70 are ripe while Hambali et al. (2008) recommended it when 50% are ripe. On the other hand, harvesting multiple maturity index in bunches would require additional postharvest handling practices such as bunch trashing and ripening treatments for the unripe fruits. Therefore, future research should be conducted on this issue.

The harvested fruit should be sent to the operational house for processing as soon as possible to ensure high oil yield and quality. This suggestion is due to implications that free fatty acids could increase with increase in processing delay. In
the oil palm industry this scenario is the crucial point and therefore they must process the fruit within 48 hours after harvest. The critical hour in jatropha has not been confirmed but Blake (2008) reported that some scientists in USA predicted it to be 24 hours after harvest. If there is a delay in the processing due to operational house failure, care must be practiced with the harvested jatropha bunches to reduce negative effects to its oil quantity and quality. It usually happens when some of units in a factory fail to turn on or due to regular maintenance where delay in processing cannot be avoided. In this situation postharvest handling practices to delay fruit quality deterioration should be applied such as application of hydro-cooling followed by cold storage.

To meet the previous harvesting objectives, success in harvesting depends on planning from the earliest stages of production, particularly in regard to planning harvesting operations in good time, arranging for labor, equipment and transport and when considering provision of full supervision at all stages of harvesting and field handling. Harvesting fruit bunches was suggested to reduce the previous uneconomical harvesting practices. However, any harvesting method that does not consider labor management may not be successful. In small-scale family production for local oil production, the labor supply will probably not be a problem but as the scale of commercial production and the distance between the rural producer and operational house is farther, more exacting requirements will have to be met in regard to training and supervising labor. It is economically sound in terms of return to invest more in proper packing and handling of the produce before it leaves the farm. Growers will have to train their own field labour, accepting whatever support local extension workers are able to provide.

Due to the previous statement on harvesting problems, the Indian Oil Company suggested deploying four workers per acre in their plantation (Jim 2009). On the other hand, BEI International predicted that jatropha plantations required 3125 men to harvest 1 acre/hour or equivalent to 500 men required to harvest 200 pounds (91 kg) of jatropha fruit per hour. Earlier, Blake (2008) reported a concern and warning by a scientist at California Davis, USA that seed harvest of this crop would
be too expensive and predicted that if mechanical harvesting is not possible then jatropha has no future.

When the crop is ready for harvest, labour and transport are available, and operations organized, the decision as to when to start harvesting will depend largely on weather conditions and the state of the jatropha fruit market. It is not advisable to harvest jatropha during wet or rainy weather due to the fact that high water can promote fungi and rotting on the fruit before it ripens. Harvesting during the coolest part of the day, either morning, afternoon or night, is advisable to reduce field heat on the fruit. Putting harvested bunches in shaded areas when transport is not immediately available should be among the practices. This is particularly due to the fact that field heat can increase respiration of the harvested produce which could reduce its oil quantity and quality.

For growers that have their own operational house they can schedule their harvesting time with the number of workers and transport to suit their daily operational house capacity. However, those growers that are located at a distance from the operational center should have their own harvesting time strategies and transport. Harvesting during late afternoon and transporting during night time or early morning could be a good strategy.

**Harvesting techniques**

Manual or mechanical harvesting techniques are under consideration in this crop. At the present time since no suitable mechanical harvester is available, manual harvesting of bunches is proposed. Hand-harvesting is recommended for this crop because as mentioned earlier this crop shows various stages of maturity within the crop, whereby there is a need for repeated visits to harvest the crop over a period of time. However, by harvesting fruit bunches the repeat visits could be reduced. Another concern in hand harvesting is the difficulty to harvest tall jatropha trees. In this case some suggest using a picking pole with collection bag attached. This difficulty has been the reason for suggesting pruning activity and specific planting
distance for this crop. In my opinion the suitable planting distance for this crop should be 2 x 1.5 meter or 3,333 trees per hectare, to be reduced over a period of time according to the performance of the trees and degree of harvesting difficulties. This is due to the fact that the production of the fruit is positively correlated with number of branches (Raden 2008). The fact is that, more branches mean more fruit production. On the other hand, the jatropha branches can easily be bent without cracking. This character could be utilized for simple hand harvesting in the future.

Simple reason for mechanical harvesting of this industrial crop is that the harvesting cost is expected to be 35 – 55% of that with hand harvesting. However, machine-harvesting is viable only in this crop when all the fruits can be harvested at one go. The challenges of introducing a harvesting machine for this crop is that in a single branch, there can be a bud, immature and mature fruit all together. Two jatropha harvesters are being tested for efficiency. The BEI International jatropha harvester and Oxbo Korvan 900 mechanical jatropha harvester are based on blueberry harvester technology. The effectiveness of the machines over hand picking is not in doubt but the use of the machines was reported to be damaging to the crop. In addition the harvesters also detected small immature fruits including buds and flowers destroyed (BEI International demonstration). Therefore, more harvester models are needed for this crop. In my opinion the combination of crop management practices such as canopy arrangement could be adopted with mechanical harvesting machines or robotic harvesters could be the solution.

Artificial Ripening

Artificial ripening treatment is done to achieve faster and more uniform ripening characteristics (Medilcott et al. 1987). In jatropha, the objective of artificial ripening application is suggested to ripen the unavoidably harvested unripe fruits, if
fruit bunches are to be recommended for increasing harvestable volume. It is important to repeat the suggestion to increase harvestable fruits by possibly harvesting mature green fruits to reduce harvesting visits and therefore, harvesting costs could be reduced. The harvested unripe fruits are required to be ripened because high extracted oil is only from ripe and senescence dry fruit (Santoso 2008; Annarao et al. 2008; Hambali 2007; Wanita and Hartono 2006; Wiesenhutter, 2003 and Heller 1996). The concept of artificial ripening treatment is to create a condition such as by introducing ripening inducers to increase ripening percentage. The selection of inducers and condition to get optimum ripening characters such as high ripening percentage and high oil quantity will become the fundamental arguments that need support data.

Unsaturated hydrocarbons, particularly ethylene and acetylene are well known ripening promoters and to induce colour changes effectively (Medilcott et al. 1987). Compounds with comparative effectiveness to ethylene and acetylene are propylene, vinyl chloride, carbon monoxide and 1-Butene (Kader 1992). Acetylene ($C_2H_2$) is the end product of hydrolysed calcium carbide ($CaC_2$) and ethylene gas ($C_2H_4$) is normally produced by heating ethanol ($C_2H_5OH$) in the presence of a catalyst. The concentrations of ethylene required for the ripening of various commodities vary, but in most cases are in the range of 0.1-1.0 ppm. The time of exposure to initiate full ripening also vary. It was also reported that ripening may take several days after exposure (Wills et al. 2007). General optimum ripening conditions are given in Appendix 10.

**Calcium carbide as a ripening agent**

Calcium carbide has been a popular ripening enhancer because it is easier and cheaper to get in the market. Calcium carbide has numerous applications in chemical, steel industries and agriculture. It is colourless when pure, but black to greyish-white in colour otherwise, with slight garlic-like odour (Siddiqui and Dhua 2010). It was reported that when it reacts with water, the calcium carbide will produce acetylene
gas, an analogue of ethylene, which quickens the ripening process. The reaction also produces traces of arsenic and phosphorus hydride, arsine and phosphine which are all in the class of carcinogenic chemicals (Bingham et al. 2001 and Jain et al. 1985). Acetylene gas is flammable and explosive even in a low concentration compared to ethylene.

Fruit ripening with CaC\(_2\) has been reported to have different effects with different types of fruits. Mangoes ripened with CaC\(_2\) were reported to ripen quickly in only two days and the ripened fruit cannot be stored for more than two days because of senescence. This short shelf life was also reported for bananas. Banana fruits were reported to start ripening within 24-48 h, depending on ambient temperature (Rahman et al. 2008). The amount of CaC\(_2\) required to ripen raw fruit was reported more to increase ripening percentage. However, when the amount of CaC\(_2\) used was high, the change with the fruits becoming more tasteless and possibly toxic was implied to be higher (Sy and Wainwright 1990). In view of the possibility of it having hazardous effect, CaC\(_2\) is banned in many countries for use on edible fruits. Application of the ripening enhancer should be allowed on non-edible fruits such as jatropha for biodiesel production. However there is no report of CaC\(_2\) being used on jatropha fruit.

**Utilization of field heat as a ripening enhancer**

In nature, fruits ripen after attainment of proper maturity by a sequence of physical and biochemical events and the processes are irreversible, ultimately leading to senescence. Whether fruits ripen on the plant or after harvest the ripening processes are similar. The environment where the fruits are allowed to ripen, in addition to the stage of fruit maturity, are the most important factors influencing the processes of ripening. Long before ripening treatment, the environment in the farm during harvesting has been related to shelf life of produce. Field heat was found to be responsible for stimulating the biochemical changes in the fruit after harvest. The high fruit temperatures measured in the field have been strongly associated with direct exposure to sunlight (Ferguson et al. 1998). Field heat accounts for about 75%
of the total heat in harvested fruit (Hardenburg et al. 1986). Boyette et al. (1994) noted that field heat accounts for 58.9% of total heat loaded in harvested produce. At high temperature, respiration increases greatly leading to depletion of nutrient reserves, and therefore, fruit senescence is accelerated.

The heat was also reported to be produced during handling, especially from naturally harvested fruit respiration. Hardenburg et al. (1986) estimated that around 2.9% of total heat in the loaded harvested fruits is from respiration. The amount of heat was reported to increase with delay in cooling. Therefore, field heat has been associated with senescence and many other disadvantages. Exposing commodities to heat treatment was found to cause heat injury to fruit, vegetables and ornamentals (Paull and Armstrong 1994). If cooling is delayed, shelf life can be significantly reduced (Robbins and Moore 1992 and Hernandez-Rivera et al. 1992). A two-hour delay in cooling after harvest could mean a loss of about 80 to 93% of marketable strawberries (Mitchell et al. 1974). Apples with a long shelf life and lower rate of respiration should be cooled within 3 days of harvest to prevent loss of apple firmness and acidity during storage for 7.5 months at 3.3 °C (Liu 1986).

The disadvantages of field heat led to several other recommendations. This included recommendations on the best harvesting time during the day. Harvesting during coolest part of the day either morning or afternoon was advisable to reduce field heat on the harvested fruits. Respiration during those recommended harvesting time was reported low (Wills et al. 1998). When there is delay in transportation, it was recommended to keep the harvested produce in a shaded area to reduce the negative effects of field heat. It was also recommended to not do harvesting during wet or rainy weather due to the fact that high humidity can promote fungi and rotting on the fruit before ripening in storage. Information on the recommendations of harvesting time during daytime for jatropha is not available at this moment.

Field heat and high temperature was also reported to have advantages. High temperature or heat treatments have been used and recommended for insect disinfection (Paull 1990 and Couey 1989). Heat treatment was also reported to reduce chilling injury developing in avocado (Florissen et al. 1996) and tomato (Lurie and
The disadvantages of field heat could be manipulated for ripening treatments but no related information can be found at this time. However, based on the disadvantages mentioned above, it is obvious that this condition is mainly responsible for rejection of harvested fruits (Robbins and Moore 1992; Hernandez-Rivera et al. 1992 and Mitchell et al. 1974). The rejection was due to ripening and senescence and reported to be up to 93%. Thus, this condition may be the choice ripening treatment because it is safe and cheap when compared with calcium carbide or other ripening enhancers.

Packaging or field containers might be required in manual harvesting so that logistics can be managed accordingly. With packaging the harvested fruits can be easily handled and quantity measurement is easier. While in packaging and there is a delay in cooling, respiration will increase and hence the product temperature will increase. Furthermore, the packed product temperature will depend on packaging design, handling practices and delay in cold storage. Besides the increase in temperature during packing the gas composition created has been identified as another factor that can affect the storage life of produce (Wills et al. 1998). Increase in temperature during shipping, handling or retail display results in decreased O₂ and increased CO₂ levels inside the package due to a rise in the respiratory rate of the product (Cameron et al. 1995).

Several negative effects of using badly designed packaging have been reported. Temperature variations during delays in handling were reported stimulating high humidity inside the package. The presence of water was implied to promote the development of decay (Brackett 1997) and may also block O₂ diffusion into the tissue and through the boundaries, causing fermentation (Cameron et al. 1995). With the effect of field heat in mind and increase in respiration during delay in cooling and increase in the effect with packaging, optimum ripening could be achievable in jatropha ripening treatments. However, there is limited information related to the potential ripening conditions for jatropha.
Control of Fruit Maturation, Ripening and Senescence

Fruit development and ripening depends on a range of preharvest factors. Some preharvest factors may be effective through influencing fruit maturity. There are many factors affecting fruit development, and in this section the focus is on processes that can be, and often are, significantly modulated during the postharvest period. Yield of jatropha is controlled by genetic (Ginwal et al. 2004) and site characteristics (rainfall, soil type and soil fertility) (Francis et al. 2005; Openshaw 2000 and Aker 1997), plant age (Heller 1996) and management (Heller 1996; Sharma et al. 1997 and Sing et al. 2006). Number of fruits (yield) per bunch per tree was reported to influence fruit development and ripening (Santoso 2008).

Wills et al. (1989) has confirmed that development and maturation of fruits is completed only when it is attached to the plant, but ripening and senescence may proceed on or off the plant. Their study showed the importance of harvesting time to fruit development and initiation of ripening. In many plants the natural development cycle is interrupted prior to its completion by harvest.

Genetic

Plants and plant parts progress through a dynamic series of genetically controlled development processes terminating in their eventual senescence and death (Kays 1991). Their development is the combination of both growth and differentiation and can be viewed at either the whole plant or individual organ level. Jatropha has not as yet undergone a careful breeding program with systematic selection and improvement of suitable germplasm (Achten et al. 2008). Therefore, the best available practice at the moment is to use planting material obtained from the best performing trees of the best performing provenance available from the selection of interest.

Tree with an annual yield of above 2 kg of seeds and seed oil content higher than 30% by weight can be considered a good source. Makkar et al. (1997) reported
on 18 different provenances of Jatropha from countries in West and East Africa, the
Americas and Asia including climatic data of three places. Large variations were
found in seed characteristics but no causal links were analyzed. Kaushik et al. (2006)
recorded coefficients of variance between 24 provenances of Haryana State, India,
which indicate a dominant role of the environment over genetics in seed size, seed
weight and oil content. Heliyanto et al. (2008) reported significant differences
between three generations of their negative mass selection program of this crop. They
claim that the first generation was able to produce 600 fruits per tree per first year
compared to only 400 and 200 from the second and third generation.

Site characteristics

Jatropha has high ecological adaptability which makes it grow in a wide range
of conditions (Heller 1996). Jatropha is well adapted to semi-arid conditions,
although more humid environmental conditions result in better crop performance.
However, Jatropha cannot tolerate frost. The crop is also able to grow at an altitude
range from sea level up to 1800 m (Foidl et al. 1996) and is not sensitive to day
length (Heller 1996).

 **Jatropha curcas** Linn is native to tropical America, but is now found
abundantly in many tropical and sub-tropical regions throughout Africa and Asia
(Heller (1996) and Tewari 2007). For semi-arid and cultural wasteland purposes an
achievable dry seed production rate of 2 – 3 t ha\(^{-1}\) yr\(^{-1}\), is confirmed by the field data
of Francis et al. (2005). When good sites (good soil and average annual rainfall of
900 – 1200 mm) are claimed and/or optimal management practice is used, 5 t dry
seed\(^{-1}\) yr\(^{-1}\) can be achieved (Tewari 2007; Francis et al. 2005 and Foidl et al. 1996).
Jongschaap et al. (2007) concluded on a potential yield range of 1.5 – 7.8 t dry seed
ha\(^{-1}\). Jatropha is reported to be highly adaptable in marginal soils with an average
annual rainfall of 250 mm but in order to support high biomass production the crop
shows high demand for nitrogen and phosphorus fertilization (Foidl et al. 1996).
Therefore, this crop has a proven capability to reclaim wasteland (Spaan et al. 2004).
Jatropha could grow in a wide range of soils but should never be planted on soils with risk of water logging such as vertisols or other heavy clay soil (Sing *et al.* 2006 and Biswas *et al.* 2006).

**Management**

While there are numerous inputs being managed during the production of oil-bearing fruits, in this section the focus is on management that can be and often is significantly modulated during fruit development and ripening. Propagation management has been given a lot of focus by many researchers but none of the reports correlate the propagation techniques to yield. It was noted that spacing of plants is a tradeoff between biomass and fruit production. A narrow spacing will lead to fast canopy closure which results in higher water and light competition and lower fruits per biomass ratio. The optimum spacing for Jatropha can only be recommended after 5 consecutive years’ growth and yield observations and this in different environments and provinces. Therefore, Achten *et al.* (2008) inferred that the best practice at this moment is to start with a densely spaced block plantation and to gradually remove rows or individuals (thinning) according to the plants’ performance. Starting from 1600 seedlings (2.5 x 2.5 m$^2$ spacing) per hectare, stand density should be thinned to 400 – 500 per hectare in the final mature stand (Openshaw 2000).

Weeding has been highlighted as required to reduce competitive weeds (Heller 1996 and Openshaw 2000). Pruning and canopy management are reported to enhance good fruit setting and seed yield (Gour 2006). Pinching the main bunch and the secondary and tertiary were recommended. Every 10 years, it is recommended that the entire tree be cut down, leaving a stump of 45 cm. All the intervention induces new growth and helps to stabilize yield (Gour 2006). Optimal fertilization and irrigation can increase seed and oil yield. The optimum level of application was observed to vary according to the age of the plantation (Patolia *et al.* 2007).
**Tree factor**

The Tree factor was first used by Abeles (1973) to describe the inhibition of ethylene production in attached fleshy fruit tissue. He studied why avocado fruits fail to ripen or show climacteric levels of ethylene production while attached to the tree. It is important to note that early-maturation cultivars frequently produce higher levels of ethylene than late-maturing cultivars and typically has a short shelf life (Watkins 2003). Low levels of ethylene will have a long shelf life but reported low quality. The problem may be associated with its low ethylene production and low rate of respiration. Recently, Lin and Walsh (2008) confirmed that the tree factor was found to decline as fruit maturity progresses.

The tree factor was hypothesized to be produced in the leaves and transported via the phloem to the fruit (Stakiotakis and Dilley 1973). They observed that defoliation and girdling of spurs promoted the onset of climacteric ethylene production in attached apple fruits. Blanpied (1993) reported that this delay in ethylene production was positively correlated with leaf/fruit ratios on ringed limbs. Recently, Lin and Walsh (2008) confirmed that girdling plus defoliation partially triggered ethylene production in the apple fruit. However they inferred that other variables, such as environmental conditions, availability of photosynthesis, water and mineral nutrients may be more important than detachment in triggering apple fruit ripening.

To date, no information on the tree factor or ripening behaviors of jatropha is available. As mentioned above the low level of ethylene during ripening reportedly influenced the quality of harvested produce. If ripening treatment is required in jatropha fruit handling then the tree factor should be considered to avoid low quantity and quality of CJO.

**Plant architecture**

Plant architecture is determined by a subtle combination of growth stimulation and inhibition confers optimal plasticity in response to environmental change. Fruit
Position within the canopy was reported to have a significant influence on the postharvest quality of fruits, i.e. apples (Krishnaprakash et al. 1983 and Tustin et al. 1988). Position on the tree strongly influences fruit mineral content, and consequently incidence of postharvest disorders such as bitter pit and water core in apples and chilling injury in avocado (Ferguson and Woolf 1999). Whether fruit position within the canopy would affect the jatropha fruit development, maturation and ripening is not known. Solar radiation is reported to be an important factor in stimulating differences in quality between inside and outside canopy fruit (Honda et al. 2002).

Earlier to this Farhoomand et al. (1977) found that top and outside fruits appeared to be more mature than those inside. Krishnaprakash et al. (1983) on the other hand, found that apples at the bottom of the tree matured earlier than those in the middle and on top.

High photosynthetic activity can accelerate capsule and seed maturity and adequate nitrogen supply was reported to not only encourage leaf development but also materially assist in retaining leaves in active photosynthesis (Cechin and Umis 2004). Raden (2008) recorded high photosynthesis rate in jatropha leaves aged 6 weeks with 8.99µmol CO$_2$m$^{-2}$s$^{-1}$. He also found high photosynthesis rate in pruned main branch at a height of 40 cm above ground (4.71 8.99µmol CO$_2$m$^{-2}$s$^{-1}$) compared to those not pruned or pruned lower than 40 cm.

**Plant growth regulators**

Ethylene, gibberellic, abscisic acid, auxin and cytokinin are five major groups of endogenous plant growth regulators with ethylene which have been frequently studied and well documented in correlation with fruit development and ripening. In general, auxin is the active ingredient in most rooting compounds in which cuttings are dipped during vegetative propagation (Trigiano and Gray 2004). Gibberellins stimulate cell division and elongation, break seed dormancy, and speed germination. Unlike other hormones, cytokinins are found in both plants and animals. They
stimulate cell division and often are included in the sterile media used for growing plants from tissue culture. Abscisic acid (ABA) is a general plant-growth inhibitor. It induces dormancy and prevents seeds from germinating; causes abscission of leaves, fruits, and flowers; and causes stomata to close.

Ethylene is unique and found only in the gaseous form. The importance of ethylene for the ripening and senescence processes have been well documented through both the molecular approach (Klee 2004 and Czam et al. 2006) and the use of ethylene-action inhibitors (Sisler et al. 2003 and Sisler 2006). Recently, Dugas-de Ley and Straeten (2008) reviewed the role of ethylene in plant growth and development. They concluded that the gas can promote root hair formation, flowering, fruit ripening and abscission, as well as leaf and petal senescence and abscission. Its role is dependent on the environmental conditions and the plant development stage, besides also being species dependent. Within a plant and even within a given organ, the effect of ethylene treatment can differ, depending on endogenous and environmental cues.

Ethylene biosynthesis has been discussed in the last chapter and therefore the main goal of this section is to expand our understanding on ethylene in the “tree factor” during development and ripening. As mentioned earlier there are two control systems in ethylene biosynthesis. Cara and Giovannoni (2008) reviewed the molecular biology of ethylene during tomato fruit development and ripening. They summarized that during fruit development system 1 was lower and system 2 is synthesized by LeACS1A, and LeACO1,3,4 (ethylene auto-inhibitory gene). At the transition stage of development and ripening, the ripening regulators were indicated to play critical roles. LeACS4 is induced and a large increase of auto-catalytic ethylene gene starts, resulting in negative feedback on system 1. LeACS2,4 and LeACO1,4 are then responsible for the ethylene production through system 2. ACS and ACO gene have been characterized in many other fruits including apple, kiwifruit and pear but not in Jatropha.

An important question related to the tree factor and this gas was reviewed recently by Lin and Walsh in 2008. They tested Stakiotakis and Dilley’s (1973)
hypothesis that the tree factor is a small molecule produced in the leaves and transported through phloem to fruit. They applied horticultural treatments to block signals from leaves to fruit in the period of commercial harvest. They found differences in ethylene production between the fruit on and off the tree and related that as a tree factor in the apple fruit. In addition they reported that girdling plus defoliation successfully affected the carbohydrate supply from the parent-tree, the partial stimulatory effect on internal ethylene concentration of girdling plus defoliation in the apple and therefore suggested that the tree factor might also be transported via the xylem as postulated by Smock (1972). They reported that their findings had a similar pattern to that which had been indicated previously in apple (Lau et al. 1986) and plum (Abdi et al. 1997).

**Nutrient concentration**

Nutrient availability and water deficiencies, in addition to wounding stress during harvest, was reported as the possible factors that induce system 1 ethylene (Rogiers and Knowles 1999). Lin and Walsh (2008) demonstrated that girdling plus defoliation successfully affected the carbohydrate supply from the parent-tree, the partial stimulatory effect on internal ethylene concentration of girdling plus defoliation in the apple.

Fertilization has a direct effect on nutrient concentration in the tree. Recently, Ghasemnezhad and Honermeier (2008) reported the negative influence of nitrogen (N) fertilization on the oil content of evening primrose (*Oenothera binnis* L.) oil seeds. The physiological reason for the negative correlation was implicated to be related to the competition for carbon skeletons during carbohydrate metabolism. In a study by Lambers and Poorter (1992), they found that the synthesis of both fatty acids and amino acids requires carbon compounds from the decomposition of carbohydrates. Since the carbohydrate content of proteins is lower than that of oils, increased N supply intensifies the synthesis of proteins at the expense of fatty acid synthesis and those reduce the oil content of the seed.
The effect of N fertilization on fatty acid composition is also well documented. Ghasemnezhad and Honermeier (2008) reported that the content of all measured fatty acids were significantly influenced by nitrogen fertilization. They observed the positive influence of nitrogen on the content of polyunsaturated fatty acids like oleic and γ-linolenic acids. However, previously Reiner and Marquard (1988) reported a negative effect of nitrogen on linolenic acid. Sekeroglu and Ozgur (2006) had also reported that nitrogen application did not have a clear influence on the linolenic acid content of O. biennis cultivated under dry land conditions. However, contradictions in the above reports show the need for more investigations on the interaction between nitrogen and other nutrients as well as climatic conditions which lead to observation conflicts.

Calcium is the nutrient most commonly associated with postharvest quality of harvested produce and bitter pit is directly or indirectly related to calcium nutrition of the fruit (Ferguson et al. 1999). A number of preharvest factors are associated with movement of calcium into the developing fruit. Apart from pollination, these are associated largely with the relationship between fruit development, position on the tree, and the dynamics of nutrient flow in relation to leaves on the fruiting branch or stem. Other factors that affect jatropha yield are pests and diseases. Heller (1996) and Openshaw (2000) have already listed numerous pests, diseases and damaging insects observed on the Jatropha tree. Shanker and Dhyani (2006) reported their observations on the economic damage in continuous jatropha monocultures due to pest and diseases.
CHAPTER 3
GENERAL MATERIALS AND METHODS

Sources of Samples

The primary source of samples for this study was from local *Jatropha curcas* Linn Luanti accession harvested from a jatropha pilot project conducted by the Institute of Agro-Biotechnology (ABI) Malaysia located at Luanti Baru Village in Keningau, Sabah, Malaysia. Another ten different accessions were also observed for fruit maturity uniformity according to different accession study. The ten selected accessions are located at Tenom Research Station, Sabah and at Binakan Sook, Keningau, Sabah, Malaysia. *Jatropha curcas* Linn Tanzania accession and IP1 accession were used for preliminary experiments and for respiration study. The Tanzania accession samples were brought from Bogor University Farm and IP1 accession were brought from Jatropha Plantation at Serang, Banten, Indonesia.

The jatropha pilot project belonging to the ABI is on Acrisol soil type. Sabah, Malaysia is characterized by a humid tropical climate which is moist and wet throughout the year with heavy rainfall (2,500 to 5,000 mm p.a.), average daily temperatures of 21-32°C and humidity averaging about 85%. Due to small seasonal variations in incoming solar radiation, the annual difference in day length is only 2 minutes along the equator and 49 minutes in the northern regions, giving a day length of 12.30 hours all year round (Nieuwolt 1982). Rainfall is affected by the North – East (November – March) and South – West (June-August) monsoons which result in heavy rainfall. For the months April-May and September-October, less rain is experienced because of changes in monsoonal winds.

The plot was previously cropped with hill paddy but has been left idle for more than a year. A one hectare plot size was prepared by manual land clearing followed by minor open burning after the weeds were dried within two weeks of slashing. The seedlings were obtained from wild jatropha trees growing around the village. Only yellow and black fruits were collected, separated from fruit coat and
dried under shade for three days. The seeds were directly planted onto the plot with a planting distance of 2 x 2 meters with two seeds per hole. No fertilizer was applied along the observation plot but weeds were controlled chemically with glyphosate (N-(phosphonomethyl)glycine) and hand weeding as needed, especially for weeds around the crop stem.

**Experimental Design and Statistical Analysis**

The predetermined targeted sample characteristics were collected randomly through all destructive and non-destructive measurable variables throughout the study. Minimum of three and maximum of 30 replications were performed to increase probability to 95% that the changes on the measurable variables were due to the selected modified variables. The data was analyzed using ANOVA and the differences between means calculated.

**Measurement of Physical Variables**

**Measurement of fruit maturity uniformity**

The jatropha ripening index was first established by modifying the guava colour index (Silip 2003) wherein Index 1 = immature fruit or small dark green fruit, Index 2 = full-sized green fruit or mature green, Index 3 = more green than yellow, Index 4 = more yellow than green, Index 5 = yellow fruit, Index 6 = more yellow than black, Index 7 = more black than yellow, Index 8 = black fruit and Index 9 = dry fruit. The established fruit colour index can be generalized into five indexes. Those are Index 1 = immature fruit or small dark green fruit, Index 2 = full-sized green fruit or mature green, Index 3 = yellow fruit, Index 4 = back wet fruit and Index 5 = dry fruit. The appearances and description of both nine and five fruit colour maturity indexes is presented in the Figure 1. The black and dry fruit are considered as
senescent fruits. Uniformity of fruits according to the established fruit maturity index was assessed by calculating the percentage number of fruits of similar maturity or similar ripening from the total number of fruits in a group such as per tree or bunch. The formula for this calculation is as follows:

\[
\text{Fruits (\%)} = \left( \frac{\text{St.y}}{\text{At1}} \right) \times 100
\]

Where: At1= the total number of fruits in the observation and St.y= the total number of fruits of a specific index.

**Measurement of total number of fruit bunches**

Total fruit bunches was obtained by counting the number of fruit bunches on each jatropha tree.

**Measurement of total fruits**

Total fruits were obtained by simply counting the number of fruits per bunch and number of fruits per tree.

**Measurement of fruit length, thickness and circumference size**

Fruit length size was determined by measuring the outer curve of individual fruits with a tape from the distal end to the point at the proximal end where the fruit coat was judged to terminate. Fruit thickness was determined by measuring the thickness at the equatorial region of each individual fruit using vernier caliper. Fruit circumference size was determined by measuring each individual fruit with a tape at the widest midpoint of each fruit.
### Appearance of the nine fruit colour maturity index

<table>
<thead>
<tr>
<th>Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Immature, small dark green fruit</td>
</tr>
<tr>
<td>2</td>
<td>Full-sized mature green fruit</td>
</tr>
<tr>
<td>3</td>
<td>More green than yellow</td>
</tr>
<tr>
<td>4</td>
<td>More yellow than green</td>
</tr>
<tr>
<td>5</td>
<td>Fully ripe yellow fruit</td>
</tr>
<tr>
<td>6</td>
<td>More yellow than black fruit</td>
</tr>
<tr>
<td>7</td>
<td>More black than yellow fruit</td>
</tr>
<tr>
<td>8</td>
<td>Black wet fruit</td>
</tr>
<tr>
<td>9</td>
<td>Dry fruit</td>
</tr>
</tbody>
</table>

### Appearance of the five general fruit colour maturity index

<table>
<thead>
<tr>
<th>Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Immature, small dark green fruit</td>
</tr>
<tr>
<td>2</td>
<td>Full-sized mature green fruit</td>
</tr>
<tr>
<td>3</td>
<td>Fully ripe yellow fruit</td>
</tr>
<tr>
<td>4</td>
<td>Black wet fruit</td>
</tr>
<tr>
<td>5</td>
<td>Dry fruit</td>
</tr>
</tbody>
</table>

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**Figure 1** The appearances and description of both nine and five fruit colour maturity indexes for measurement of *J. curcas* L. fruit maturity uniformity.
**Measurement of color**

Colour of each sample was measured at a single point in the equatorial region using a Konica Minolta Colour Reader (CR-100, Minolta Corp. Japan). The measurement was expressed in L*, C* and h° colour values. The measurements were made under constant light-source of fluorescent bulb at room temperature (26±2 °C). The values of L* (lightness), a* (red-green axis) and b* (yellow-blue axis) which represent coordinates in the colour chart indirectly reflected Chroma (C*) and hue angles (h°). L* formed the vertical axis with values ranging from 0 = black to 100 = white. Values of a* and b* were used to compute chroma \[C^* = (a^{*2} + b^{*2})^{1/2}\] which represents the hypotenuse of a right angle and hue (h° = tan⁻¹ b*/a*). It is defined as beginning at the +a* axis and is expressed in degrees where 0° would be +a* (red), 90° would be +b* (yellow), 180° would be –a* (green) and 270° would be -b* (blue).

**Measurement of firmness**

An indication of firmness was obtained by the force necessary to cause penetration of a standard probe within a specified distance into the product. A stand mounted penetrometer or the penetrometer in combination with a drill press was used for measuring coat and seed firmness. Force required to penetrate 1 cm into coats and seeds were measured using a 6 mm diameter cylindrical probe mounted on a bench-top firmness tester. Coat and seed firmness is usually reported in kilogram force (kgf) or newtons (N) (1 kgf=9.80665N)
Measurement of Chemical Variables

*Extraction of CJO using Modified Hydraulic Presser*

Oil extraction was carried out by mechanical pressing using screw pressing. Prototype of a modified hydraulic presser (MHP) was developed based on modifications of a similar presser developed by Situmorang (2009). The MHP was made with thermostat, mold compartment and 5 ton hydraulic jack (Appendix 11).

*Extraction of CJO by chemical solvent*

The soxhlet technique was used for chemical extraction with hexane solvent (boiling point of 40 – 60 °C). The extracted lipid was obtained by filtrating the solvent using a rotary evaporator apparatus at 40 °C followed by heating in an oven at 105 °C for three hours to evaporate any remaining solvent and water.

*Measurement of extracted oil yield*

The extracted oil yield was measured by dividing the amount of extracted oil by the weight of sample before extraction.

*Measurement of total soluble solid concentration*

The SSC of coat and seed was determined using a hand refractometer (Model N1, Atago) modified by Dadzie and Orchard (1997). A total of 30 g sample tissue in 90 ml distilled water was blended using a kitchen blender for 2 min and filtered through a filter paper. A drop of the filtrate was placed on the prism glass of the refractometer. The refractometer was pointed towards a light source and readings of SSC (%) were recorded. The recorded values were multiplied by a factor of three (because the initial tissue sample was diluted three times with distilled water) and the readings were corrected to a standard temperature of 20 °C according to Bourne (1982).
**Measurement of pH value**

The remaining juice from the SSC determination was used to measure juice pH using a glass electrode pH meter (Crison Micro pH 2000). The pH meter was calibrated using a buffer of pH 4.0 and pH 7.0 before use.

**Measurement of free fatty acid**

Acid value of kernel oil was determined according to the American Organization of Chemical Scientist Official Method Cd 3a-63 and the percentage of free fatty acid was calculated using oleic acid as a factor.
2. Dilihat mengenai informasi dan manfaat produk etiobain dan etiobiont nutrisi hama anti lalat dalam daftar bunga opor aman tanpa lain.

B. Pendekatan lakes merugikan penugasan tugas wajar IPB:

- Jika informasi tentang bagaimana penugasan tugas wajar IPB:
- Dilihat mengenai etiofungsi produk etiobain dan etiobiont nutrisi hama anti lalat dalam daftar bunga opor aman tanpa lain.

- Hak cipta Diliudungu Luyung-Luyung
CHAPTER 4

STUDY ON REPRODUCTIVE CHARACTERISTICS OF JATROPHA

Introduction

Poor harvesting has been the major retarding factor for commercialization of this crop and this has been highlighted in many publications (ERIA 2010; Biswas et al. 2006 and Heller 1996). Mechanical harvesting of this crop was considered impossible due to this indeterminate flowering and growth habit. Today, jatropha fruits are still harvested by hand in small and plantation scale farms. The phenophases in plants depends on the interaction between various phytohormones with the environment (Bruns 2009). Time of harvesting after anthesis of this crop can vary from as early as 37 days (Annarao et al. 2008) to 90 days (Heller 1996). Contrary recommendations on harvesting time, based on days after anthesis, was also thought to be due to this indeterminate growth habit of the crop but little information exists on these characteristics.

Long term solutions of the poor harvesting problem could be by breeding of varieties whose growth habits are determinate with uniform fruit maturity. These traits can make harvest scheduling possible for maximum economic yield. Unfortunately, the breeding of new varieties is costly and time consuming and, therefore, near-term solutions are also needed during domestication of local accession. One of the solutions involves harvest and postharvest treatments. Since the poor harvesting efficiency has been attributed to the reproductive growth habit, thus main objective of this study is to focus on characterizing the habit. This involved monitoring the lifecycle duration, measurement of the number of active and non-active branches, number of inflorescence, measurement of fruit maturity uniformity on the tree and measurement of fruit size development.
Materials and Methods

Test samples for study on fruit maturity uniformity of different jatropha accessions

To obtain information on the maturity uniformity characteristics of different jatropha accessions, data on ten selected accessions at two jatropha pilot projects in Sabah, Malaysia was collected. The pilot projects are the jatropha pilot project belonging to the Sabah Department of Agriculture at Tenom Research Station and the jatropha pilot project belong to the Sabah Land Development Board at Binakan, Sook, Keningau, Sabah, Malaysia. Both pilot projects started first planting in March 2008. The data was collected at the end of March, 2009 when the trees were exactly a year old. In this survey, only five trees per accession were randomly selected for data collection because technically, counting the number of total fruits based on maturity stage was exceedingly time consuming.

Test sample for study on fruit maturity uniformity at harvest

The test sample for this study was from seven selected accessions out of ten from the two pilot projects described above. During a study visit to the site in March, 2009, the officer in charge of the project was requested to harvest five bunches per accession. The fruit bunch character used by them was bunches that have more ripe yellow fruits.

Test samples for study on reproductive characteristics throughout the year

The test sample for this study was from the main source sample in this study as described in Chapter 3. Ten jatropha trees were randomly selected in the pilot project and the variables were measured every month at week three from January to December 2010. The reproductive characteristics observed were the active and non-active branches, number of inflorescence, number of buds, number of fruits and
percentage of maturity. The rainfall data for 2010 was collected from the Metrology Department of Malaysia for correlation study.

**Test samples for study on reproductive lifecycle duration**

The test sample for this study was from the main sample source in this study, as described in Chapter 3. To start determining the lifecycle duration, the date of planting was recorded (July 16, 2009). For determination of bud development, flowering, fruit maturation, ripening and senescence duration, 30 trees were randomly tagged in the plot. Following this, the inflorescence on each tree, which normally emanates from the main stem, was tagged. The changes in the reproductive variables, from inflorescence to fruiting, and sequence of fruit development and maturation, were recorded daily. Fruit maturity stages were predetermined as described at Chapter 3.

**Test samples for study on fruits’ size during growth and development on the tree**

The test sample for this study was from the main sample source in this study as stated earlier. The girth, length and thickness size of fruit during maturation, ripening and senescence were measured every day from the day after fruit bloom (DAFB) until the fruit was ripe and senescence. Two conditions on the measurements on the size we made. First was measurement of dominant fruit per bunches from a randomly selected bunches per trees. Fruits grow at the tip of the bunch and naturally the dominant fruits were selected for this first measurement. Second was measurement of each individual fruits per bunches from randomly selected three bunches per trees.
Measurement of total active and non-active branches

An active branch is a branch that has any of the reproductive variables such as fruit and inflorescence. The non-active branch refers to absence of reproductive variables. Both variables were measured for each of the randomly selected trees.

Measurement of fruit maturity uniformity

Measurement of fruit maturity uniformity was according to the methods described in the Chapter 3.

Measurement of total inflorescence

The number of flowers and/or buds per tree was measured by simply counting the variables on each of the randomly selected trees.

Measurement of fruit size

The size of the selected individual fruits and all the fruits in similar bunches, during growth and development, were measured according to the methods described in Chapter 3.

Experimental design and statistical analysis

The Experimental design for all five studies in this chapter has been indicated in the explanation of each test sample. Experimental design for study on fruit maturity uniformity from different jatropha accessions is non-experimental quantitative research type with variables identified but not manipulated. Five trees for each of seven selected accessions were identified for the study on heterogeneity of fruit ripening on the tree (n=50), while five bunches from seven selected accessions were identified for study on heterogeneity of fruit ripening on the bunch. The
collected data were analysed descriptively which means values were obtained, summarized and described. Experimental design for the study on reproductive characteristics throughout the year was a completely randomized design (CRD) with the month as a fixed identified variable and replicated ten times from ten randomly selected trees. Both variables became sources of variance in this study. Experimental design for the study on reproductive lifecycle duration was non-experimental quantitative research type. Experimental design for the study on fruit size during growth and development was a CRD with different trees and bunches as fixed identified variables, replicated eight times for trees and ten times for bunches. The data collected for non-experimental quantitative research type was analysed descriptively. The Minimum, maximum and average were summarized and described. Data collected from CRD was analysed using one way ANOVA. The differences between means were calculated from the error bar at 5%.

Results and Discussion

Fruit maturity uniformity in whole tree from different jatropha accessions

Variability of fruit maturity in the whole tree for ten selected jatropha accessions was determined. The results showed that, all accessions have high fruit maturity variability (Figure 1). On average, 50% of the fruits in any single tree had ripening index one. This decreased to 2% at maturity stage six followed by an increase in number of fruits with advancing maturity stage, to about 15% at the final maturity stage. Higher percentage of fruits at ripening index one was expected because this stage also includes the immature fruits or young fruits. Appendix 15 showed the fruit maturity of multiple bunches in single branch of jatropha.
Figure 2 Percentage of fruits according to maturity index of selected *J. curcas* L. accessions trees at Sabah, Malaysia in March 2009. Different legends indicate the different accessions and the solid line indicates the average percentage of fruits according to maturity per tree.

The results of this study are in agreement with previous studies in that ripening of jatropha fruits on the tree is not uniform (Biswas *et al.* 2006 and Heller 1996). A high negative polynomial relationship ($R^2=0.73$) between the percentage of fruits at maturity stage in this study demonstrated the level of ripening heterogeneity occurrence in this crop (Figure 2). The method used to explain fruit maturity, ripening and senescence heterogeneity in this study showed an alternative method to measure these occurrences. The importance of the maturity stage in post-harvest handling of many horticultural produce has been well known for many years. Ripening index standards have been developed in many countries as national standards. International ripening index standards for many horticultural produce are also available and can be found in the CODEX alimentarius.

As mentioned earlier, concern over the problems of ripening heterogeneous in this crop is unquestionable when it is related to harvesting problems. Long term
solutions could be by controlling all factors related to the problem such as genetic characteristics (Ginwal et al. 2005), site characteristics such as rainfall, soil type and soil fertility (Francis et al. 2005; Openshaw 2000 and Aker 1997), plant age (Heller 1996) and management (Heller 1996 and Sharma et al. 1997). According to Bruns (2009) the phenophases in plants depends on the interaction between various phytohormones with the environment. Thus future understanding on the reproductive characteristics implied could provide an alternative to reduce the present problem of lower harvesting volume per visit and difficulty in harvesting schedule.

Fruit maturity uniformity in bunches of selected jatropha accessions

Fruit maturity uniformity in harvested fruit bunches from selected jatropha accessions was determined because some reports in literature recommend harvesting of bunches instead of individual fruits. The results of this study showed that irrespective of accession, fruit ripening was not uniform in any single harvested bunch. A high fruits ripening percentage was observed at maturity stage five or fully yellow fruits of around 25%, while lower percentages were observed at both maturity stage one and nine, with values of only 1% and 3% respectively (Figure 3). Appendix 16 showed the appearance of fruit maturity uniformity per bunch in photos. The relationship between percentage of fruits and maturity stage is best described by the positive polynomial model with a high correlation of about 80%. Variability of fruit maturity in this study showed that this problem is a natural phenomenon in this crop. Therefore, this study corroborates many previous reports that variability in fruit maturity in this crop was not only within the whole tree but also within individual fruits in bunches.
Figure 3  Percentage of fruits according to maturity index of randomly harvested *J. curcas* L. accession bunches at Sabah, Malaysia in March 2009. Different legends indicate the different accession and the solid line indicates the average percentage of fruits according to maturity per bunches.

If this natural phenomenon is taken into account in the argument relating to harvesting recommendations, it is believed that more information is required to come up with practical harvesting and post-harvest handling recommendations. Our interest in the harvesting recommendation of bunches relates to unripe and over ripe fruits. Unripe fruits might require sorting and postharvest ripening treatments. However no such treatment is available in current literature on jatropha. In addition, which maturity stage will result in high quantity and quality of crude jatropha oil for biodiesel feedstock is still not clear. It is also important to note that there are physiological and biochemical differences between fruits attached to and off the tree. According to Wills *et al.* (1989) the development and maturation of fruits is completed only when it is attached to the plant, but ripening and senescence may proceed on or off the plant. Therefore, this study opens up many future research possibilities in the area of post-harvest physiology.
**Fruit maturity uniformity throughout the year 2010**

The trend of maturity uniformity was monitored throughout the year. The results showed that immature young and dry fruits were dominant throughout the year (Figure 4). Percentage of immature fruits, which indicated the amount of new fruits, showed the three highest and lowers points throughout the year. January, middle of May and June and November were the high points while March, August and December was the lowest points. The production trend of new fruits was in direct contrast to the amount of dry fruits. The point of highest number of new fruits was also the point of lowest number of dry fruits. The other maturity indexes were also seen to be available throughout the year but at lower percentages of not more than 10%.

![Figure 4 Trend of fruit maturity uniformity of *J. curcas* L. Luanti accession throughout the year 2010.](image_url)
The results of this study showed that the fruit maturity uniformity of jatropha appeared throughout the year. This indicates a problem with harvesting due to this variability and requires a solution during domestication of local accession. Based on information that high oil content was found in the dry fruit (Heller 1996; Wiesenhutter 2003; Nurcholis and Sumarsih 2007; Priyanto 2007 and Hambali 2007) and based on the results of this study, the trend of high percentage of dry fruits could be the reason for previous researchers recommending it as a harvesting indicator. However, this recommendation implies high harvesting costs because harvesting individual fruits can lead to frequent harvesting visits being required. Thus, future study is recommended to confirm this recommendation.

The three highest numbers of fruits in this study was in agreement with a previous report by Careles (2009) on this crop. The researcher suggested harvesting at the peak period. The results of this study are not in agreement with the researcher’s recommendations. Obviously, there were two types of three production peaks in this study. Both immature and dry fruits showed three peaks in production throughout the year of observation. This implied that the researcher should refer the recommendation to any one of the fruit groups. This study also implied occurrence of fruit fall with delay in harvesting. Decrease in the number of dry fruits after reaching the peak was implied due to fruit fall. Thus, future study should be conducted to identify the effect of delay in harvesting on the loss of fruits due to fall fruits.

Variation of total active and non-active branches

The characteristics of active and non-active branches were monitored throughout the year. Irrespective of branch characteristics, the variation on the number per tree was significantly high. Almost each of the observed samples was significantly different from each other throughout the months of observation (Figure 5). In general, the number of non-active branches increased with advancing age of crop. The average number of non-active branches was less than 10 branches per tree in January but increased to about 30 per tree in October 2010. Slight increase in the
number of active branches from early in the year to the end of the year of observation was recorded. Significant increase in the number was seen from April to May from only about five active branches in April to about 20 in May. Fluctuation in the number of active branches from April to May was probably due to the changes in rainfall. The Dry season in the area was in February, while rainfall was available in March and April but decreased slightly in May 2010 (Appendix 12).

Figure 5 Characteristics of *J. curcas* Linn Luanti accession active and non-active branches throughout the year 2010. Different legends indicate replication of data and the solid line indicates the average number of branches per tree from the ten observed trees.
An active branch refers to branches that has either/or fruits bunches inforescence and buds. To this extent, increase in number of branches in this study did not indicate an increase in fruit production. Obviously, total numbers of branches have always been used as a common variable to determine yield of this crop (Appendix 3). Results of this study were in agreement with Raden (2008) that not all branches are productive or producing bud, inforescence or fruit. The production prediction should ensure that only active branches are to be counted in the prediction. Agro-ecologic practices related to management of these branches are water sprout management and pruning. Available data in this study suggest that water sprouts should be removed regularly in the jatropha farm and the objective of pruning is not to increase the number of new branches but to make harvesting more easily. Pruning is reported to lead to delay in flowering and fruiting in jatropha (Carels 2009).

**Variation in production of inforescence**

Figure 6 shows the production trends of inforescence throughout the year or *Jatropha curcas* Linn Luanti accession. The variability in number was considerably high throughout the month of observation. The data showed that the minimum and maximum inforescence production in May 2010 was about 10 and 40 respectively. The phenophase development in this study was seen to be affected by the agro-climate. Stress on the plant during the dry season in February followed by increase in rainfall in the following month resulted in a burst of inforescence (Appendix 12). The number decreased when there was a sudden decrease in rainfall in August but increased again when the rainfall increased in the following month (Figure 6).

This relationship between the weather and the data in this study could indicate that dry seasons resulted in water deficit which increased the number of flowers and small fruits abortion. Flowering is generally considered to be advanced by water deficits in many woody perennial species. Mwanamwenge et al. (1999) reported a significant abortion on faba bean flowers and small pods due to water deficit. This
Study contradicts the Mwanamwenge et al. (1999) report. Sharp et al. (2009) demonstrated that in Rhododendron flowering is promoted with water deficit treatments. Early drop of flowers is a normal process in many species (Guitián 1993). The reasons are unclear, but low flower bud drop is related to improved fruit set (Jackson and Hamer 1980). Fruits from cross-pollinated flowers in the crop was reported to be significantly larger, heavier and more numerous than those produced by autogamous self-pollinated flowers. Therefore, it is not surprising that honeybees play a positive role in jatropha pollination (Abdelgadire et al. 2008).

Figure 6 Production trends of flower buds of J. curcas Linn Luanti accession throughout the year 2010. Different legends indicate replication of data and the solid line indicates the average number of branches per tree from ten observed trees.
Variations in fruit production

Figure 7 shows the fruit production trends throughout the year for the *J. curcas* L. Luanti accession at Keningau, Sabah, Malaysia. The data showed huge variability in any month of observation. The high difference in fruit production per tree was recorded in June and July. Higher and lower fruit production per tree in both months were about 425 and 100 in June and about 400 and 60 in July respectively. The trend of fruit production is seen as similar to the trend in inflorescences production (Figure 6). The high number of inflorescences produced in May resulted in an increase in the number of fruits in June.

Figure 7 Fruit production trends throughout the year of *J. curcas* Linn Luanti accession. Different legends indicate replication of data (different trees) and the solid line indicates the average number of branches per tree from ten observed trees.
Variability in fruit production is affected by various factors. In this study the weather conditions are implied to influence flowering. According to Burgos et al. (1993) the weather affects pollination, therefore, stigma receptivity, ovule fertility, ovule longevity and fruit set are directly affected. Furthermore the researcher explained that there are many genotype-dependent factors related to floral biology, that influenced fruit set and, consequently, productivity, such as flower bud production, flower bud drop, flowering time, ovule development stage at anthesis, pollen germination, height difference between the stigma and the superior plane of the anthers, aborted pistils and the autogamy level. However, the related variables are not monitored in this study.

Fruit production variability in this study could also indicate the potential of failing in a production prediction for this crop. Various variables are used by many researchers to calculate jatropha fruit production (Appendix 3). In this study minimum and maximum number of fruits can be calculated by multiplying the total fruits per tree with number of jatropha trees per unit area (Figure 7). With 2 x 2 m planting distance, minimum 250,000 and maximum 1,062,500 individual fruits can be harvested in a hectare in May. If each fresh fruit weight is 15 g the production is equivalent to a minimum of 3,750 kg/ha and maximum of 15,938 kg/ha. If the fresh weight of seed per fruit is 3.5 g, the minimum and maximum fresh seed production are 875 kg/ha and 3,719 kg/ha. Thus if fresh seeds contain 30% moisture content, minimum and maximum dry weight in May are 612.5 kg per ha and 2,603.3 kg per ha respectively. Furthermore, if the seed is to be extracted and there is only 25% extraction efficiency with mechanical extraction, the minimum and maximum extracted oil yield will be only 153 kg per ha and 651 kg per ha in May respectively.

The fact with the above calculation is that not all fruits in the trees were ready to be harvested. Previous data in Chapter 4 Figure 4 indicate the variability of fruit maturity and thus the calculation should be revised based on this. The maturity variability indicated only about 50% of the fruits is in dry stage, 20% are in immature stage and the other group of fruits are counted to be around 30%. As dry fruits were the recommended harvested fruit, thus the minimum and maximum harvestable dry
seeds in May was only about 306 and 1,302 kg per ha. The dry seeds are equivalent to minimum and maximum extracted oil yield of about 77 and 325 kg per ha.

The reduction in the total number of fruits per hectare was observed from July to September 2010 (Figure 6). This indicates occurrence of fall fruit during delay in harvesting. There was no harvesting throughout the observation in this study. This indicates that it is important to understand the fall fruits characteristics because it is expected that these factors contribute to loss in biomass and the point of minimum harvesting visits. On the other hand, total loss should be included in the calculation of real harvestable volume of jatropha during specific months of production.

**Variations on total bunches per tree and frequency of fruits per bunch**

The total number of bunches per tree throughout the year 2010 for jatropha Luanti accession planted at Keningau, Sabah, Malaysia showed not uniform (Figure 8). The average production of the bunches per tree showed increase in the first six months from January to June after which there was a decrease in July reaching minimum in September. Slight increase after September was observed until end of the observation period. The trend of total bunches per tree was similar to the trend of total fruits per tree (Figure 7). The frequency of fruits per bunch indicated the function of bunches and the average variability in frequency is presented in Figure 9.

The frequency of total fruits per bunch in this study showed that the highest number of fruits per bunch was five and six followed by nine, eight and seven. Frequency of fruits per bunch of more than 10 was only about 10%. Results of this study were not in agreement with the report by Kumar and Sharma (2008). The researcher reported that each inflorescence yields a bunch of approximately 10 or more void fruits. There are many factors that could affect the frequency of occurrence. Plant growth regulators have been tested by Abdelgadir et al. (2010). The researcher reported a positive effect of 2, 3: 4, 6-di-O-isopropylidene-2-keto-l-gulonic acid with more fruits per bunch and more seeds. However, the researcher identified more fruits per bunch, around five to six fruits per bunch, which was considerably
lower in this study. High number of fruits per bunch should be where a bunch has more than 15 fruits.

Figure 8 Variations in total bunches per tree throughout of the year for *J. curcas* Linn Luanti accession. Different legends indicate different trees and the solid line indicates the average number of branches per tree from 10 observed trees.

Figure 9 Frequency of total fruits per bunch for *J. curcas* Linn Luanti accession. Vertical lines indicate the error bars of measurement at 5%.
Variation in fruit size during growth and development

The changes in the fruit length, thickness and girth size from day after fruit bloom (DAFB) to physiologically mature, ripe and senescence is presented in Figure 10. The data shows variability in size irrespective of the size characters and sources of variance. In general, the trend of the fruit size changes from DAFB to advancing maturation, ripening and senescence were similar, which is best described by polynomial trend lines (Figure 10).

Figure 10 Changes in *J. curcas* L. Luanti accession fruit size (length, thickness and girth) during growth and development from day after fruit bloom to ripe and senescence. Different trees (T) and different individual fruits (F) from similar bunches are the sources of variance. The solid lines indicate the average polynomial with R value and the dashed line indicates the means of the data.
The trend followed normal fruit growth in many crops and can be divided into three sub-phases: an early accelerating phase, a linear phase and a plateau phase for ripening. In this study, the data showed that irrespective of fruit size character, the size of fruits from similar bunches was low compared to fruits from different trees. Average length, thickness and girth size value at 24 DAFB in fruits from similar bunch was about 3.0, 2.5 and 8.5 cm respectively. The average length, thickness and girth size value at 24 DAFB in fruits from different trees was about 3.5, 3.0 and 9.0 cm respectively. Fast fruit length, thickness and girth size changes was observed in the first two weeks after fruit bloom from only about 1.0, 0.6 and 2.5 cm in the first DAFB to about 3.4, 3.0 and 8.5 cm after 12 DAFB respectively.

The variability in size in this study provides information on the possibility to harvest jatropha according to size. However, fruits of similar size might not be of similar maturity stage. The state of fruit maturity is important because it has a different physiological character at different stages and thus requires different postharvest handling. For example ripe and senescence fruit, both recommended as harvesting indicators, will be directly processed for storage or oil extraction. However, harvested mature green fruit might require postharvest handling such as ripening treatment before further handling. Variation in fruit size poses problems in grading harvested fruits and as a consequence additional costs for the operational house to install grading machines or to pay additional labour cost. To make the task more efficient, a grading machine with computerised grader is normally installed, however this installation increases cost. Applying specific harvesting practices at the farm level can be used as an approach to reduce grading cost. This approach is recommended for manual harvesting in apples because variations have been identified (De Silva et al. 2000). Variability in fruit size can be affected by various factors. The yield of Jatropha is controlled by genetic characteristics (Ginwal et al. 2004), site characteristics (rainfall, soil type and soil fertility) (Francis et al. 2005; Openshaw 2000 and Aker 1997), plant age (Heller 1996) and management (Heller 1996; Sharma et al. 1997 and Sing et al. 2006).
Days required for reproductive variables to reach specific stage of development

The results showed that jatropha starts to bear flowers within 93 to 124 days after seeding (Table 1). First buds appear within 85 to 98 days after seeding and will develop to become flowers within 7 to 18 days. Flowering to fruit set occurred within one to eight days. Fruits developPhysiologically or reach mature green stage within 21 to 35 days from fruit set. Soon after physiological maturity, the fruits start to ripen or senesce which required 2 to 4 days to become fully yellow or fully ripe fruit and 3 to 9 days to become fully black or fully senesced fruit. The results of this study indicate that the lifecycle of the local Luanti jatropha accession planted at the Agro-Biotechnology plot showed indeterminate growth habits. The fruits’ lifecycle for this accession reached completion within a wide range of days (Table 1).

Table 1 Days required by *J. curcas* L. Luanti accession reproductive variables: growth or changes from seeding, appearance of buds to fruit maturation, ripening and senescence.

<table>
<thead>
<tr>
<th>Reproductive variables</th>
<th>Min.</th>
<th>Max.</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeding to first appearance of bud</td>
<td>85</td>
<td>98</td>
<td>91.5</td>
</tr>
<tr>
<td>Bud development</td>
<td>7</td>
<td>18</td>
<td>12.5</td>
</tr>
<tr>
<td>Flowering to fruit set</td>
<td>1</td>
<td>8</td>
<td>4.5</td>
</tr>
<tr>
<td>Fruit set to mature green fruit</td>
<td>21</td>
<td>35</td>
<td>28</td>
</tr>
<tr>
<td>Mature green to yellow fruit</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Mature green to black fruit</td>
<td>3</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Mature green to dry fruit</td>
<td>6</td>
<td>17</td>
<td>11.5</td>
</tr>
<tr>
<td>Flower to yellow fruit</td>
<td>24</td>
<td>47</td>
<td>35.5</td>
</tr>
<tr>
<td>Flower to black fruit</td>
<td>27</td>
<td>56</td>
<td>41.5</td>
</tr>
<tr>
<td>Flower to dry fruit</td>
<td>36</td>
<td>73</td>
<td>54.5</td>
</tr>
</tbody>
</table>

Variability in first flowering and fruiting in this study are in agreement with the report by Carels (2009). However, the researcher reported that in general the first flowering and fruiting after planting started between 4 and 5 months. Furthermore the researcher stated that this only happened after 7 months and/or lasted till the second year. The plant is pruned to increase production. Pruning is recommended for...
building tree architecture (Openshow 2000). These practices implied mechanization of cropping, promote branching as does nitrate (N) fertilization and water.

The results of this study demonstrate difficulty in harvesting scheduling. If dry fruits were recommended as the harvesting indicator then harvesting visits need to be done within 6 to 17 days for the same tree. Furthermore, if a yellow ripe fruit is to be recommended as the harvesting indicator then harvesting visits is required to be done within 2 to 4 days only. The data of this study agrees with the argument of high harvesting costs reported by ERIA (2010), Biswas et al. (2006) and Heller (1996) for this crop due to the requirement for regular harvesting visits.

Today, most of industrial crops are classified as determinate crops. Therefore management of these crops is easier and can be manipulated for maximum economic yield (Bruns 2009). However, realistically crop development and/or its maturation are affected by light, temperature changes and interactions with phytohormones. For example, well known determinate soybeans were reported to be only suitable for specific locations and its determinate habit changes into indeterminate habit if planted in other places (McWilliams et al. 2004). Therefore, efforts to find determinate jatropha accession should be done in the future.

Conclusion

All reproductive variables observed in this study had comparably high variability. Days required to reach recommended harvesting index varies, implying that harvesting visits to the same tree is should be done rapidly and in a short duration. Jatropha fruits are available throughout the year but there is high variation between observed trees. As a consequence the jatropha production prediction is difficult. In addition, the crop showed variation in sizes, which is expected to lead to difficulty in grading of harvested fruits for further handling practices. Rainfall was found to have a direct effect on fruit production. After the dry season and start of rain showed increase in the number of inflorescence, however increase in the number of
branches does not affect the number of fruits and/or inflorescence. Thus, recommendation to prune to increase number of new branches is not advisable. The frequency of total fruits per bunch in this study showed a positive relationship with total fruit production. Thus, this finding suggests future study to increase the frequency of more fruits per bunch as an approach to increase fruit production. With the high variation amongst the variables, this study suggests that jatropha should be classified as an indeterminate class of crop. As an indeterminate crop, the harvesting problem needs to be addressed by future studies to identify other important variables of the crop so that more solutions to the problem can be suggested.
CHAPTER 5
CHANGES IN PHYSICOCHEMICAL CHARACTERISTICS
DURING THE LIFE OF JATROPHA FRUITS ON THE TREE

Introduction

Like others plant, jatropha fruit development and ripening are a combination of biochemical and physiological events. In previous study (Chapter 4), the data showed the reproductive character during development of the fruits. The variations in the reproductive characters throughout the observation led to the conclusion of classifying the crop in the indeterminate class. As an indeterminate crop, harvesting problems are expected and therefore short term solutions were suggested, using harvesting and postharvest handling practices approach. Basic problem with harvesting individual fruit is an inconsistence recommendation on harvesting index indicator. Main indicator has been the oil content. The inconsistent recommendation base on the indicator is shows in Appendix 9. Obviously many of the reports suggesting dry fruit but some suggested black senescent or yellow ripe fruit. Dry fruit may contain higher oil content compared to those at early stage of fruit maturation. Other than oil content several physicochemical variables related to postharvest handling are expected to change during the life on the tree. Thus the main objective of this study was to determine selected physicochemical variables during the life of the jatropha fruit on the tree.

Materials and Methods

Test sample for physicochemical analysis

Jatropha fruits for this study were from the Jatropha Pilot project located at Kuanti Baru village in Keningau as described in Chapter 3. Fresh fruits at five different maturity stages were collected from the plot for analysis. The stages include
immature, mature, yellow ripe, black senescence and dry senescence. The selected healthy, uniform sized fruits were harvested manually from the plot and immediately after harvest the samples were taken to the School of Sustainable Agriculture Laboratory, at Universiti Malaysia Sabah for analysis.

**Test samples for respiration study**

This study was completed at Bogor Agricultural University, Indonesia. Two types of samples were used. The sample for no pre-handling treatment was a Tanzania accession located 15 minutes walking distance from the laboratory. The accession is owned by the Laboratory of Agricultural Energy and Rural Electrification, Department of Agricultural Engineering, Faculty of Agricultural Technology, Bogor Agricultural University. Sample with pre-handling treatment was a IP1 accession, which was brought from the Jatropha Plantation at Serang, Banten, Indonesia, which required eight hours open air transport from farm to laboratory. Pre-handling interruption hours before respiration test was 28 hours. Fruits were kept in the respirometer bottle from the open topside and were kept with the lid closed while inserting neoprene gasket in between. Three different storage temperatures were used (27±3°C, 15±3°C and 7±3°C) for this test.

**Measurement of fruit size**

Length, thickness and girth size of sample were measured as described in Chapter 3.

**Measurement of fresh weight**

Fresh fruits, coats, shells and kernels were separated and weighed individually using an electronic balance set to two decimal places.
**Measurement of color and firmness**

Colour was measured as described in Chapter 3 and firmness was measured as described in Chapter 3.

**Measurement of moisture content**

The initial moisture content of the samples was determined using standard hot air oven method at 105±1 °C for 24 h (Pradhan et al. 2008).

**Measurement of extracted oil yield and total soluble solid concentration**

Extracted oil yield was determined using chemical solvent technique as described in Chapter 3. Total soluble solid concentration was measured as described in Chapter 3.

**Measurement of pH value and free fatty acids**

The pH value and free fatty acids was measured as described in Chapter 3.

**Carbon dioxide measurement**

Gas inside the airtight respirometer bottle with volume of 3300ml was measured using Infrared Continuous Gas Analyzer Model IRA-107 (Shimadzu, Japan). Gas composition was analyzed at intervals depending on the storage temperatures. Preliminary experiment was conducted to determine suitable interval our measurement of CO₂ and minimum weight of fruit per respirometer bottle. Gas measurement was ceased when the fruits were fully senescence.
Calculating respiratory rates

The respiration rates in terms of CO₂ at given temperature were calculated using the following equation as given by Kays (1991). Milliliters of gas are converted to milligrams to remove the effect of temperature on the volume of gas by temperature correction according to methods by Kays (1991).

\[
\text{ml kg}^{-1}\text{hr}^{-1} = \frac{(\Delta \% \times 10) \times (\text{free space volume of respirometer bottle in liters})}{(\text{productfwt in kg})(\text{timerespirometer bottle is close in hours})}
\]

Where \( \Delta = \Delta \text{CO}_2 \) or concentration time 2 – concentration time 1

Experimental design and statistical analysis

A complete randomized design was used in this study for the physicochemical characteristics with predetermined maturity index as fixed variables and the physicochemical characters as measureable variables with a minimum of five replications. Factorial complete randomized design with two type of samples (no delay and with delay in handling before experiment) and three storage temperatures (27±3°C, 15±3°C and 7±3°C) was designated for the study on respiration with five replications (n=30).

Results and Discussion

Changes in size

Size of freshly harvested fruit and seed, according to maturity stage, are presented in Table 2. The results showed significant differences in fruit length and girth for different maturity stages. However, for seed, only seed length was statistically different while the seed girth was not significantly different at different
maturity stages. The fruit length and girth size showed significant reduction upon full senescence. The seed length size increased to maximum when fully ripe but started to shorten when senescence and was stable when dry.

Table 2 Size (length and girth) characteristics of *J. curcas* L. Luanti accession fruit and seed according to maturity stage (YF: young fruit, MG: Matured Green, MGY: more green than yellow, MYG: more yellow than green, Y: yellow, MYB: more yellow than black, MBY: more black than yellow, Black: black fruit and Dry: Dry fruit) (n=45).

<table>
<thead>
<tr>
<th>Maturity stage</th>
<th>Fruit</th>
<th>Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length (mm)</td>
<td>Girth (mm)</td>
</tr>
<tr>
<td>YF</td>
<td>10.54ab</td>
<td>10.16ab</td>
</tr>
<tr>
<td>MG</td>
<td>10.64ab</td>
<td>10.34ab</td>
</tr>
<tr>
<td>MGY</td>
<td>10.92a</td>
<td>10.38ab</td>
</tr>
<tr>
<td>MYG</td>
<td>10.94a</td>
<td>10.42ab</td>
</tr>
<tr>
<td>Y</td>
<td>10.83a</td>
<td>10.76a</td>
</tr>
<tr>
<td>MYB</td>
<td>10.9a</td>
<td>10.70a</td>
</tr>
<tr>
<td>MBY</td>
<td>10.16b</td>
<td>10.00b</td>
</tr>
<tr>
<td>Black</td>
<td>9.42c</td>
<td>8.88c</td>
</tr>
<tr>
<td>Dry</td>
<td>8.86d</td>
<td>8.38c</td>
</tr>
<tr>
<td>Sig.</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

NS. Non significant or significant at P≤0.05.

Mean for each treatment followed by the same letter at a similar column are not significantly different at p≤0.05 with *Duncan Multiple Range Test (DMRT)*.

Results of this study show yellow ripe fruit as the biggest fruit and seed length size. After reaching the biggest size point, the size decreases again when the fruits and seeds are senescence and dry. The trend of these changes has also been seen from observation of fruit size changes from day after fruit bloom, as stated in Chapter 4. After plateau the polynomial calculation showed decrease at the end of observation which was the senescence stage (Figure 10). The biggest size of the ripe fruit could indicate the peak of biomass enlargement and the final stage of metabolic storage. Upon senescence, the stored metabolites will respire and transpire. The metabolites stored in the fruit coat might be transpired for lipid biosynthesis during senescence before becoming dry. However, there is no information available to support this
argument. Salas et al. (2000) has proven that the degradation of six-carbon via glycolysis is the first involved in the oil biosynthesis.

The data from this study indicates that it is impossible to use size as a tool for sorting immature and mature jatropha fruit but could be used for sorting senescent and non-senescent fruits. Sizes of harvested horticultural products are also referred to as surface area required for logistic management. Based on this study, it is indicated that a high surface area is required for handling fruits compared to seeds. Almost double the surface area is required to handle fruits when compared with seeds. Shells of seeds might also contribute to an increase in surface area. According to Sirisomboon et al. (2007) the surface area of jatropha fruit was larger than those of the seed and kernel by 5.88% and 10.24% respectively. For logistic management benefits it is suggested to remove fruit coats prior to handling or transporting harvested jatropha over a distance.

**Changes in fresh weight**

Fresh weight of fruits, coats, seeds, shells and kernels changed during maturation, ripening and senescence (Figure 11). Fruit, coat, seed and shell fresh weight increased significantly to maximum for the ripe or fully yellow fruit but reduced when senescent. However, the fresh kernel did not increase when the fruit was ripe but was found to decrease significantly when dry. This indicated that biomass kernels fresh weight of immature, mature and ripe fruits is similar but significantly low when senescent. The kernel is where the oil can be extracted, thus it is important to focus on its character. Low fresh weight of senescence kernels could be due to low moisture content and high fresh weight in immature, mature and ripe kernels could be due to high moisture content. Biomass of jatropha fruits were previously reported as significantly different according to maturity stage due to high water content at physiological maturity stage and low water content at senescence and dry stage (Gunaseelan, 2009).
Data from this study can be a guide for jatropha fresh fruit trading. Trade based on fresh fruit weight offers an effective means of biomass valuation because maturity of fresh fruit can be judged based on fruit coat color. It is obviously difficult to differentiate between the seed color of mature, ripe and black fruits with the naked eye because all are black. However, the color can now be easily compared by using the color numeric interpretation or can be differentiated by observing surface character using a light microscope. Further calculation on the real value of jatropha based on the maturity stage will depend on the moisture content and oil content. Both variables will be discussed in the following subsection in this chapter.

Figure 11 Fresh weight of *J. curcas* L. Luanti accession fruits, coats, seeds, shells and kernels, according to maturity stage. Vertical bars indicate the error bar of measurement at 5% (n=45).
Changes in color

Color changes on jatropha fruit coats, shells and kernels during on-tree maturation, ripening and senescence are presented in Table 3. Fruit coat color changes from green during immature and mature stage to yellow when ripe and finally black when senescence. Strong and brightest colour was observed at ripe or yellow fruit stage.

Shell color is indicated as black and the data showed three significant differences in the blackness. Significant dark black color was at maturity index of MYB and MBY with lower L* reading of only a value of about 22. Kernel color is indicated as white and the data was also showed three significant groups of whiteness. A superior white kernel was at the maturity index of mature green and ripe fruit stage. The lower whiteness was in dry fruit kernels.

Table 3 Jatropha fruit coat, shell and kernel color (L*, C* and h° value) according to predetermined maturity stages. YF (immature young green fruits), MG (mature green), MGY (more green than yellow), MYG (more yellow than green), Y (ripe yellow fruits), MYB (more yellow than black) and MBY (more black than yellow).

<table>
<thead>
<tr>
<th>Maturity Stage</th>
<th>Coats</th>
<th>Shells</th>
<th>Kernels</th>
</tr>
</thead>
<tbody>
<tr>
<td>h°</td>
<td>L*</td>
<td>C*</td>
<td>h°</td>
</tr>
<tr>
<td>YF</td>
<td>117.12a</td>
<td>47.41d</td>
<td>30.74d</td>
</tr>
<tr>
<td>MG</td>
<td>113.22a</td>
<td>56.78c</td>
<td>39.04c</td>
</tr>
<tr>
<td>MGY</td>
<td>104.22b</td>
<td>62.86b</td>
<td>44.64b</td>
</tr>
<tr>
<td>MYG</td>
<td>94.68c</td>
<td>57.66d</td>
<td>46.22b</td>
</tr>
<tr>
<td>Y</td>
<td>90.72c</td>
<td>73.96a</td>
<td>55.06a</td>
</tr>
<tr>
<td>MYB</td>
<td>75.36d</td>
<td>63.60c</td>
<td>38.08c</td>
</tr>
<tr>
<td>MBY</td>
<td>59.92e</td>
<td>41.12e</td>
<td>20.84e</td>
</tr>
<tr>
<td>Black</td>
<td>55.68f</td>
<td>25.84f</td>
<td>4.66f</td>
</tr>
<tr>
<td>Dry</td>
<td>50.96f</td>
<td>27.00f</td>
<td>6.68f</td>
</tr>
<tr>
<td>Sig.</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

* = significant at P<0.05
γ = Different letter within the row denotes significant difference by using DMRT at P<0.05

In this study, the predetermined maturity stage was not significantly different on hue angle values (Table 3). This indicates that the predetermined maturity stage cannot be recommended. The predetermined color can only be used by experts because the brightness (L* value) and vividness (C* value) can help in differentiating each of the indexes. New groups of the fruits based on the significant differences in fruit coats
hue angle value can be suggested. These are group 1 (immature and mature fruit), group 2 (more green than yellow), group 3 (more yellow than green and the yellow fruit itself), group 4 (more yellow than black), group 5 (more yellow than black) and group 6 (more black than yellow) (Figure 12).

Figure 12 Changes in the color (hue angle value or h°) of *J. curcas* L. Luanti accession fruit coats according to nine fruit color maturity stages from YF (immature small green fruits), MG (mature green), MGY (more green than yellow), MYG (more yellow than green), Y (ripe yellow fruits), MYB (more yellow than black) and MBY (more black than yellow). Solid line indicates the linear trend and vertical bars indicate the error bar of measurement at 5% (n=45).

The change in colour of the skin and or flesh of horticultural products is due to the change of colour pigments (Wills *et al.* 1989). In most fruits, the loss of chlorophyll is accompanied by the unmasking or biosynthesis of carotenoid pigments (Gross 1987). During ripening the green colour turns to yellow as chlorophyll gradually degrades, unmasking the colour of the previously available carotenoid pigment. The degreening of banana and lemon (Gross 1987) are due to this pattern. However, information on the pattern in jatropha is not available in cited literature.
Changes in firmness

Texture of fresh jatropha fruit coats, shells and kernels was significantly changed during on-tree maturation, ripening and senescence (Table 4). Major changes in fruit coat firmness were observed during senescence. The shell and kernel firmness was significantly harder when ripe and senescence. The firmness of seed shells was 3 – 4 times harder than kernels were at any maturity stage (Table 4). Texture is associated with softening of parts of the fruits during ripening. Therefore, texture is an important physical attribute that has always been associated with ripening. Results of this study were in agreement with a report by Sirisomboon et al. (2007). The researcher reported high value of rupture force, hardness and toughness in jatropha seed (nut) compared with value of coats and kernels. Pradhan et al. (2009) reported that the crushing strength of jatropha seed was moisture dependent.

Table 4 Firmness (N) of fresh *J. curcas* L. Luanti accession fruit coat, shell and kernel according to maturity stage.

<table>
<thead>
<tr>
<th>Maturity Index</th>
<th>Coats</th>
<th>Shells</th>
<th>Kernels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immature</td>
<td>14.32ab</td>
<td>23.83b</td>
<td>06.67b</td>
</tr>
<tr>
<td>Mature green</td>
<td>13.24b</td>
<td>24.42b</td>
<td>06.28b</td>
</tr>
<tr>
<td>Fully yellow</td>
<td>16.67ab</td>
<td>35.99a</td>
<td>11.47a</td>
</tr>
<tr>
<td>Black senescence</td>
<td>07.45c</td>
<td>41.39a</td>
<td>11.97a</td>
</tr>
<tr>
<td>Dry senescence</td>
<td>13.83b</td>
<td>33.90ab</td>
<td>10.98a</td>
</tr>
</tbody>
</table>

* = significant at p<0.05
\* = different letters within a row denote significant difference by using DMRT at p<0.05

Changes in moisture content

Water content in the jatropha kernels changes during maturation, ripening and senescence on the tree (Figure 13). The moisture content was high during immature stage and decreased with progress in maturation. The moisture content of jatropha kernels in this study was in agreement with Gunaseelan (2009). The moisture content was high at immature stage at about 80% but reduced linearly when advanced in maturity, ripe, black senescence and dry by about 55, 40, 30 and 15% respectively.
Moisture content has been predetermined as one of the important factors affecting oil extraction efficiency in oil–bearing material (Gutierrez et al. 2008) and according to Bernardini (1982) oil recovery increased with decrease in moisture content. The relationship between moisture content present with oil content will be analyzed in the section on jatropha kernel oil content.

Figure 13 Changes in the moisture content (%) during on-tree maturation, ripening and senescence of *J. curcas* L. Luanti accession kernels. Different legends indicate the replications and solid line indicates the average linear trend (n=15).

Changes in the kernel moisture content did not follow the same trend as the changes in seed size (Figure 10) and kernel weight (Figure 11). The data indicated that the maximum increase in fruit weight and volume during nearly ripe stage was
not due to increase in water content but solely due to genuine increase in harvested weight. The point which is the heaviest and largest size could also reflect maximum cell enlargement and nutrient storage. The type of nutrient remains unknown at this point of discussion but in the following subsection and chapter this question will be explored further. The fact is that, harvested biomass weight and volume will affect logistic management. Heavier and larger volume of harvested biomass could increase transportation and other postharvest handling practice costs and uneconomical especially if the final product is relatively small. High moisture content in harvested products is also always related to several disadvantages. Apart from the disadvantages mentioned above, early harvest with high moisture content was reported to induce more hollow and brittle kernels in almond kernels (Connell et al. 1989). Thus, the following experimental results and discussions are very interesting.

**Changes in soluble solid concentration**

Soluble solid concentration (SSC) in fruit coats, shells and kernels changes during maturation, ripening and senescence (Figure 14). The SSC in the kernels increased significantly from immature to mature and reach maximum at the ripe stage but then decreased when the fruit senesced. The results of this study indicate that increase in sugar from immature to ripe could be due to increase in degradation of high molecular compounds such as starch which might be converted into smaller molecular weight compounds such as fructose (Wills et al. 1989) but later decreases during senescence because the sugar is converted to oil. According to Baud and Lepiniec (2010) plant cells require sugar and amino acids to synthesize lipids and degradation of six carbon via glycolysis was said to be the first one involved in oil biosynthesis.
Changes in pH value

The study shows that pH value of fruit coats, shells and kernels changed during maturation, ripening and senescence (Figure 15). During the immature stage, all the samples were acidic but soon after ripening and senescence the pH of whole samples increased. The pH value of the shells was above pH seven when mature, ripe and senesced. The pH value of fruit coats was only above seven when senesced. The increase in the pH value of kernels was not above seven indicating that this sample was not alkaline at any time during maturation, ripening and senescence. Increase in pH value throughout maturation, ripening and senescence was due to metabolic processes in the fruits that resulted in decrease of organic acids (Coseteng and Lee 1987).
values. During prolonged storage, the pH levels declined because the acids are respired or converted to sugar (Wills et al. 1989). However, the results on pH value in this study are not in agreement with the report by the research team.

![Figure 15](image_url)

Figure 15 The pH value of *J. curcas* L. Luanti accession fruit coats, shells and kernels at various maturity stages. Vertical bar indicates the error bar of measurement at 5% (n=75).

*Changes in the extracted oil yield*

The results showed that the chemically extracted oil yield of fresh jatropha kernels changed significantly during its life on the tree (Figure 16). Highest oil content (w.b) was in fresh dry senescence kernel fruit and lowest in fresh immature kernel fruit at about 41% and 4% respectively. Oil content in fresh yellow ripe and wet black senescence kernel fruits were not significantly different at about 21 and 24% respectively. However, the unripe harvested fresh mature green kernel was the second lowest after immature young fruits, containing only around 15% oil.

Positive linear trend in the increase of chemically extracted fresh kernel oil content but negative linear trend in moisture content was confirmed in this study (Figure 17). The
relationship trend between moisture content and oil content in the results could indicate the role of moisture in extraction efficiency. Moisture content has been predetermined as one of the important factors affecting oil extraction efficiency in oil-bearing materials (Gutierrez et al. 2008) and according to Bernardini (1982) oil recovery increased with decrease in moisture content. It is important to note that not all oils in the kernels can be extracted during extraction. Oil extraction was reported to range from 70 – 80% (Achten et al. 2008).

Figure 16 Percentage of extracted oil yield (w.b) from fresh harvested J. curcas L. Luanti accession kernels according to maturity stage. Solid line indicates the linear trend. Verticals bars indicate the error bar of measurements at 5%. Displayed data levels are mean values (n=20).
High oil content from harvested fresh dry jatropha fruit in this study was in agreement with many reports (Heller 1996; Wiesenhutter 2003; Nurcholis and Sumarsih 2007; Priyanto 2007 and Hambali et al 2007) but not with Wanita and Hortono (2006) and Santoso (2008) who suggested yellow ripe fruit instead. With available data, the earlier harvesting time recommendation in Chapter 4 would be substantiated. However, with regards to the relationship between oil content and moisture content, it is obvious that future studies should investigate the function of moisture content. Drying has been recommended as one of the postharvest handling practices prior to extraction or before long term storage of jatropha (Tobin and Fulford 2005).
Changes in free fatty acids

Free fatty acids in jatropha kernels during maturation, ripening and senescence is considerable low at less than 2% irrespective of maturity stage (Figure 18). This study indicated that jatropha oil will only require esterification for biodiesel processes. However, the statistical results showed significant differences in FFA content among the maturity stages which implied propagated future source of shortening oil storage shelf life.

The low FFA reading in this study was in agreement with research reports by Gubitz 
 et al. (1999), Forson et al. (2004), Kandpal and Madan (1995) and Reddy and Ramesh (2006) but only for samples of dry fruit. Annarao et al. (2008) reported that the amount of FFA was high in immature fruit, ranging from 63 – 74% but declined drastically when senescence at only around 2.0 – 3.5%. The research team suggested
that linoleic acid might primarily be involved during initial development at the immature stage when sterol concentration was high and then it gives way to linoleic acid as the seed starts to mature. Sterol was reported to have an essential role at the cellular level for hormonal signalling, organized divisions and embryo altering (Hartmann et al. 2002). Major fatty acids reported in J. curcas by Martinez-Herrera et al. (2006) were oleic (41.5-48.8%) and linoleic (34.6-44.4%).

**Changes in respiratory rate**

The respiration data corresponding to different storage temperatures and different samples indicated an upsurge in CO$_2$ concentration (Figure 19). The point of upsurge in CO$_2$ concentration differed based on storage temperatures. The peak was observed as early as at 54 hours at storage temperature of 27±3°C but it was only observed at 90 and 116 hours at storage temperatures of 15±3°C and 7±3°C respectively. The results of this experiment suggest that jatropha fruits exhibit some respiration characteristics of climacteric fruits. Kays and Paull (2004) and Perin et al. (2002) characterized climacteric ripening as an upsurge in the respiration rate during ripening. However, Kays and Paul (2004) and Perin et al. (2002) also cited that the trend of respiration should be accompanied by autocatalytic ethylene gas production. As information on the ethylene production trend is not available, thus this study could not confirm whether this fruit is climacteric or non-climacteric. During the respiration study, most of the fruit samples were observed to be fully ripe or in yellow colour stage when reaching the peak of upsurge in CO$_2$ production. The characteristics of colour changes during ripening are a common character of climacteric fruits such as mango, banana and papaya.
Figure 19  Respiratory rate of jatropha fruits at three different storage temperatures (A=27±3°C, B=15±3°C and C=7±3°C) and two types of samples (directly used or no delay and indirectly used or has a delay before experiment).

Classification of fruit into climacteric and non-climacteric should not be over simplified because similar genus but different species can have different respiration patterns (Obendo et al. 2007). The climacteric rise in respiration was described as early as 1908 in apple and pear fruits (Kays 1991). The respiration of an unripe fruit declines after harvest to what is termed the preclimacteric minimum occurring just before the
climacteric rise in respiration. Subsequently, respiration increases dramatically, often to levels that are two to four times that of the preclimacteric minimum. Data from this study show that increase in the peak of respiration was only at less than one time of that minimum of preclimacteric respiration (Figure 19). On the other hand, non-climacteric fruits were defined as those that do not exhibit an upsurge in respiration but rather a progressive, slow decline during senescence until microbial or fungal invasion (Kays, 1991). Thus the respiration pattern in this study was not in agreement with the non-climacteric character proposed by Kays (1991).

The present harvesting problems of this crop related to drudgery and being time consuming now have a hope of being reduced. The results of this study indicate potential to harvest mature green fruits to increase harvestable fruits. It is important to note that harvesting mature fruits is a prerequisite in some cultivars due to the fact that respiration upsurge was reported to be inhibited while the fruit is attached to the tree (Kays, 1991). Hence, the results of this study offer opportunities for future studies on jatropha fruits’ postharvest ripening treatments and its effects on the quantity and quality of crude jatropha oil.

**Conclusion**

All ten variables observed in this study experienced changes when attached on the jatropha tree. Physical variables i.e. size, firmness, fresh weight and firmness showed differences between maturity stages. The physical variable data indicate benefits in removing the fruit coat prior to further handling practices such as transportation and storage because fruit coats implied increased weight and surface area. Trade of jatropha is suggested to be best with fresh fruits because maturity of harvested fruit can be judged with the naked eye. Recommended harvest index for jatropha is dry harvested fresh fruit because it has high chemically extracted oil yield. However, the recommendation requires future study because the efficiency of oil extraction yield was affected by several factors. The relationship between extracted oil and water content revealed the function of moisture content. Changes in the
kernels’ soluble solid concentration during the life of the fruit indicated low oil synthesis during the ripe stage but increased during senescence. The pH value of kernels at any maturity stage was between pH six and seven indicating the presence of low ionic value in the sample. Percentage of free fatty acids at any maturity stage in this study was below two percent which indicates the benefit of only requiring esterification during biodiesel processing. Respiratory study indicated jatropha fruits as climacteric fruits with up surge in production of carbon dioxide during off-tree fruit ripening. This study suggests future studies on the effect of several handling practices such as the effect of drying prior to oil extraction and extracted oil yield from off-tree ripe and senesced fruits. The handling practices may influence the oil extraction yield.
CHAPTER 6

STUDY ON THE EFFECT OF SELECTED POSTHARVEST HANDLING PRACTICES ON OIL EXTRACTION YIELD

Introduction

Crude jatropha oil (CJO) is a main product of jatropha crop which is claim as the ideal feedstock for biodiesel fuel. Mechanical extraction methods is a commercial method to extract crude jatropha oil while chemical extraction methods in not commonly used. Results from previous study in Chapter 5 show that the dry fruit confirmed having high chemically extracted CJO. The result was in agreement with several reports recommending this stage as the harvesting indicator (Heller (1996), Wiesenhutter (2003), Hambali et al. (2007) and Annarao et al. (2008)). On the other hand, the results contradicted with other reports showing earlier maturation as containing the highest oil content (Santoso 2008 and Wanita and Hartono 2006).

Obviously, the data of previous study indicated several factors contributing to the oil extraction efficiency such as the moisture content and sample conditions. The factors are implied due to variability in postharvest handling practices prior to extraction.

Drying was implied to have an effect on extractable oil yield because an effect of moisture content has been indicated earlier in Chapter 5. Previous respiration tests have also indicated the possibility for harvested mature green fruits to ripen off the tree. However, an effect of those off-tree ripening and senescence on extracted oil yield was unknown. It is important to know if the off-tree ripened fruit will give similar extracted oil yield as those on-tree ripened because harvesting mature green fruit has the benefit of cost reduction for harvesting. Therefore, experiments in this chapter were designed to compare selected postharvest handling practices, including the effect of off-tree ripening, drying and extraction methods on extractable oil yield.
Materials and methods

Test sample for study on effects of drying and extraction methods on oil yield

For this study jatropha fruits were brought from the main sample source described in Chapter 3. The fruits at identified fruit maturity stages as described in Chapter 5 were harvested early morning and transported to the Laboratory of the School of Sustainable Agriculture, Universiti Malaysia Sabah within three hours on an open air transport for further analysis. Upon arrival at the laboratory, the fruit coats were carefully removed to get only seeds. The seeds were dried under the sun for three days. The character of moisture content and drying time for different drying conditions were documented in this study. Appendix 13 shows the drying rate character of jatropha seed during different drying conditions documented at Bogor Agricultural University. After being dried, the shells of the seeds were carefully removed to obtain only kernels. Subsequently, the kernels were crushed with a kitchen blender for about 10 – 15 seconds. The oil was extracted using chemicals with soxhlet technique as described at Chapter 3 and mechanically with a modified hydraulic presser (MHP) as described in Chapter 3 and the oil percentage was calculated as described in Chapter 3. Fresh samples were not dried but were directly prepared for extraction within 12 hours after harvest.

Test sample for study on sample conditions effect on extracted oil yield

Only ripe yellow jatropha fruits were used in this study. The fruits were from the main sample source described in Chapter 3. Four types of sample conditions were prepared for this study i.e. whole seeds, crushed seeds, whole kernels and crushed kernels. The Crushed sample was prepared by using a kitchen blender. The oil was then extracted using the MHP as described in Chapter 3 and the percentage of extracted oil was calculated as described in Chapter 3.
Test sample for study on MHP handling effects on extracted oil yield

The sample for this study was similar to the preparation of the sample for the above study on sample conditions’ effect on extracted oil yield. Best handling practices from the previous study in this Chapter was applied prior to extraction and the percentage of extracted oil was calculated as described in Chapter 3.

Test sample for study on effect of off-tree ripening and senescence on oil extraction yield, SSC and firmness

Jatropha fruits for this study were brought from the main sample source described in Chapter 3. Identified physiological mature fruits were harvested early in the morning and transported to the laboratory of the School of Sustainable Agriculture, Universiti Malaysia Sabah within three hours on open air transport for further handling. The harvested mature green fruits were late to ripen and senesce naturally at room temperature (28.5±3°C). More than 50% of the samples were ripe after three days in storage and almost 85% were senescence after five days of storage. Six different samples were prepared in this study from three maturity stages, mature, ripe and senescence, and ripened and senescence on or off the tree. The six samples were prepared using the best handling practices from previous experiments in this chapter. The soxhlet technique was used for chemical extraction as described in Chapter 3 but has been previously prepared in best handling practices from the result of the study in this Chapter. Percentage of extracted oil was calculated as described in Chapter 3. Test sample for soluble solid concentration (SSC) and firmness was from fresh samples of the six samples. The SSC and firmness of the samples were measured as described in Chapter 3.
Results and Discussion

Effect of drying and extraction methods on extracted oil yield

The results showed significant effects of drying and extraction methods on oil extraction yield (Figure 20). Irrespective of extraction methods, drying prior to extraction resulted in high extracted oil yield. The percentage of extracted oil yield between ripe, black and dry kernel fruit was not significantly different when samples were dried before extraction with either chemicals or mechanically. However, extracted oil yield with the chemical method was significantly higher compared to the mechanical extraction method. Only about 40% of oil was extracted with mechanical extraction from dried ripe, black and dry kernel fruits but about 49% was extracted using the chemical extraction method on similar samples. The extracted oil yield from fresh samples was significantly low irrespective of extraction method and maturity stage. Obviously, no oil was extracted from fresh immature, mature, and ripe kernel fruits with mechanical extraction. Results of this study showed that water content plays an important role in the extraction efficiency especially when using the mechanical extraction method. The moisture content of the fresh samples was 80, 62, 37, 29 and 12% in immature, mature, ripe, black senesced and dry senesced fruits respectively (Figure 13).

Moisture content was reported to be the most important factor affecting cake residual and oil content. A moisture content of 6% was reported to be the optimum for hydraulic pressing of sunflower seeds (Sing et al. 1984). Further reduction in moisture content (4.1%) was not beneficial and resulted in more sediment in the screw-pressed uncooked crumbed seed (Vergas-Lopez et al. 1999). The high moisture content was reported to increase plasticity and thereby reduced the level of compression resulting in poor oil recovery. The high moisture content was also reported to act as a lubricant in the barrel resulting in insufficient friction during pressing (Ruber 1992). However, the most suitable moisture content for optimum jatropha seed oil extraction is not reported in literature. Drying is a process to remove sample moisture content up to a specific level to reduce the rate of deterioration due
to biological or chemical factors (Hall, 1957). The characteristics of moisture release during drying were documented in detail by Henderson et al. (1997), Henderson and Perry (1976) and Brooker et al. (1992). According to Brooker et al. (1992) the drying efficiency was not only dependent on the drying temperature and relative humidity in the drier but also depends on the natural physic-chemical characteristics of the product.

Figure 20 Percentage of extracted crude *J. curcas* L. Luanti accession oil (w.b) using two extraction methods namely chemical with soxhlet technique (Chem) and mechanical with modified hydraulic presser (MHP) from fresh (n=20) and dried kernels (n=25) at different maturity stages. Vertical bars indicate the error bar from measurements at 5%.

Results of the effect of extraction methods in this study showed the real value of extracted oil yield. For commercial crude jatropha oil production, mechanical extraction method is used. Chemical extraction method is normally used at laboratory scale. Thus, improving extraction efficiency with mechanical extraction method should be the focus of future study. Samples might contain high oil content but cannot be extracted mechanically. Based on this study drying the samples has been
recommended prior to extraction and this is in agreement with similar recommendations by Tobin and Fulford (2005).

High oil extraction yield from dried ripe, black and dry kernel fruit in this study was not significantly different but significantly low in immature and mature fruit kernels (Figure 20). These indicate loss of biomass and thus harvesting at those maturity stages should be avoided. The data showed high potential loss in the immature fruit which only produced 5% of extracted oil compared to about 31% in mature fruit kernels. There is about seven to eight percent difference in extracted oil yield between mature and the group of ripe, black and senescence fruits. This implied that off-tree harvested mature green fruit could have similar extracted oil yield as the on-tree ripe and senescence fruits. Review of literature has revealed that no research has been conducted on the effect of off-tree fruit ripening and senescence on extracted oil yield in jatropha.

Similar extracted oil yield from kernels of on-tree ripened and senescence fruit in this study also indicate the need to review the harvesting time recommendation. This study recommends ripe, black and dry fruit as the harvesting index because the oil extraction yield was similar irrespective of extraction methods but requires drying prior to extraction. Thus, this study disagrees with many of the harvesting times recommended by previous researchers (Appendix 9). Harvesting both ripe and senescence fruit will increase harvesting volume in a single harvesting visit. More harvesting volume is expected if mature green fruit is harvested. Thus, the study on off-tree ripening and senescence of harvested mature green jatropha is important.

**Effect of sample conditions on extracted oil yield**

The results show that sample conditions affect oil extraction yield (Figure 21). Crushed kernels have significantly higher extracted oil yield followed by uncrushed kernels, crushed seeds and uncrushed seed. This suggests recommending the requirement to use kernels and the need for it to be crushed prior to mechanical
extraction. If seeds are to be used, crushing before extraction is recommended. Using whole uncrushed seeds should be avoided because it significantly reduces the amount of extracted oil. The hardness of the shells limited the capability of the MHP to press the oil from the kernels. It is well known that oil bodies in plant are trapped in the meshwork of protein and cellulose or hemicelluloses structure (Shah et al. 2004). The firmness of seed shells was 3 – 4 times harder than kernels at any maturity stage (Table 4). The results indicate that removing the shells prior to extraction is necessary but the shells might be beneficial during seed storage. This requires further investigation.

Figure 21 Effect of sample conditions on extracted crude jatropha oil (CJO) with mechanical extraction using a modified hydraulic presser. Vertical bars indicate the error bar of measurements at 5% (n=80).

**Effect of MHP handling on extracted oil yield**

Percentage of extracted oil yield using the modified hydraulic presser (MHP) was significantly affected by heating temperature, preheating duration and pressing duration (Figure 22). Heating temperature of 50, 60 and 80 °C showed no significant difference in extracted oil yield with an average of about 35% but significantly low
extracted oil yield of only about 32% when depending on an ambient temperature. These indicate 50°C as the minimum heating temperature. Preheating time of 10, 20, 30 and 60 minutes was not significantly different with average extracted oil yield of about 35% but significant low oil yield was experienced when using only 5 minutes, with an average extracted oil yield of only about 20%. This indicates 10 minutes as the minimum preheating time. Increase in pressing time showed increase in extracted oil yield. The plateau was not reached even after 40 minutes of pressing. This indicated requirement for further tests on the aspect of handling.

The results of this study revealed that using crushed kernels, 50°C heating temperature, 10 minutes preheating time and more than 40 minutes pressing time increased extracted oil yields. Pretreatment of seeds such as cooking increased oil yield of screw press by up to 81% after a single press and 91% after dual press (Beerens 2007). Sudrajat et al. (2006) reported his study on the effect of boiling jatropha seed on oil quality. They found that the treatment increased oil extraction yield. However, Sirisomboon and Kitchaiya (2009) reported that high heat treatment prior to extraction will increase oil extraction yield but also increase acid value and oleic acid content.
Extracted oil yield from off-tree ripe and senescence fruits

The percentage of extracted oil yield for on-tree and off-tree ripened fruit kernels were compared. The results showed that extracted oil yield from off-tree ripe and senescence fruit kernels was significantly higher compared to the on the tree ripe and senescence fruit kernels (Figure 23). The percentage of oil extracted from off-tree ripe and senescence fruit kernels were about 59 and 65% compared to only 50 and 8% in on-tree ripe and senescence fruit kernels. Results of this study indicated several benefits of harvesting physiologically mature fruit - increased amount of extracted oil yield and increase in harvesting volume in a single visit. Thus, this study recommends harvesting physiological mature green jatropha fruits and for the third time in this dissertation the harvesting recommendation was reviewed.

Figure 23  Difference in percentage of extracted oil yield (w.b) between on-tree (n=12) and off-tree (n=10) ripening and senescence of *J. curcas* L. Luanti accession fruits. MG= mature green. Vertical bars indicate the error bar of measurements at 5%.
Early work on the oil content in Chapter 5 recommended that the best harvesting time is when fruits are dry. Following work on the extracted oil yield in this Chapter recommends ripe, black and senescence fruit as the harvesting index. Significant, harvestable volumes are expected when physiological mature green fruits are harvested with those advanced in maturity stage. As a result, harvesting cost is implied to be reduced. Future studies on the cost benefits of this finding should be conducted before recommending this new finding. The new recommendation may lead to additional postharvest handling costs such as selection of mature green fruits after harvest and might lead to delay in further handling due to ripening treatment. Harvesting high moisture content seeds could also lead to increase in drying costs, as indicated by Wright and Steele (1979). Therefore, further research is indeed.

Ability of harvested physiologically mature fruits to ripen off the tree was expected because earlier study has indicated that this fruit shows climacteric class characteristics based on its respiratory pattern (Figure 19) and color changes during on-tree ripening (Chapter 5). However, significant high extracted oil yield from off-tree ripe and senescence fruit was not expected. The lipid synthesis may be accumulated without utilization in the off the tree ripened and senesced fruit while utilization of accumulated lipid in fruits that ripened and senesced on the tree might occur. Utilization of reserved lipid for seed germination has been reported by Eastmond and Rawsthorne (2000). Different conditions for on and off-tree ripening and senescence has been highlighted by Wills et al. (1989). Wills and his co-worker cited that development and maturation of fruits is completed only when it is attached to the plant, but ripening and senescence may proceed on or off the plant.

Changes in SSC during off-tree ripening and senescence

Soluble solid concentration (SSC) in off-tree ripe and senescence fruits was significantly different when compared to SSC in on-tree ripe and senescence fruit (Figure 24). SSC on the off-tree ripe and senescence fruit kernels decreased when ripe but increased when senescent. There was no increase in SSC from ripening to
senescence in on-tree ripe and senescence fruit kernels. Increase in SSC from off-tree senescence fruit could indicate that the seeds are ready to germinate. However, the lipid oxidation to sugar in this study might not have reached the point where oil extraction yield is affected as yet. It is important to note that seed germination in off-tree senescence fruit was observed during prolonged storage. The wet condition resulting from senescence fruit coats might provide a favourable condition for seed germination. The occurrence of seed germination on the ripe on the tree fruit seed is only observed during the rainy season. Thus, future study is important to confirm this argument.

Figure 24 Percentage of soluble solid concentration (SSC) during off tree ripening and senescence of *J. curcas* L. Luanti accession kernels. Vertical bars indicate the error bar of measurements at 5%.

Massive accumulation of starch, protein and lipid during seed maturation is a natural occurrence and widely reported. The accumulation is the most critical phase in higher plants to ensure a sustainable life cycle. The designated accumulation may be metabolic processes responding to prevailing environmental conditions so that the seed can grow (Holdsworth, Kurup, and McKibbin, 1999). Production of sugar as fuel for seed growth and development in off the tree ripened and senesced fruit seeds in this study could not be from fruit coats (Figure 14) but from oxidation of reserved
lipid in the kernels as reported by Kornberg and Beevers, (1957) in the case of castor bean. This argument is supported by data on the percentage of soluble solid concentration obtained in this study (Figure 24).

**Changes in firmness during off-tree fruit ripening and senescence**

The kernels’ firmness significantly changed during on-tree fruit ripening and senescence but there were no significant changes in the off-tree fruit ripening and senescence samples (Figure 25). The hardness of the off-tree kernels was around 8 N but kernel harness of on-tree kernels increased from around 8 N during mature green stage to 12 N when ripe. Results of this study showed low energy requirement to press samples of off-tree ripen and senescence fruit compared to the on-tree sample. This character increases the advantage of the off-tree sample because high extracted oil yield with the mechanical oil presser is expected. The difference in firmness could be due to difference in the degree of dehydration. According to Keys (1991), texture of the fruit is affected by degree of dehydration, composition of cell walls and cellular constituents.

![Graph showing firmness changes](image-url)

**Figure 25** The Kernels’ firmness (N) changes during on and off-tree fruit ripening and senescence of *J. curcas* L. Luanti accession kernels. Vertical bars indicate the standard error of measurements (n=30).
Conclusion

This study confirmed several effects of postharvest handling practices on oil extraction yield. Chemical extraction methods showed high extracted oil yield but the mechanical extraction method revealed the expected because crude jatropha oil is produced commercially using this method. It confirmed the positive effect of drying the sample to increase oil extraction yield. To increase extraction efficiency with the modified hydraulic presser, specific handling practices were recommended. Prior to extraction, samples should be crushed as crushed kernels resulted in higher extracted oil yield compared with non-crushed or using seed samples. Preheating temperatures, preheating time and pressing duration was best at 50°C, 10 minutes and longer time to press, respectively. Significant high chemically extracted oil yield was recorded from off-tree ripened fruit compared with the on-tree ripened sample. The new finding implies requires further investigation. The success of this new finding depends on the success in harvesting physiologically mature green fruits. The harvesting indicator will be discussed in the next chapter.
2. Diakses menugaskan don menurunkan sedang terebut dan seluruh kejadian lalu ini dalam bentuk opuson tampak lain.
3. Penduduk lembu merasakan keperluan yang waktu terutama.
4. Penduduk kanya dengan keperluan penduduk, penduduk, penduduk karya limith, perusahaan logorr, pensiunan logorr, pensiunan karya limith, don menyediakan don menyediakan.
CHAPTER 7
STUDY ON HARVESTING CONSIDERATIONS IN JATROPHA

Introduction

Previous study in Chapter 4 argue that main reason of poor harvesting in this crop is actually due to variability in the reproductive variables. After study the oil content (Chapter 5) and effect of postharvest handling (Chapter 6) to extractable oil yield, three harvestable groups of individual jatropha fruits has been recommended in this dissertation. Recommended harvestable fruit group one is dry fruit only because according to the results in previous study, the fresh kernels from this fruit has the highest extracted oil yield (Figure 16). Recommended harvestable fruit group two is a mixture of ripe, black and dry fruits. This group of fruits if dried prior to extraction showed similar extracted oil yield (Figure 20). Recommended harvestable fruit group three is a mixture of mature, ripe, black and dry fruits. This third recommendation was based on the previous study in Chapter 6. The mature green was included because the fruits, if ripe and senescent off the tree will give significantly higher extracted oil yield (Figure 23).

The harvestable fruit number three recommended has an advantage when compared with the other recommended harvestable fruit groups because harvesting physiological mature green fruits could increase harvestable fruit volume and directly decrease the number of harvesting visits required. However, the advantages of the harvestable fruit group number three are implied depending on the capability of harvesters to pick the right physiological mature green fruits in the field. Therefore, one the objectives in this chapter is to determine the individual fruits’ and bunches’ harvesting indicators. To indicate a specific big harvest in a year, the experiment was designed to monitor the trend of the harvestable groups throughout the year 2010. The character of fall fruit was also determined to indicate the effect of delay on harvesting on percentage of fall fruits. It was implied that harvesting in a jatropha plantation could be scheduled and thus directly reduce harvesting costs.
Materials and Methods

Source of jatropha fruits and trees

The sources of jatropha fruits and trees for this study were from the main sample source described in Chapter 3.

Test sample for study on individual fruit harvesting characteristics

Three individual fruits were harvested for characterization for this experiment. These included small sized immature young light green fruits, full sized mature dark green fruits and mature green with trace of yellow. Results from previous study on the fruit size (Table 2) were used when determining the normal size of mature fruits. Not less than a hundred fruits of each predetermined fruit group were harvested randomly from different trees in the plot and were left to ripen naturally without any ripening agent under room temperature (28.5±3°C). Ripening percentages were measured every 6, 12, 24, 36 and 114 hours after harvest.

Test samples for study on fruit bunches’ harvesting characteristics

Five fruit bunches’ characteristics were predetermined for the bunch harvest indicator study. For each bunch this included (1) 100% of fruits still mature green, (2) more than 80% of fruits still green, (3) 70 – 80% of fruits still green, (4) 50 - 70% of fruits still green and (5) less than 50% of fruits still green. Not less than a hundred fruits of each predetermined fruit bunch type were harvested randomly from different trees in the plot and were left to ripen naturally without any ripening agent under room temperature (28.5±3°C). Ripening percentages were measured every 6, 12, 24, 36 and 114 hours after harvest. Ripening percentages were measured as described in Chapter 3.
**Test samples for study on fall fruit on the farm**

Twenty five fruit bunches which had at least eight fruits per bunch and at least one fruit at yellow maturity stage. The samples were randomly selected in the pilot. The number of fall fruits was measured every three days for 60 days.

**Test sample for study on oil extracted yield from non-fall fruits**

During the dry season in the pilot plot, several levels of dry fruit bunches still attached to the parent plant from bottom to tip of any main branches were observed. These non-fall fruits were collected for oil extraction yield analysis according to their level of attachment on the branch. Five levels of bunch attachment were identified and the fruits collected for this study. Preparation of the samples prior to oil extraction analysis was based on previous study in Chapter 6.

**Test sample for study on harvestable fruit production**

Ten trees were randomly selected in the pilot project for this study. Total fruits according to maturity stage were measured every month throughout the year in 2010. The fruit maturity stages were the general five fruit maturity index as described in Chapter 3. The total fruits measured were then grouped into predetermined harvestable groups. The harvestable groups of fruits were only dry fruits (harvestable group one), dry and yellow fruits (harvestable group two) and dry, yellow and mature green fruits (harvestable group three).

**Measurement of ripening percentages**

The ripening percentage was measured according to the method described in Chapter 3.
**Measurement of fall fruit percentages**

The percentage of fall fruit was measured by dividing the total available fruits during observation day with total fruits number during first day of observation and then multiplied by hundred.

**Measurement of CJO content**

The CJO content was analyzed chemically according to the method described in Chapter 3 and the CJO percentage calculated according to the calculation described in Chapter 3.

**Experimental design and statistical analysis**

Experimental design of all four studies in this chapter is indicated from explanation of each test sample in study. Randomized complete design was the experimental design for all experiments with each having two sources of variance while there was only one source of variance in the study on harvestable fruit production. Data collected was analyzed using one way ANOVA and the differences between means were calculated from the error bar at 5%.

**Results and Discussion**

**Harvesting indicator for individual jatropha fruits**

The results showed that the harvested mature green with trace of yellow fruits have higher ripening percentage compared to harvested mature green and immature fruits after 24 hours of storage (Table 5). The ripening percentage in the harvested mature green with trace of yellow fruit was 91% compared to only 5 and 25% from harvested immature and mature green fruits respectively. The harvested mature green with trace of yellow fruit also showed 100% senescence after final day of...
observation. The senescence percentage from harvested immature and mature green fruits during the final days of observation was only 10 and 65% respectively. These results indicate harvested mature green with trace of yellow fruit as the best individual fruit harvesting indicator.

Percentage of unripe fruits from harvested immature green fruits were still more than 80% during the final days in storage compared to less than 40% among the harvested mature green fruits. These results could indicate a difficulty in differentiating between immature and mature fruits with the naked eyes during harvesting. This problem has been projected earlier while analyzing previous data on fruit color in Chapter 5. The previous data showed that the difference in color hue angle value between immature and mature fruits was not significantly different. The previous data was also showed that other physical characters observed in the study, such as size, firmness and fresh weight were also not significantly different between harvested immature green and mature green fruits.

Table 5 Changes in the percentage of unripe, ripe and senescent fruits between harvested immature, mature green and mature green with trace of yellow *J. curcas* L. Luanti accession fruits during storage.

<table>
<thead>
<tr>
<th>Ripening Storage (hours)</th>
<th>Immature</th>
<th>Mature Green</th>
<th>Trace of Yellow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unripe (%)</td>
<td>Ripe (%)</td>
<td>Senescent (%)</td>
</tr>
<tr>
<td>0</td>
<td>100a</td>
<td>0c</td>
<td>0b</td>
</tr>
<tr>
<td>6</td>
<td>100a</td>
<td>0c</td>
<td>0b</td>
</tr>
<tr>
<td>24</td>
<td>95a</td>
<td>5b</td>
<td>0b</td>
</tr>
<tr>
<td>36</td>
<td>90ab</td>
<td>10a</td>
<td>0b</td>
</tr>
<tr>
<td>114</td>
<td>85a</td>
<td>5a</td>
<td>10a</td>
</tr>
</tbody>
</table>

* = significant at p<0.05
y = different letters within a row denote significant difference by using DMRT at p<0.05

High percentage of unripe fruits among the harvested immature fruits was expected because it has been long known that harvested fruits which have not reached development and maturation stage as yet will not ripen off the tree (Wills et al. 1989). The research team confirmed that development and maturation of fruit was completed only when attached to the plant, but ripening and senescence may proceed on or off
the plant. The percentages of ripe and senescent fruits among the mature fruits were considerably higher as compared to the immature fruit. This indicates potential to improve the percentage through several ripening enhancers. However, there is limited information related to such treatment in the reference list on jatropha.

Harvesting indicator for jatropha fruit bunches

The results showed that increasing number of ripe individual fruits per bunch will hasten the ripening and senescence process (Table 6). Harvested bunch with 100% green character showed high percentage of unripe fruits at the final day of storage. The other harvested bunches’ characters had no unripe fruits after three or four days of storage. These results indicate maximum 80% green fruits per bunch as the best bunch harvesting indicator for jatropha. The 80% green fruits per bunch are equal to minimum 10 to 20% of ripe yellow fruits per bunch. So if there are one or two individual ripe yellow fruits per bunch from ten fruits per bunch, this bunch is recommended to be harvested. As the numbers of fruits per bunch are not uniform, (Figure 18) interpretation on the percentage should be modified accordingly.

Recommendation of bunch harvesting indicator in this study was not in agreement with any previous bunch harvesting recommendation. Priyanto (2007) recommended harvesting bunches when 75% of the fruits are ripe. Nurchholis and Sumarsih (2007) suggested when 60-70% was ripe while Hambali et al. (2008) recommended harvesting when 50% are ripe. The suggested bunch harvesting indicator in this study implies increased harvesting volume in a single harvesting visit and directly decreases the number of harvesting visits required.

Potential to harvest bunches with 100% green fruits were shown in this experiment. The balance of 35% unripe fruits at the final day of observation could be ripened by extending the ripening storage duration. The ripening percentages could also be higher if a ripening enhancer is introduced. As there is no information related to the effect of ripening treatments on this crop, future experiments are suggested. The harvesting volume per harvesting visit will be higher if the 100% mature green
fruit bunches are to be harvested. The effects of several ripening enhancers are reported in Chapter 8 in this dissertation.

Table 6 A change in percentage of ripe, unripe and senescent fruits from harvested five different fruit bunch characters during storage.

<table>
<thead>
<tr>
<th>Fruits bunch characters</th>
<th>Maturity Stages</th>
<th>Storage Duration (days)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>100% Green</td>
<td>Unripe (%)</td>
<td>100a</td>
<td>92a</td>
</tr>
<tr>
<td></td>
<td>Ripe (%)</td>
<td>0e</td>
<td>8d</td>
</tr>
<tr>
<td></td>
<td>Senescent (%)</td>
<td>0d</td>
<td>0d</td>
</tr>
<tr>
<td>&gt;80% Green</td>
<td>Unripe (%)</td>
<td>84a</td>
<td>32b</td>
</tr>
<tr>
<td></td>
<td>Ripe (%)</td>
<td>16d</td>
<td>68b</td>
</tr>
<tr>
<td></td>
<td>Senescent (%)</td>
<td>0e</td>
<td>0e</td>
</tr>
<tr>
<td>70-80% Green</td>
<td>Unripe (%)</td>
<td>70a</td>
<td>16b</td>
</tr>
<tr>
<td></td>
<td>Ripe (%)</td>
<td>30d</td>
<td>79ab</td>
</tr>
<tr>
<td></td>
<td>Senescent (%)</td>
<td>0f</td>
<td>4e</td>
</tr>
<tr>
<td>50-70% Green</td>
<td>Unripe (%)</td>
<td>56a</td>
<td>16b</td>
</tr>
<tr>
<td></td>
<td>Ripe (%)</td>
<td>44d</td>
<td>75ab</td>
</tr>
<tr>
<td></td>
<td>Senescent (%)</td>
<td>0f</td>
<td>9e</td>
</tr>
<tr>
<td>&lt;50% Green</td>
<td>Unripe (%)</td>
<td>43a</td>
<td>8b</td>
</tr>
<tr>
<td></td>
<td>Ripe (%)</td>
<td>57c</td>
<td>90a</td>
</tr>
<tr>
<td></td>
<td>Senescent (%)</td>
<td>0e</td>
<td>2d</td>
</tr>
</tbody>
</table>

* = significant at p<0.05
\( \gamma \) = different letters within a row denote significant difference by using DMRT at p<0.05

**Harvestable fruit production throughout the year**

Jatropha planted in the pilot project was fruiting throughout the year in 2010 (Figure 26). Irrespective of harvestable fruit group, the results showed three maximum and minimum harvestable fruits per year. The maximum was in March, August and December while the minimum was in January, May and October. High percentage of fruits from harvestable group C was expected because it included the mature green fruits. There were no mature green fruits in harvestable group A and B. Low percentage of fruits in the harvestable group A was due to only harvesting dry fruits. Results of this study confirm a suggestion by Carels (2009) to have three harvesting times in a year for jatropha. The researcher implied that because flowering
and fruiting in jatropha occurred four times a year the harvesting should be done three times a year.

![Graph showing trends of immature and harvestable groups](image)

Figure 26 Trends of immature and harvestable groups (harvestable fruits A = dry fruits, harvestable fruits B = dry fruits + ripe fruits and harvestable fruits C = dry fruits + ripe fruits + mature green fruits) of *J. curcas* L. Luanti accession fruits planted at Luanti Baru Village, Keningau, Sabah, Malaysia.

The percentage of harvestable fruits in this study should be converted to real fruit production and this can be done by adopting the fruit production data shown in Figure 7. The fruit production data showed that the peak of fruit production is in June and July (Figure 7). By adopting the information from this harvestable group data, peak production is indicated to be in July. The amount of fruits was similar in June and July but due to the high number of immature fruits in June and low such numbers in July, thus peak harvesting is confirmed to be in July. The percentage of immature fruits in June and July was 50 and 20% respectively. Lowest immature fruit
percentage was actually in August but because the total fruit in that month was significantly lower compared with that in July, thus August was not the month with high volume of harvestable fruits.

Obviously, low percentage of immature fruits could not indicate optimum harvesting volume and this indicated that mechanical harvesting could become more challenging. Reduction in total fruits from July to September was observed due to natural occurrence of fall fruits. Thus it indicates the importance of understanding the occurrence and to recommend minimum delay in harvesting to reduce loss of fruits due to fall fruits. The following subsection in this chapter is the result of observation of the occurrence.

**Fall fruits during delay in harvesting**

The results showed a logarithmic trend ($R^2=0.94$) in fall fruits with delay in harvesting (Figure 27). Delay of 1, 2, 3 and 4 weeks will cause about 38, 45, 55 and 70% of fall fruits respectively. After two months delay in harvesting, about 95% of fruits fall and this is the plateau of the occurrence. Results of this study highlighted the importance of reducing delay in harvesting. This result was also not agreement with the three harvesting times per year recommended by Carels (2009) for this crop.

Fall fruits which normally occur during senescence phase indicate the limit of minimum delay in harvesting for this crop. Study in Chapter 4 showed that number of days required to reach wet black senescence from fruit set was 34 days on average (Table 1). However, only about 6 days on average was recorded to reach wet black senescence from mature green stage. Thus this study indicates that first harvest after first flowering should be done after 34 days and about 6 days is suggested as the interval harvesting visit time after first flowering to avoid falling fruits. Maximum and minimum days required by fruit at mature green maturity stage to reach black senescent maturity stage was 9 and 3 days respectively (Table 1).
As increase in the percentage of fall fruits increased with delay in harvesting and most of the occurrences were during the wet black senescence stage, the findings from this study are not in agreement with the recommendation of harvesting at dry senescence stage (Appendix 9). This study implies that if the senesced fruits did not fall for a period of time then the harvesting visit could be delayed for that period of time. This approach is suggested as an important selection character to reduce harvesting problems in this crop. However, there is limited information on this characteristic in literature and thus future research is suggested.

The percentage of fall fruit in this study was seen to be very much affected by the agro-climate especially rainfall and wind. All organisms will eventually die
(Kivillan and Bandurski 1981) as with the jatropha fruit. Environmental and other factors that accelerate senescence and abscission (e.g. mineral deficiency, drought, low light and lack of pollination) have been well documented (Keys 1991). During the dry season at the plot, up to five levels of dry fruit bunches were still attached on the same branch. However, only one, two or three levels of dry fruits bunch were still attached on the same branch during normal or rainy season. The related important question on this character will be the extracted oil yields from different levels of dry fruit bunch development in the same tree. The following subsection in this chapter discusses the extracted oil yield. Realistically, occurrence of fall fruit is a natural process. This is called abscission and it is seen as an effort by the jatropha tree to remove senescent fruits.

**Extracted oil yield from non-fall fruits**

Interestingly, the extracted oil yield from the different fruits bunches from the same branch were significantly different (Figure 28). The extracted oil yield (chemical extraction), was significantly high in fruit bunch number two from bottom, at about 60% compared to only about 55% from the other bunches. The highest oil yield observed in this case is identical to similar extraction of those ripened off the tree. This result indicates the benefit of harvesting during the dry season.

High extracted oil yield in this sample was expected because the collection of samples for this experiment was during the dry season. High extracted oil yield was also reported by Santoso (2008) during the dry season compared to during the wet season. No reason was found in the present literature on why high oil content does during dry season. The reason could be due to changes on the oil body during dry season. The oil body which is mostly coated with a protein derivative such as olesin could be in inactive condition so that oil becomes easily released during extraction.

On the other hand, extracted oil yield from this study showed the benefit of having multiple dry fruit bunches that were still attached on the tree. However, due to the
The mechanism of abscission-disperse in *J. curcas* L. fruit and seed implied that it does not follow the normal seed dispersal method of other legume crops. The separation between fruit and seed was seen to be not completed and this implies that there is potential to use this character as selection criteria of jatropha accession. In general, the occurrence was reported to be a species-dependent mechanism (Addicott 1982). Jatropha accession without this character will give the benefit of low risk of seed loss during delay in harvesting. However, there is limited information on the character in jatropha cited in the literature list.

**Extracted oil yield from fall fruits**

Extracted oil yield for fall fruits was significantly lower compared with the off-tree senescence and on-tree dry fruits (Figure 29). Extracted oil yield from fall fruits was only about 40% compared to about 50% and 60% from off-tree senescence and on-tree dry fruits respectively. This result indicates the disadvantage of fall fruits and why they should be avoided. Reduction in extracted oil yield was expected as the
fall seeds are preparing for germination. The oil might be converted to chemicals required for the germination processes (Kornberg and Beevers 1957).

![Figure 29](image_url) The percentages of extracted oil yield (w.b) from different harvested fruit conditions (off-tree senescence (n=3), on-tree dry (n=5) and fall fruits (n=2)). Verticals bars indicate the error bar of measurements at 5%.

Low extracted oil yield from fall fruit in this study could also be due to the variation in samples. Most of the collected seed might already have fallen for a certain period of time and the fruits might be from wet black senescence or from dry senescent fruit. There may be different extracted oil yields according to prolonged duration of fall, variation of sample conditions and environmental conditions enhancing the occurrence. For example, results from a previous experiment in this chapter showed variations in the extracted oil yield from different dry samples from the same branch. This indicates the requirement for future research to identify the rate of oil content reduction during wide post falling occurrences. The information is important to provide an alternative to solve the problem related to the unavoidable fall fruits in this crop. If the rate of reduction is low than harvesting visits could be
reduced. Calculation of harvesting costs between reductions in oil content should compare picking costs for economic viability decision making.

Hand picking of fall fruit and seed as harvesting approaches for this crop was proposed when the basic mechanical harvester are not available (Henning 2003). The approach is by hitting the dry fruit with a stick. The picker then has to collect the fall fruit. The report implied that the best way to harvest jatropha fruits is by using a long wooden stick with a circular comb with a cotton bag at one end. With this tool the dry fruits can be picked from the trees, the fruits fall into the bag and do not have to be collected on the ground. However, the picking cost for jatropha is high and thus several mechanical harvesting techniques have been reported. Placing a net under the fruit tree is commonly used for many fruits such as olive, mango and durian. Many shake-and-catch systems for processing apples have been evaluated (Markwardt et al. 1969). Besides manual shaking, chemical desiccation was reported as an alternative harvesting method in rapeseed (Pouzet, 1995) and cuphea (Johnson et al. 2005). According to Bowerman (1984) it can be a way of limiting seed loss and improving seed quality. A Jatropha harvester called OxboKorvan 900 which is based on blueberry harvesting technology could be the only jatropha mechanical harvester available but no scientific data has been reported on its efficiency. Thus, future research on harvesting technology for this crop is needed.

**Conclusion**

The study has identified individual and fruit bunch harvesting indicators for jatropha. Individual fruit character of mature green with trace of yellow was recommended as the individual harvesting indicator. Fruit bunch harvesting indicator was those bunches that has maximum 80% of fruits that were still green in color while the others were advancing in maturity as either yellow ripe or senescent. The trend of harvestable fruit production throughout the year confirms three big harvesting times in a year. Those are in March, August and December. However,
the data on fall fruit during delay in harvesting suggests that the harvesting times should be repeated within 6 and 17 days to avoid fall fruits. Increase in fall fruits percentage was a function of time and was best described as a logarithmic trend ($R^2=0.94$). The fall trend showed a plateau after about two months of observation indicating occurrences of multiple dry fruit bunches in the same branch. The occurrence was easily observed during the dry season. The extracted oil yield from up to five different levels of dry fruit bunches from the same branch was found to be almost uniform at about 55% except for the samples from the second from bottom of the branch which has about 60% yield. However, the extracted oil yield from fall fruits was found to be significantly low at only about 40%. The disadvantage of fall fruit in this study suggests that the harvesting visits could be prolonged if 100% mature green fruits can ripen off the tree. Thus, the following chapter in this dissertation will discuss the potential of several ripening enhancers for harvested mature green jatropha fruits.
Bogor Agricultural University

Hak cipta milik IPB (Institut Pertanian Bogor)
CHAPTER 8

STUDY ON ENHANCING FRUIT RIPENING
OF HARVESTED MATURE GREEN JATROPHA

Introduction

Mature green jatropha has been recommended to be harvested along with those fruits that are advanced in maturity such as ripe and senescence fruits, to increase harvestable volume and indirectly reduce harvesting visits and reduce harvesting costs. Several other reasons gained from previous experiments in this study have also strengthened the argument to harvest mature green fruits. One of the most important findings was the quantity of extracted crude jatropha oil from off-tree ripened and senescence fruits which was significantly higher as compared to yield from those ripe and senescence on the tree (Chapter 6). In addition, the harvested mature green was also found to ripen naturally off the tree without any ripening enhancers (Chapter 7). However, the ripening percentage and ripening rate was found to be low and slower rate as when it is left to ripen naturally under ambient temperature.

It was a great hope that the ripening of harvested fruit could be uniform so that future handling processes can be scheduled and there is no occurrence of germination. Occurrence of germination was predetermined as a limiting factor in delaying processing as, according to Kornberg and Beevers (1957), oil in the seed kernels could be converted to chemicals required for the germination processes. Therefore, the main objective of this study was to determine the effect of selected ripening enhancers to increase the ripening percentage and to understand better the effect of harvesting and handling practices, the effect of harvesting time and packaging on the ripening percentage were also measured. The germination percentage after ripening was also quantified to have an indication of the limit of ripening storage before compulsory processing.
Materials and Methods

Source of samples

Sources of jatropha fruits and trees for this study were as described in Chapter 3. Fruit samples for this study were from fruits bunches that have at least 10-20% of ripe fruits or more than 80% were still green in colour. Justification for using the fruits bunches’ character has been discussed in Chapter 7.

Arrangement for calcium carbide treatments

Fruits were harvested at 08:00-10:00 hour’s local time and brought directly to the storage room within five minutes after harvest. Fruits were separated from the bunch by careful cutting with secateurs, leaving around one cm of peduncle. Industrial calcium carbide (CaC₂) grade of 5.0 g was prepared and packed with 10 cm² newspaper. Around 90 to 110 fruits were randomly selected for each experiment and filled inside a five litre polyethylene bag. The prepared packed carbide was soaked in tap water for three to five seconds and the bag filled with it. The bags were directly tightened with commercial plastic rope and to ensure no air leakage the top of the bag was folded and re-tightened again. The method was designed to stimulate a simple and cheap ripening technique. The fruits were taken out form the bag after reaching designated exposure duration of 3, 6, 12 and 24 hours. The control sample was not exposed to carbide. Ripening room temperature was 28.5±3°C. The ripening and senescent percentage was monitored each day from harvest day until day five. Senescent fruit is referred to fruit that turn to black colour.

Arrangement for harvesting time effect

Harvesting of pre-determined fruits bunch characters was performed at specific predetermined times of 06:00-07:00, 10:00-11:00, 12:00-13:00, 15:00-16:00 and 19:00-20:00 local time. Preparation of samples was made within an hour after
harvest. The samples were put in an open air room with temperature of 28.5±3°C and the ripening percentage was measured every day from day after harvest until day 5.

**Arrangement for packaging condition effect**

Fruit samples of predetermined fruit bunch character were harvested between 08:00-10:00 local time. The samples were prepared within an hour after harvest and packed under two conditions. First packaging design was using five L polyethylene bag with around 80 holes of diameter size 5 mm each. The second packaging design was without holes. The Control was without packaging. The fruits were filled into the two different packaging which were tightened with plastic rope. All samples were put in the room with temperature of 28.5±3°C and the ripening percentage was measured every day from day after harvest until day 5.

**Arrangement of field heat effect**

Fruit samples of predetermined fruit bunches character was harvested between 08:00-10:00 local time. The fruits were prepared within one hour after harvest and were packed in ventilated packing before being subjected to two direct sunlight exposures. The two exposure durations were three and six hours starting from 11:00 until 14:00 local time for three hours exposure and prolonged to 17:00 local time for six hours exposure. The fruits were taken out from the bag upon reaching designated exposure duration and left to ripe in an open air room with temperature (28.5±3°C). The Control sample was not exposed to sunlight. The ripening percentage was measured each day from harvest day until day five.

**Arrangement of temperature documentation**

Character of temperature at the pilot project site was documented. Two temperature readers were used. Firstly the portable thermometer supplied by
Postharvest Division, University of California, Davis, USA and the second was the portable HANA branded thermometer thermostat made in Singapore. Both readers were supplied with a metal coated plate for easy penetration into the samples. Temperature of room storage, shade area, direct exposure to sunlight, pulp of green fruit, pulp of ripe yellow fruit and pulp of black senescence fruits was measured throughout the day at 07:00-08:00, 10:00-11:00, 12:00-13:00, 15:00-16:00 and 19:00-20:00 hours local time.

**Measurement of ripeness percentages**

The ripening percentage was measured according to the methods described in Chapter 3.

**Measurement of seed germination percentage**

Germination percentage of all samples in this study was measured at day six, after six days of storage. Fruit coats and seeds were separated and checked for any sign of germination. Visual subjective character of early seed germination can be judged from appearance of shell cracking. Appearance of hypocotyl and radicle are at advanced germination stage. The percentage was calculated by dividing the amount of germinated fruits with amount of fruits in the treatments before multiplying with 100.

**Experimental design and statistical analysis**

The experimental design for this study was a completely randomized design with fixed identified variable and minimum number of individual fruits per fixed identified variable of not less than 100 capsules and replicated three times to increase probability that changes in the fixed variables are due to changes in the measurable
variables. The data was analysed using one way ANOVA and the differences between means were calculated from error bar at 5%.

Results and Discussion

Effect of exposure to calcium carbide on ripening percentage of harvested mature jatropha fruits

Exposure to calcium carbide (CaC$_2$) at 3, 6 and 12 hours showed fast ripening compared to exposure of 24 hours and control (Table 7). After 24 hours of storage, the ripening percentage of fruits exposed to minimum 3 hours showed significantly high ripening percentage of about 65% compared to only 25 and 20% in the fruits exposed for 6 and 12 hours respectively. At similar storage duration the control did not show any ripened fruits. Senescence was also slow in the control compared to any of the treated samples. Only 17% of the fruits were senescent in the control sample after three days of storage compared to 69, 61 and 53% in the fruits exposed for 3, 6 and 12 hours respectively. Senescence percentages in the sample exposed for 24 hours was similar to the control sample at only about 21%. Appendix 17 (5a-5d) showed the appearance of the fruits ripening uniformity treated with several exposure duration with calcium carbide.

This study showed CaC$_2$ to tremendously hasten ripening processes and therefore agrees with previous study (Bhullar 1988 and Medlicott et al. 1987). Acetylene gas produced from oxidation of CaC$_2$ was expected to function like ethylene gas to quicken the ripening process. Minimum three hours was best as exposure duration to get fast ripening and senescent processes. Thus this study demonstrated the potential of off-tree ripening treatment on harvested mature green fruits. The 100% harvested mature green fruits can be 100% ripened and senescent off tree and this supports the recommendation of harvesting the unripe physiologically mature green fruits. With this recommendation the harvesting volume
is expected to increase, harvesting visits can be reduced and it directly reduces harvesting costs.

Table 7 Effect of exposure duration (h) with calcium carbide on ripening uniformity of harvested mature green jatropha fruits.

<table>
<thead>
<tr>
<th>Exposure Duration (h)</th>
<th>Group of fruits (%)</th>
<th>Ripening duration (day)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>Unripe</td>
<td>100a</td>
<td>100a</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Unripe</td>
<td>100a</td>
<td>36b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>0f</td>
<td>64b</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0d</td>
<td>0d</td>
</tr>
<tr>
<td>6</td>
<td>Unripe</td>
<td>100a</td>
<td>73b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>0</td>
<td>27c</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>Unripe</td>
<td>100a</td>
<td>80b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>0</td>
<td>20d</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>Unripe</td>
<td>100a</td>
<td>100a</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Significant at P<0.5.
* Mean for each treatment followed by the same letter in the same vertical row are not significantly different at p<0.05 with Duncan Multiple Range Test (DMRT).

Effect of harvesting at different times of day on ripening percentage of harvested mature green jatropha fruits

The results showed that harvesting at 12:00-13:00 hours caused fast ripening and senescence compared with those fruits harvested in the morning or afternoon (Table 8). After 24 hours of storage, 61% of the fruits harvested at 12:00-13:00 hours were ripe and after four days of storage 100% of the fruits were fully senescent. Ripening percentages of fruits harvested in the late afternoon and early morning were about 50% and 40% respectively after 24 hours of storage. The percentage of senescent fruits between fruit harvested in the morning and afternoon was also showed differences. After four days of storage, only about 80% of fruits harvested in the morning were senescent compared to 90% in the fruits harvested in the afternoon.
Faster ripening and senescence of fruits harvested at mid-day (12:00-13:00) was expected because of the high temperature. High temperature in the harvested fruits, which is also called field heat, might strongly increase respiration leading to depletion of nutrient reserves, and therefore the fruits ripen and senescence is accelerated. Field heat has been long known to be the main factor responsible for rejection of harvested horticulture fruits (Robbins and Moore 1992; Herdandez-Rivera et al. 1992 and Mitchell et al. 1974). The rejection is due to ripening and senescence and is reported to be up to 93%.

### Table 8 Effect of harvesting at different times of day on ripening uniformity of harvested mature green jatropha fruits.

<table>
<thead>
<tr>
<th>Day time harvesting</th>
<th>Group of fruits (%)</th>
<th>Ripening duration (day)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>06:00-07:00</td>
<td>Unripe</td>
<td>85a</td>
<td>57b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>15d</td>
<td>40c</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0f</td>
<td>3e</td>
</tr>
<tr>
<td>10:00-11:00</td>
<td>Unripe</td>
<td>86a</td>
<td>45b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>14e</td>
<td>47c</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0e</td>
<td>8d</td>
</tr>
<tr>
<td>12:00-13:00</td>
<td>Unripe</td>
<td>88a</td>
<td>36b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>12d</td>
<td>61b</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0e</td>
<td>4d</td>
</tr>
<tr>
<td>15:00-16:00</td>
<td>Unripe</td>
<td>92a</td>
<td>50b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>8d</td>
<td>50b</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0d</td>
<td>0d</td>
</tr>
<tr>
<td>19:00-20:00</td>
<td>Unripe</td>
<td>92a</td>
<td>53b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>8d</td>
<td>47b</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0d</td>
<td>0d</td>
</tr>
</tbody>
</table>

* Significant at P<0.5.
* Mean for each treatment followed by the same letter in the same vertical row are not significantly different at p≤0.05 with Duncan Multiple Range Test (DMRT).

The effect of field heat could also be responsible for the different ripening and senescence percentages between fruit harvested in the morning and afternoon. Slow ripening and senescence in the fruit harvested in the morning could be due to the fact that field heat during that harvesting time is low and thus respiration is low. On the other hand, field heat in the afternoon is slightly higher than during the morning.
hours and as a result there is a slight increase in the percentage of ripening and senescence. The temperature at farm is presented in Appendix 14. This indicates the importance of harvesting at different times of the day. Harvesting during the coolest part of the day is advisable in perishable horticultural produce to reduce the effect of field heat (Wills et al. 1998). Thus this study indicates that field heat could be manipulated for ripening treatment because it is safe and cheaper when compared with calcium carbide. However the real potential of this suggestion has not been reported in literature and thus future study is suggested.

**Effect of packaging conditions on ripening percentage of harvested mature green jatropha fruits**

Packaging conditions showed different effects on the ripening and senescent percentage of harvested mature green fruits (Table 9). Fast ripening and senescence was in unpacked fruits followed by ventilated packed fruits. Slow and abnormal ripening was observed in the unventilated packed fruits. After four days of storage, 6% and 93% of fruits were ripe and senescence respectively in unpacked fruits but only about 20% and 80% of fruits were ripe and senescence respectively in ventilated packed fruits. At similar storage duration, only 12% and 10% of fruits in unventilated packed fruits were ripe and senescence respectively.

Packaging without ventilation in this study showed abnormal ripening such as uneven ripening, sunken spots and blister of the fruit coat. This showed a disadvantage of the practice and thus it should be avoided. The results were also showed high percentage of unripe fruits on the fifth day of the experiment, which is 68%. The benefits of easy handling and quantity measurement with packaging will not be useful when the quality of the product deteriorates. Results of this study showed that providing ventilation to packed products will result in normal ripening. Occurrence of abnormal ripening in unventilated samples could be due to decreased level of \( O_2 \) and increased level of \( CO_2 \) (Cameron et al. 1995). The created
microenvironment is not suitable for normal respiration processes and as a result abnormal ripening is manifested.

Table 9 Effect of packaging conditions on ripening uniformity of harvested mature green jatropha fruits.

<table>
<thead>
<tr>
<th>Packaging conditions</th>
<th>Group of Fruits (%)</th>
<th>Ripening duration (day)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Unpacked</td>
<td>Unripe</td>
<td>85a&lt;sup&gt;z&lt;/sup&gt;</td>
<td>49b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>15d</td>
<td>46b</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0e</td>
<td>4d</td>
</tr>
<tr>
<td>Ventilated Packed</td>
<td>Unripe</td>
<td>87a&lt;sup&gt;z&lt;/sup&gt;</td>
<td>57b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>13e</td>
<td>42c</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0f</td>
<td>1e</td>
</tr>
<tr>
<td>Unventilated Packed</td>
<td>Unripe</td>
<td>87a&lt;sup&gt;z&lt;/sup&gt;</td>
<td>81a</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>12b</td>
<td>17a</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0e</td>
<td>1d</td>
</tr>
</tbody>
</table>

* Significant at P<0.5.
<sup>z</sup> Mean for each treatment followed by the same letter in the same vertical row are not significantly different at p<0.05 with Duncan Multiple Range Test (DMRT).

Slow ripening and senescence percentages in fruits in ventilated packaging were observed when compared with unpacked fruits. This could be due to the fact that high humidity is created in the packed environment which delayed respiration processes. High humidity can delay moisture loss and as a result slow ripening and senescence is manifested. The relationship between moisture loss and the rate of deterioration was demonstrated by Silip (2003) in guava fruit. The author reported 6% as a limit for moisture loss for the fruit before it starts to lose its green appearance. However, the limit and rate of moisture loss in harvested jatropha fruit so that ripening and senescence can occur has not been documented to date.

Significant difference in the rate of ripening and senescence between ventilated packed and unpacked fruits implied that it has an effect on oil biosynthesis. Fast ripening and senescence might result in low oil synthesis compared with those that ripen slowly. Results from previous study in Chapter 6 showed that oil extracted yield from unpacked ripe fruit was significantly higher than that from off-tree ripened fruits. As no report is available on the effect of slow ripening on extracted oil yield in
literature, thus this study draws attention to the need for future study on this issue. Obviously, packaging is commonly used today in the handling practices of any agriculture produce. The new environment introduced to harvested produce might have a negative effect on the quality of the produce. High humidity in the packed product environment is implied to promote development of decay (Brackett 1997) and cause fermentation (Cameron et al. 1995).

Effect of sunlight exposure duration on ripening percentage of harvested mature green jatropha fruits

Exposure to sunlight has tremendously hastened ripening and senescence of harvested mature green jatropha compared to non-exposure (Table 10). No ripening was recorded after 24 hours of storage in the non-exposed control sample but significant higher 70% and 77% ripening was recorded in the samples with sunlight exposure of three and six hours respectively. In addition, after three days of storage only 7% of fruits were senescence in the control sample but the percentage was higher in the samples exposed to sunlight for three and six hours at 59% and 74% respectively. 100% of fruits, irrespective of sunlight exposure duration, were fully senescent at final day of observation. However, only 93% was senescent in the control sample. Results of this study demonstrates the potential of the handling practices as ripening treatment for harvested mature green jatropha fruits.

High ripening and senescence percentage from exposure to sunlight in this study was expected based on previous study in this Chapter. The high temperature increased respiration and as a result high ripening and senescence occurred. Minimum three hours exposure to sunlight is suggested because prolonged exposure of six hours was also resulted in 100% ripening after four days of storage (Table 10). The effect of exposure to sunlight in this experiment showed similar results with the use of CaC$_2$ (Table 7). Obviously, treatment with exposure to sunlight resulted in much better ripening and senescence. After five days of storage 100% of the fruits exposed to sunlight, irrespective of exposure duration, were fully senescent. Less than 100% of senescent fruits were observed in the sample exposed to CaC$_2$. In addition,
occurrence of abnormal ripening with exposure to this chemical indicates need for future study on the use of this chemical.

Table 10 Effect of sunlight exposure duration on ripening uniformity of harvested mature green jatropha fruits.

<table>
<thead>
<tr>
<th>Exposure duration (h)</th>
<th>Group of fruits (%)</th>
<th>Ripening duration (day)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>Unripe</td>
<td>100a(^z)</td>
<td>100a</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>0e</td>
<td>0e</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0e</td>
<td>0e</td>
</tr>
<tr>
<td>3</td>
<td>Unripe</td>
<td>100a(^z)</td>
<td>30b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>0e</td>
<td>70b</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0c</td>
<td>0c</td>
</tr>
<tr>
<td>6</td>
<td>Unripe</td>
<td>100a(^z)</td>
<td>23b</td>
</tr>
<tr>
<td></td>
<td>Ripe</td>
<td>0d</td>
<td>77a</td>
</tr>
<tr>
<td></td>
<td>Senescent</td>
<td>0e</td>
<td>0e</td>
</tr>
</tbody>
</table>

* Significant at P<0.5.
\(^z\) Mean for each treatment followed by the same letter in the same row are not significantly different at p≤0.05 with Duncan Multiple Range Test (DMRT).

Several disadvantages of CaC\(_2\) have been reported. Reaction of the chemical with water was reported to produce traces of arsenic and phosphorus hydride, both of which are in the class of carcinogenic chemicals (Bingham et al. 2001 and Jani et al. 1985). In addition, the acetylene gas was reported to be flammable and explosive even in low concentrations compared with ethylene gas. Thus, treatment with field heat should be the best alternative for harvested mature green jatropha. However, the application of this treatment requires future study to improve efficiency. For example, the treatment might be not be effective during the rainy season and thus stimulated heat treatment using several heat sources should be tested.

Heat treatment does not always give positive results if not handled carefully. Exposing commodities to heat treatment was reported to cause heat injury to fruit, vegetables and ornamentals (Paull and Armstrong, 1994). Loss of vitamin C is generally more rapid at high storage temperature (Watada 1987). However, high temperature or heat treatments have been used or recommended for insect disinfections (Paull 1990 and Couey 1989). Heat treatments could also reduce chilling injury development in avocado (Florissen et al. 1996) and tomato (Lurie and
However, effect of heat treatment to extracted oil yield and other oil quality in jatropha is not reported in literature. This indicates requirement for future research on this issue.

Effect of harvesting time and packaging conditions on germination percentage of ripened harvested mature green jatropha fruits

Germination was high in ventilated packed fruits compared to unpacked fruits and no germination was recorded in unventilated packed fruits (Table 11). The occurrence of germination was higher at over 20% in the sample harvested in the morning between 07:00 to 11:00 hours local time followed by ventilated packing. With similar postharvest handling practices, no germination was recorded in the sample harvested during 12:00-13:00 and 19:00-20:00 hours. However, about 3% of germination was recorded in the sample harvested at 15:00-16:00 hours. Appearance of seed germination in photos is presented in Appendix 18.

Table 11 Effect of packaging conditions and harvesting time on germination percentage of off-tree senescence of harvested mature green jatropha fruits.

<table>
<thead>
<tr>
<th>Packaging conditions</th>
<th>Harvesting time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>07:00-08:00</td>
</tr>
<tr>
<td>Unpacked (%)</td>
<td>0</td>
</tr>
<tr>
<td>Ventilated packed (%)</td>
<td>28</td>
</tr>
<tr>
<td>Unventilated packed (%)</td>
<td>0</td>
</tr>
</tbody>
</table>

Occurrence of germination in the ventilated packed fruits in this study could be attributed to the stimulated microenvironment which led to favourable conditions for germination. Presence of water in the sample harvested in the morning followed by ventilated packed could be the reason for the occurrence. Moisture content is one important factor contributing to germination after suitable temperature and air composition (Rojas-Arechiga and Vazques-Yanes 2000). Interestingly, the occurrence was only pronounced in the sample harvested during morning hours compared to the sample harvested in the afternoon. This could be due to the fact that
water content in the sample was relatively high. After six days of storage the packed sample was observed to be in wet condition compared with those unpacked which were slightly dry.

Measurement of germination in this study was made after six days of storage. This implied that the occurrence of germination could be before the measurement day. If that happens then the fruit should be processed to avoid oil degradation which is implied to occur just before the occurrence of germination. Oxidation of reserved lipid was reported by Kornberg and Beevers (1957) in castor bean during germination. As the number of days after harvesting for such occurrence is not confirmed in this study future studies is suggested. The recommendation is critical to avoid loss on the main product of the crop. The rate of degradation due to delay in processing in this crop also remains unknown. At this point, processing is suggested to be done after whole harvested mature green fruits are ripe.

**Conclusion**

This study demonstrates the effectiveness of CaC\textsubscript{2} and direct sunlight exposure as ripening enhancers for harvested mature green fruits. Treatment with any of the enhancers will hasten ripening and senescence. Minimum three hours but not more than six hours exposure to CaC\textsubscript{2} is recommended to get best ripening and to avoid ripening disorder. There is no limit on sunlight exposure duration as no ripening disorder was observed during the experiment. In addition, treatment with sunlight exposure ensured 100% senescent fruits at final day of observation. Harvesting time and packaging conditions was confirmed to affect the rate of ripening, senescence and germination percentage. Fruits harvested during 07:00 to 10:00 hours and ventilated packaging showed slightly slower rates of ripening and senescence compared to samples harvested after 10:00 AM local time. Germination was also shown to be higher in the sample harvested during 07:00 to 10:00 hours. The occurrence of germination suggests minimum delay in processing of harvested fruit of five days or when all fruits are ripe.
2. Ditarung menunjangkan dan memperdalam pembahasan cakup seluas karya link ini dalam bentuk opini kumparan.

B. Pendukung link dan memperdalam pengembangan spesifik perubahan.

G. Pendukung karya untuk memperdalam pembahasan dan pelaksanaan karya. Pendukung karya itu meliputi: penulisan logorgan, pendukung link dan pelaksanaan dalam membuka masalah.

H. F. Cipta Dilinurungi Liking-Lidung

Bogor Agricultural University
CHAPTER 9
GENERAL DISCUSSION

Harvesting Strategies for Jatropha Fruits

The harvesting problem has been the main well known retarding factor for commercialization of this crop (ERIA 2010; Biswas et al. 2006; Blake 2008 and Heller 1996). Thus reducing the cost of harvesting was the main targeted benefit of this present work. Several reasons were cited for the problem and the most repeatedly written reason was the presence of immature and mature fruits in the same tree. The condition was reported to lead to laborious and time consuming harvesting as farmers had to select only the ripe fruits or fruits have to be harvested manually at regular intervals (Heller 1996 and Biswas et al. 2006). With this problem in mind, several studies related to the problem have been completed in the present work to better understand the problem and as a result harvesting strategies are recommended.

This study recommends harvesting multiple maturity indexes to increase harvesting volume in a single harvesting visit. The fruits were dry, wet black, ripe yellow and mature green. This new recommendation is totally contrary to previous harvesting recommendations (Appendix 9). However, this study suggests the requirement for additional postharvest handling practices to enjoy the advantages. The main concern was the requirement for ripening treatments for harvested mature green fruits. Data in this study has confirmed that harvested mature green jatropha can ripen off the tree. Respiration tests indicated that jatropha respiration followed climacteric fruit respiration trends (Chapter 5). Furthermore, off-tree ripe and senescent fruit offer the additional benefit of having high extracted oil yield compared with on-tree ripe and senescent fruits (Chapter 7). Proper postharvest handling practices prior to extraction were also predetermined to be important to be considered to enjoy the advantages.
Potential of having a minimum of three harvesting times in a year in a humid area is indicated based on the availability of fruits throughout the year. Data from the present study showed three peaks of the highest number of harvestable fruits throughout the year of observation. This was in March, August and December (Chapter 7). By having only three harvesting times in a year, significant reductions on harvesting visits and thus harvesting cost is implied. However, the occurrence of fall fruit is the concern in this recommendation. Data in this study showed tremendous increase in the percentage of fall fruit with increased duration in delay in harvesting (Chapter 7). Lower occurrence of fall fruit is indicated in arid areas or during dry season in humid areas. Thus further study is suggested to confirm this new recommendation.

Harvesting fruit bunches instead of individual fruits are recommended to increase harvesting volume and directly reduce harvesting visits. Present work even recommends fruit bunch harvesting indicators to increase the advantage. These are fruit bunches with maximum 80% of fruits still in green stage while the others were either ripe or senescence (Chapter 7). The study showed that fruit bunches with more advanced fruit maturity will be much better. On the other hand, it was confirmed that the harvested unripe fruits will ripen off the tree. This finding has revealed the potential and is totally different from the fruit bunch harvesting indicators of Priyanto (2007), Sumarsih (2007) and Hambali et al. (2007). The present work has also indicated the potential of harvesting 100% unripe mature green as a fruit bunch harvesting indicator, provided that the fruits were at least mature green with a trace of yellow. Additionally, it is suggested that the harvested unripe fruits be subject to postharvest ripening treatments.

This study proposed the potential for direct harvesting of jatropha. The concept is to harvest whole fruits irrespective of maturity. This concept has been used for many field crops, such as in peanuts, since many years ago (Wright and Steele 1979). By harvesting whole fruits, mechanization is implied possible in this crop and as a result harvesting volume is expected to increase and harvesting visits is possible to be scheduled. Data from the present study show low free fatty acid irrespective of
maturity (Chapter 5) and thus, no problems were indicated in harvesting immature fruits. However, harvesting immature fruits indicated a loss due to non-developed kernels which were confirmed to have low oil content. Furthermore, immature fruits have higher moisture content and thus more energy is expected for drying prior to storage and extraction. Difficulty to remove fruit coats to get the seed from harvested young fruits was also expected and thus more research is suggested before implementing this recommendation.

To reduce fall fruit due to delay in harvesting, potential for harvesting 24 hours a day is recommended. In the present study, observations on harvesting time of day showed problems of germination occurrences when harvesting during early morning. However this only occurred when the harvested fruit were ventilated packed prior to ripening storage (Chapter 8). Zero germination was observed when harvested fruit were not packed or ventilated packed but had to be subjected to sunlight exposure after morning harvest. Harvesting while raining was definitely not recommended because wet conditions will increase cost of drying and rotting is expected to occur. Recommendations of possibility to harvest 24 hours a day is expected to benefit the harvester because the harvester can have more flexible timing for harvesting. However, harvesting efficiency and payment mode for time and output of harvester should be further investigated before implementation of this recommendation.

Harvesting by machine should be the primary method to increase harvesting volume and to solve the problem of unavailability of labor. However, the fact was that no jatropha harvesting machines are available in the market. As such hand harvesting is the only option. Picking fruit bunches is suggested to be best by hand with gloves for reachable bunches and using a picking pool with collecting bag for higher unreachable bunches. It is suggested that the harvester brings along a simple collecting bag and a collecting bin be placed not too far from the harvesting area to increase harvesting efficiency in the farm. Preparation of a collecting net under the jatropha tree is another option to increase harvesting efficiency in the farm. However, it was implied that the installation of the net could increase investment, but
on the other hand harvesting will be much easier and all fall fruits can be collected. Harvesting scheduling is also indicated to be possible with installation of the net. However, information related to this idea is not available in the literature list, thus future research is suggested. Along with the suggested research, investigations on the effect of delay in collecting fall fruits on oil extraction yield should also be investigated. Lower oil yield from the fall fruits has been confirmed in this study (Chapter 7) but the rate of expected degradation was not confirmed.

Postharvest Handling for Harvested Jatropha Fruits

Harvested jatropha fruits require good postharvest handling to attain maximum quality and avoid quality deterioration. The focus of good postharvest handling in this discussion will be on how to attain high extractable oil yield. After harvesting, the first handling is the transportation of the harvested fruit from farm to operational house. Data in this study suggested having at least three groups of fruit being sent into the operational house. These are fruits harvested before 1000 local time, fruit harvested at mid-day or from 1000 – 1400 and fruits harvested in the afternoon or 1400 – 2000 local time. The fruits in each of these groups showed different potential of deterioration and this suggested requirement for different handling practices. The data in this study showed that fruit harvested before 1000 local time, if ventilated packed during ripening storage, resulted in high germination occurrences (Chapter 8). On the other hand, fruit harvested during mid-day showed fast ripening and senescence while fruit harvested in the afternoon has slow rate of ripening and senescence.

Soon after delivery, the first handling practices at the operational house should be grading. Grading according to maturity is suggested for easier future handling practices. First grading should be to separate unripe fruits because the unripe fruits require further ripening treatment. After that the ripe yellow fruit, wet black
senescent and dry senescent fruit should be separated. The fact is that every maturity level has different moisture content and this implies the need for different drying requirements. The drying characteristics of jatropha were observed to vary much depending on the drying methods. For example, the data from the present study showed that about 900 minutes were required with sunrise drying but only 150 minutes by using controlled drier of 80°C and 20% relative humidity to reach 5% moisture content of fresh harvested ripe fruit seeds (Appendix 13).

The graded unripe fruits are recommended to be subjected to ripening treatment before future processing to attain maximum oil synthesis. Data from this study showed that the ripe and senescence harvested mature green fruit showed significantly high extracted oil yield (Chapter 6). Two ripening enhancers are recommended based on the present study. These are either the chemical agent called calcium carbide or the use of natural field heat. Both enhancers have shown to tremendously hasten the ripening and senescence rate of harvested mature green jatropha fruit. Application of both enhancers has their own advantages and disadvantages. The CaC$_2$ has a hazardous potential and requires careful handling (Bingham et al. 2001 and Jani et al. 1985). In addition, the data from the present study showed that prolonged exposure to this chemical resulted in abnormal ripening. Using field heat is generally safe but indicates high dependency on environmental conditions and thus further study is recommended. During normal sunny days, ripening treatment by exposing to sunlight is recommended. Future issues with off-tree ripening treatments to the harvested mature green fruit refer to the normal oil synthesis effect. Data from the present study has indicated an increase in the synthesis with zero ripening enhancer (Chapter 6). However, limited information is available related to the issue in the reference list.

Future handling of the harvested fruits after grading and ripening treatment is fruit cracking to separate fruit seed from fruit coats. The fruit coat thrasher machine is very helpful in this work because manual separation is not economical. Fruit grading is very important before performing the machine separation because dry, wet black and yellow ripe fruits have different physical fresh harvest characteristics. Since the
physical character of the harvested fruit is not uniform, two options are suggested to handle the fresh fruits. First is to dry the fruits before trashing or second to have different thrashers to suit the differences. The decision on which option to follow is implied depending on production volume. Small farmers are recommended to use the first option and big plantations the second option. The fact with handling huge fruit production is the requirement for handling space and thus trashing earlier where the fruits coats will benefit in the drying space area and it is more economical in terms of transportation. The data from the present study has shown to be in agreement with Sirisomboon et al. (2007) about the benefit of low surface area of seed compared to fruit (Chapter 5).

Seed cracking practices to have only kernels is recommended prior to further handling practice. The fact was that more than 97% of jatropha oil was reported to be stored in the kernels (Achten et al. 2008). Thus removing seed shells will be beneficial in terms of the surface area. Furthermore, data from the present study has shown a disadvantage of shells in oil recovery with mechanical extraction (Chapter 6). The shells increase the need for energy to press oil from the kernels with about 20 to 30 N increase when the kernels are included. Dry kernels were also indicated to be much easier and cheaper to deal with compared with seed. However, presence of shells is also indicated to be important for long storage of seed. Thus, more study on this issue is suggested.

It is recommended that the kernels as final products be given special handling just before extraction for optimal oil recovery. The dried kernels are recommended to be crushed before extraction. The data from the present study showed about 5% oil recovery difference between uncrushed and crushed kernels prior to extraction with modified hydraulic presser (Chapter 6). The amount of extractable oil was further observed to very much depend on the presser handling and efficiency. For example, in the study the heating temperature, preheating time and pressing duration with modified hydraulic presser were shown to significantly affect oil recovery (Chapter 6). Thus standard operational procedures for the presser machine to be used should be available before production. Minimum heating temperature and minimum preheating
duration with modified hydraulic presser used in this study were 50°C and 10 minutes respectively.

Crude jatropha oil (CJO) will be the product extracted from jatropha kernels. This straight vegetable oil (SVO) is recommended to be directly subjected to simple purifying processes such as degumming, filtration and deacidification before storage or further processing for biodiesel production. Interestingly, in this study, readings of free fatty acids irrespective of the maturity stage of the harvested fruits were all below 2%. This indicates the advantage of only needing esterification for biodiesel processing. However the differences in the readings amongst the different maturities implied propagated potential of oxidation during prolonged storage. High number of unsaturated fatty acids in the CJO could also lead to an increase in oil oxidation during storage.

The by-product of CJO production includes kernel cakes, shells and fruit coats. It is recommended that these by-products be subject to special handling for different purposes. The shells and fruit coats could be used as biomass for heat production or used as mulching in the farm. The shells themselves could be processed into activated charcoal. The kernel cakes were reported to be more useful. Seed cake crude protein was reported to be about 58.1% with gross energy content of about 18.2 MJ per kg (Achten et al. 2008). Existence of bio-degradable toxins, mainly phorbol esters, makes the by-product only recommended to serve as biopesticide, molluscicide, and fertilizer and as feed for biogas production.

Estimating Real Yield and Value of Jatropha

Yield of crop is referred to as total harvested part of the crop. Yield in jatropha is normally calculated based on dry seed weight (Jones and Miller 1993; Heller 1996; Henning 1996; Francis et al. 2005; Francis et al. 2005, Foidl et al. 1996; Schmidt 2003) and extracted oil yield (Jones and Miller 1993; Frost and Sullivan
Other products of this crop like seedlings, fresh fruits and fresh seeds are not included. It would be interesting to discuss the real yield and value of this crop because the crop has been confirmed as an indeterminate crop in this study.

It is predetermined a challenging during estimating a real yield or the oil extracted yield of indeterminate crop because physiological maturity of the harvested part of the crop is not uniform (Chapter 4). Berti and Jonsson (2008) have also reported difficulty in the indeterminate character of the cuphea crop. Estimation of jatropha real yield could be easy if the fruits ripen at the same time. Realistically, all reproductive variables observed in this study showed high variability (Chapter 4). Jatropha planted in humid areas like in the research plot in this study showed continuous flowering throughout the year from January to December. Thus, fruits are continuously available throughout the year. In comparison, jatropha planted in arid or dry areas will have sheltering seasons (Santoso 2008) and thus production could be easily calculated.

Potential yield loss in jatropha planted in humid areas is expected to be higher than those planted in arid areas. In the present study the data showed a high percentage of fall fruits occurrences during the rainy season which is expected to be more pronounced with hard wind (Chapter 7). On the other hand, the occurrence was observed during dry season because the fruit bunches dried on the tree. Multiple dry fruit bunches were observed during the short dry season in the pilot project. The trend of fall fruits was best described as a logramatical trend ($R^2=0.94$) in this study indicating high percentage of fall fruit at the early stage. In this study delay of three and 15 days showed about 10 and 50% losses of harvestable fruits respectively. This result indicates the importance of considering this character when calculating real yield of this crop because each day of delay in harvesting will affect the yield.

Harvested jatropha fruits of today are increasingly from at least three maturity stages based on the recommended harvesting characteristics (Appendix 9). These are dry, wet black senescent and yellow ripe fruits. Interestingly, each of these maturity levels has been reported and confirmed in this study as having differences in extracted oil yield (Chapter 5, Chapter 6 and Chapter 7). Thus, estimation of yield if
all of those fruits with different maturities are to be harvested at the same time should be considered. It is suggested that the term of oil content be defined as extracted oil yield to clarify the amount of oil that a producer can extract from harvested fruits. The extractable oil is affected by several factors. This study confirmed the effect of extraction methods, drying before extraction, sample conditions before pressing, handling of presser and postharvest treatment of fresh sample.

Crude jatropha oil (CJO) is the primary product of this crop as feedstock for biodiesel and it can be extracted either by chemical or mechanical methods. The mechanical method is the popular technique for commercial use because it is cheaper and easier to handle but relatively not as efficient compared with the chemical technique. Today there are many types of mechanical pressers with different extraction efficiency. Efficiency of the modified hydraulic presser used in this study was only 76% (Chapter 7). As a comparison, extracted oil yield from dry kernel with chemical extraction is about 50% but only 38% with the modified hydraulic presser. Thus, calculation of oil yield should consider extraction methods and its efficiency.

Decision on either using seed or kernel as feedstock for extraction was also found to affect the extraction yield. Results in this study showed high extracted oil when using only the kernel and as being much higher if the kernels were crushed before extraction with modified hydraulic presser (Chapter 7). In comparison, if shells were not removed prior to extraction, only low oil yield could be recovered. In calculation, there was about a 100% difference in oil recovery, between crushed kernels and uncruushed seeds. The data showed that only 20% of oil was extracted with uncruushed seed as compared to 41% in crushed kernels. A difference in extraction efficiency was found to be due to the disadvantage of having shells. The presence of shells implied an increase in energy required to press oil within the sample.

Moisture content could be the primary factor affecting calculation of the real yield and value of any product. This is due to the fact that trading of products is usually in weight units. Interestingly, trade of dry jatropha seed did not specifically state the moisture content. However, for long storage, moisture content of seed is
suggested to be within 7 – 9% (Sutopo 2004). Moisture content of fresh harvested jatropha seeds was actually different according to maturity stage and in this study the trend was negatively linear ($R^2=0.97$) with advancing maturity (Chapter 5). High moisture content of around 70% average for immature seeds to only about 15% in harvested dry fruits was shown in the study. Available information related to fresh harvested moisture content and target of dry moisture content implied the possibility to have a trade in fresh seeds.

The moisture content was also found have a positive relationship with oil yield recovery with chemical extraction and thus implied that it will affect the calculation. The data in this study showed a negative linear trend with the moisture content with advancing fruit maturity but positive linear ($R^2=0.93$) trend was shown with the oil extracted yield (Chapter 5). The effect of moisture content in the kernels on oil extraction yield with mechanical extraction was more distinct. The data in this study showed zero oil could be extracted from fresh kernels of high moisture content immature, mature and ripe kernel fruits (Chapter 6). This result indicated the importance of stating the sample’s character, either dry or fresh prior to extraction so that calculation of real yield can be predicted. Effects of specific moisture content on oil recovery remains unknown at this point of time.

Oil content from harvested mature green fruits was found to change with ripe and senescent off the tree and thus implied that this should be included when calculating the real value of jatropha. The data in the study showed significant increase in the extracted oil yield, about 12% to 18%, from mature green to ripe and senescence off the tree. In comparison, there was only about 5% increase from mature green to ripe and senescence on the tree. This new finding, revealed the additional new sample group which makes the calculation more difficult. It is felt that this new finding can be used as a new approach to reduce the harvesting problems of this crop. Besides the advantages of extracted oil yield, harvesting this fruit in the farm was implied to decrease harvesting visits, increase harvesting volume and directly reduce harvesting cost.
Operation of the mechanical presser was also found to affect the amount of extracted oil and thus it is suggested that it be included when calculating the real yield of jatropha. The data in this study showed significant effect of heating temperature, preheating time and pressing time. The results recommended minimum 50°C as heating temperature and 10 minutes as preheating time. However, best pressing time remains unknown because the data showed increased amount of extracted oil with increased duration of pressing. As different machines have different characters thus it is suggested that the real yield of jatropha be calculated based on a specific machine’s characteristics.

Occurrence of germination was implied to affect the amount of extracted oil yield and thus this factor is also suggested to be included when calculating the real yield of jatropha. In the study, germination was observed in the fruit harvested in the morning followed by ventilated packing. Germination was also stated in unpacked fruit (Chapter 8). Low extracted oil in fall fruit was also implied due to the fact that the seeds were about to germinate. The fundamental effect of germination to reduction of oil yield was based on findings by Kornberg and Beevers in 1957. However, the rate of lipid degradation with appearance of germination signals remains unknown.

There are many other sources of variation which may affect the calculation of real yield and value of jatropha. Appendix 3 shows the common variables used by many researchers and Appendix 1 and 2 shows the production potential of jatropha.
B. Penciptaan budi percibahan reproduksi yang wajar cipta

3. Penciptaan budi percibahan reproduksi yang wajar cipta

2. Penciptaan budi percibahan reproduksi yang wajar cipta

Hak cipta dilihndungi Undang-Undang

Bogor Agricultural University

Hak cipta millik IPB (Institut Pertanian Bogor)
CHAPTER 10
CONCLUSIONS AND RECOMMENDATIONS

Selective reproductive characteristics and physiological occurrences during the life on-tree and off-tree of jatropha fruit have been studied. Following are six important conclusions and five recommendations that can be drawn from this study.

Conclusions

1. This study concluded that jatropha is an indeterminate crop. Fruit maturation of this crop is not uniform within trees and bunches of any observed jatropha accession. The fruit maturation was also not uniform throughout the months of observation. In addition the number of days required to reach recommended harvesting index was also found to differ within observed samples. Given its indeterminate character, poor harvesting of this crop is expected and this data supports the importance of finding short term solutions to this problem for domestication of local accessions.

2. This study recommends a new harvesting approach to tackle the present harvesting problem of rapid harvesting visits and low harvesting volume per harvesting visit for this crop. Physiological mature green fruit together with ripe and senescence fruits are recommended to be harvested in a single harvesting visit. By harvesting this group of fruits, the harvesting visits can be reduced and harvesting volume increased. This new recommendation is due to the novelty finding in this study that the off-tree ripened harvested physiological mature green fruit showed significantly higher extracted oil yield when compared with on-tree ripe fruit.

3. Extractable oil yield was found to be not only affected by fruit maturity stage but also by several handling practices prior to extraction. These include extraction...
methods, drying, sample condition (seeds or kernels) and extractor machine handling practices (heating temperatures, preheating time and pressing duration).

4. The study also concluded a new bunch harvesting indicator to increase harvesting volume per harvesting visit. The Bunch harvesting indicator is proposed to replace previous recommendations on harvesting individual fruits which led to harvesting problems. Result from this study fruit bunches with at least 20% of the fruits ripe is recommended as the bunch harvesting indicator.

5. Incidence of fall fruit was found to be a major harvesting problem in this crop after uniformity in ripening. Logarithmic fruit loss trend due to fruit fall was confirmed to cause high loss during early senescence but reduced when dry. Low extracted oil yield was also confirmed in the fall fruit.

6. Field heat was found to be a promising natural ripening enhancer in this crop. Harvested physiological mature green jatropha fruit was found to ripen and senescence faster when exposed to minimum three hours sunlight. The rate of ripening was equivalent to that with exposure to calcium carbide.

**Recommendations**

1. Several approaches to increase fruit production in many crops such as by introducing good fertilization practices and crop protection from diseases. New recommendations to increase fruits production in this crop are suggested by increasing the number of fruits per bunch and to have a good pruning program. Results from this study found that the bunch production trends follow the fruit production trend. However, the frequencies of fruits per bunch are not uniform with less fruits to have more than 10 fruits per bunch. Thus, future research could be to increase the frequency to increase production. On the other hand, increase in crop branches was found not to follow the fruit production trend. Thus, the idea to increase bunches is not recommended but pruning of non-active
branches such as new sprouts is recommended to be tested for its effect on fruit production.

2. Several factors have been confirmed to have a significant effect on the amount of kernel extractable oil yield in this study. However, the mechanism of oil release from kernel oil cells compartments during mechanical extraction remains unknown. Obviously, the oil body might play an important role during secretion. The oil body which is mostly protein and functions to reduce oil dehydration during storage may prevent oil release. Understanding the physical character of the oil body may increase the extractable oil yield and thus future research on this issue is recommended.

3. Fall fruit have been confirmed as the real problem in scheduling harvesting in this crop. The occurrence leads to repeating harvesting visit within 6 to 17 days. Thus, potential of mechanical harvesting should be the approach to reduce a cost on laborious, drudgery and time consuming with hand harvesting. Potential of using netting might be a good alternative to solve this problem. Netting has been use in harvesting edible fruit such as durian to avoid the fruit fall on the ground. However, no information on the effectiveness of the netting in this crop. Related question with this fall fruit is the rate of oil degradation during prolong collection of fall fruit on the ground and on the netting itself. Thus, future study on this issue is purposed.

4. To increase harvesting volume per harvesting visit, harvesting bunches instant of individual fruit was recommended in this study. The character of bunches harvesting indicator has also been confirmed which is having at less 20% of a fruits are ripe. More suggestion is indicated to increase the harvesting volume per harvesting visit. Indication to harvest multiple bunches which include a bunch with 100% are still green in a similar branch is indicated a benefit to not only having more harvestable volume but directly extend following harvesting visit. The present data showed that the FFA of irrespective fruit maturity was below 2% which indicated has no problem in processing of extracted oil for biodiesel. The remaining question on the recommendation was a processing difficulty prior to
extraction. It is indicated a difficulties in separating between fruit coats and seed of immature green fruit. Thus, future study on this issue is purposed.

5. Potential and advantage of sunlight exposure to the rate of ripening and senescence of harvested mature green fruit is confirmed in this study. Obviously sunshine is difficult to be predicted in tropical country thus, it is therefore important to have a modified ripening chamber for this crop. A chamber that could accommodate tons of harvested mature green fruits. This offer more study in this issue.
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Hasnam. 2007. Status perbaikan dan penyediaan bahan tanaman jarak pagar (Jatropha curcas L.) Prosiding Lokakarya II: Status teknologi jarak pagar


Ryan TW, Callahan TJ, Dodge LG. 1982. Characterization of vegetables oils use as fuels in diesel engines. Vegetables oil fuels – proceeding of


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APPENDIX 1

Production potential in ton (t) per hectare of selected jatropha varieties in Indonesia.

<table>
<thead>
<tr>
<th>Jatropha variety</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IP-1A</td>
</tr>
<tr>
<td>Production</td>
<td></td>
</tr>
<tr>
<td>Potential / ha</td>
<td>0.5 - 0.6 t</td>
</tr>
<tr>
<td>at 1\textsuperscript{st} year</td>
<td>at 1\textsuperscript{st} year</td>
</tr>
<tr>
<td>t at 5\textsuperscript{th} year</td>
<td>t at 5\textsuperscript{th} year</td>
</tr>
<tr>
<td>t at 5\textsuperscript{th} year on</td>
<td>t at 5\textsuperscript{th} year on</td>
</tr>
<tr>
<td>year on</td>
<td>year on</td>
</tr>
<tr>
<td>year on</td>
<td>year on</td>
</tr>
</tbody>
</table>

Source: Hasnam (2007) and Heliyanto et al. (2008).
**APPENDIX 2**

Predicted yield of *J. curcas* L. at different plantation conditions.

<table>
<thead>
<tr>
<th>Yield Dry seeds</th>
<th>Condition of plantation</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 – 3 t.ha⁻¹yr⁻¹</td>
<td>Semi-arid area</td>
<td>Heller (1996); Henning (1996) and Francis <em>et al.</em> (2005).</td>
</tr>
<tr>
<td>5 t.ha⁻¹yr⁻¹</td>
<td>Rainfall of 900-1200mm.</td>
<td>Francis <em>et al.</em> (2005); Foidl <em>et al.</em> (1996).</td>
</tr>
<tr>
<td>6.25 t.ha⁻¹yr⁻¹</td>
<td>Zulu-Afrika</td>
<td>Schmidit (2003)</td>
</tr>
<tr>
<td>15 t.ha⁻¹yr⁻¹</td>
<td>Fifth year old</td>
<td>Philippine National Oil Co. (Jim, 2009).</td>
</tr>
<tr>
<td>794 kg.ha⁻¹</td>
<td>Thailand</td>
<td>Heller (1996)</td>
</tr>
<tr>
<td>1,733 kg.ha⁻¹</td>
<td>India at year 3</td>
<td>Heller (1996)</td>
</tr>
<tr>
<td>5,000 kg.ha⁻¹</td>
<td>Nicaragua</td>
<td>Heller (1996)</td>
</tr>
<tr>
<td>8,000 kg.ha⁻¹</td>
<td>Mali</td>
<td>Heller (1996)</td>
</tr>
<tr>
<td>100,000 – 4,000 kg.ha⁻¹</td>
<td>Paraguay. From year 3 – 9.</td>
<td>Heller (1996)</td>
</tr>
<tr>
<td>638 kg.ha⁻¹</td>
<td>Thailand</td>
<td>Jones and Miller (1993)</td>
</tr>
<tr>
<td>4,000 – 6,000 kg.ha⁻¹ yr⁻¹</td>
<td>Brazil</td>
<td>Jones and Miller (1993)</td>
</tr>
</tbody>
</table>
APPENDIX 3

Common variables used by researchers to determine yield of jatropha.

<table>
<thead>
<tr>
<th>Variables used to determine jatropha yield</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflorescences, total fruit set, total bunches and total fruits.</td>
<td>Sri Hartati <em>et al.</em> (2009).</td>
</tr>
<tr>
<td>Planting distance, trunk diameter, tree height, total fruits, total seeds and seed weight.</td>
<td>Nazar and Hendra (2008)</td>
</tr>
<tr>
<td>Fertilizers, height, total and weight of seeds and total and weight of fruits.</td>
<td>Emmyzer and Karmawati (2008)</td>
</tr>
<tr>
<td>Fertilizer, planting distance, plant height, trunk diameter, total of primary branch.</td>
<td>Erythrina (2006)</td>
</tr>
<tr>
<td>Fertilizer, plant height, total branch, total bunches, total fruits, weight of 100 seeds and weight of seed per hectare.</td>
<td>Romli <em>et al.</em> (2006)</td>
</tr>
<tr>
<td>Watering intervals, plant height, total sprouts, total leaf, leaf diameter, flowering percentage</td>
<td>Saefudin and Pranowo (2006)</td>
</tr>
</tbody>
</table>
### APPENDIX 4

Summary of selected morphological characters from selected seven jatropha ecotypes.

<table>
<thead>
<tr>
<th>No.</th>
<th>Selected morphological characters</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Number of secondary per primary branches</td>
<td>$1^{st}$ yr = 4.3, 2nd yr = 6.1</td>
<td>$1^{st}$ yr = 5.5, 2nd yr = 10.3</td>
</tr>
<tr>
<td></td>
<td>Tree age starting to produce flower (day)</td>
<td>105</td>
<td>163</td>
</tr>
<tr>
<td></td>
<td>Days after anthesis to yellow fruits</td>
<td>55.2</td>
<td>59.3</td>
</tr>
<tr>
<td></td>
<td>Number of fruits per bunches</td>
<td>$1^{st}$ yr = 6.7, 2nd yr = 10.6</td>
<td>$1^{st}$ yr = 10.9, 2nd yr = 15.6</td>
</tr>
<tr>
<td></td>
<td>Number of fruits per tree</td>
<td>$1^{st}$ yr = 56.6, 2nd yr = 152.1</td>
<td>$1^{st}$ yr = 78.3, 2nd yr = 184.7</td>
</tr>
<tr>
<td></td>
<td>Fresh weight of individual seed – yellow (g)</td>
<td>0.7</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Fresh weight of 100 seeds – yellow (g)</td>
<td>60.6</td>
<td>75.8</td>
</tr>
<tr>
<td></td>
<td>Dry weight of seeds per tree (g)</td>
<td>$1^{st}$ yr = 140.7, 2nd yr = 350.4</td>
<td>$1^{st}$ yr = 269.9, 2nd yr = 486.1</td>
</tr>
<tr>
<td></td>
<td>Dry weight of seed / ha (kg)</td>
<td>$1^{st}$ yr = 351.7, 2nd yr = 875.5</td>
<td>$1^{st}$ yr = 674.7, 2nd yr = 1,215</td>
</tr>
</tbody>
</table>

Source: Santoso (2008).
APPENDIX 5

Density value, cetane number and composition of major jatropha fatty acids (number in brackets signifying temperatures at which densities were determined).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>C16:0</th>
<th>C18:0</th>
<th>C18:1</th>
<th>C18:2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition (%)</td>
<td>14.54</td>
<td>6.30</td>
<td>42.02</td>
<td>35.38</td>
</tr>
<tr>
<td>Density [kg/m$^3$]</td>
<td>884 (20)</td>
<td>852 (38)</td>
<td>874 (20)</td>
<td>904 (15)</td>
</tr>
<tr>
<td>Cetane Number</td>
<td>74.3</td>
<td>75.7</td>
<td>55.0</td>
<td>22.7</td>
</tr>
<tr>
<td>Kinematics viscosity at 40°C [mm$^2$/s]</td>
<td>4.32</td>
<td>5.56</td>
<td>4.45</td>
<td>3.64</td>
</tr>
</tbody>
</table>

APPENDIX 6

Physical and mechanical properties of jatropha shells and kernels.

<table>
<thead>
<tr>
<th>Physical and mechanical properties</th>
<th>Kernels</th>
<th>Shells (nut)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rupture force (N)</td>
<td>146.63±14.82</td>
<td>67.72±19.03</td>
</tr>
<tr>
<td>2. Hardness (N/mm)</td>
<td>69.98±6.22</td>
<td>38.52±5.59</td>
</tr>
<tr>
<td>3. Energy use for rupture</td>
<td>124.44±19.95</td>
<td>51.61±26.84</td>
</tr>
<tr>
<td>4. Length (mm)</td>
<td>21.02±1.03</td>
<td>15.45±0.54</td>
</tr>
<tr>
<td>5. Bulk density of 3 samples (g/cm^3)</td>
<td>0.45±0.01</td>
<td>0.42±0.1</td>
</tr>
<tr>
<td>6. Surface area (mm^2)</td>
<td>534.12±31.81</td>
<td>206.48±22.08</td>
</tr>
<tr>
<td>7. 100-unit mass (g)</td>
<td>1322.44±14.6</td>
<td>688.1±5.7</td>
</tr>
</tbody>
</table>

Source: Sirisomboon et al. (2007).
APPENDIX 7

Quality standard for pure plant oil (PPO) as a fuel and biodiesel (FAME).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>PPO</th>
<th>Biodiesel (FAME)</th>
<th>Testing Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Density (1kg/m³) at 15°C</td>
<td>900-930</td>
<td>850-890</td>
<td>ASTM D40 / ASTM D1298</td>
</tr>
<tr>
<td>2. Flash Point (°C)</td>
<td>&lt;210</td>
<td>&lt;100</td>
<td>EN ISO2719</td>
</tr>
<tr>
<td>3. K. Viscosity (mm2/s) (40°C)</td>
<td>30-40</td>
<td>2.3-6.0</td>
<td>ASTM D445</td>
</tr>
<tr>
<td>4. Cetane Number</td>
<td>≥45</td>
<td>≥51</td>
<td>ASTM D 613</td>
</tr>
<tr>
<td>5. Carbon Residue (Mass-%)</td>
<td>≤0.4</td>
<td>≤0.3</td>
<td>ASTMD D 4530</td>
</tr>
<tr>
<td>6. Iodine Number (g/100g)</td>
<td>90-120</td>
<td>≤120</td>
<td>DIN 53241-1</td>
</tr>
<tr>
<td>7. Sulfur Content (mg/kg)</td>
<td>≤20</td>
<td>≤0.01</td>
<td>ASTM D5453-93</td>
</tr>
<tr>
<td>8. Total Contamination (mg/kg)</td>
<td>≤25</td>
<td>≤24</td>
<td>DIN EN 12662</td>
</tr>
<tr>
<td>9. Acid Value (mg KOH/g)</td>
<td>≤2</td>
<td>≤0.5</td>
<td>DIN EN ISO 660</td>
</tr>
<tr>
<td>10. Oxidation Stability (h) at 110°C</td>
<td>5</td>
<td>6</td>
<td>ISO 6886</td>
</tr>
<tr>
<td>11. Phosphorus content (ppm)</td>
<td>10-50</td>
<td>≤10</td>
<td>FBI-A01-03</td>
</tr>
<tr>
<td>12. Ash Content (Mass-%)</td>
<td>≤0.01</td>
<td>≤0.02</td>
<td>DIN EN ISO 6245</td>
</tr>
<tr>
<td>13. Water Content (Mass-%)</td>
<td>≤0.075</td>
<td>≤0.7</td>
<td>Pr EN ISO 12937</td>
</tr>
</tbody>
</table>

APPENDIX 8

Fuel properties of Jatropha oil and Jatropha biodiesel.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Jatropha oil</th>
<th>Jatropha Biodiesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Density (kg/m³) at (°C)</td>
<td>920 (15)</td>
<td>879 (15)</td>
</tr>
<tr>
<td>2. Flash Point (°C)</td>
<td>210 – 236</td>
<td>191</td>
</tr>
<tr>
<td>3. Viscosity (mm2/s) (°C)</td>
<td>52 (30)</td>
<td>4.84 (30)</td>
</tr>
<tr>
<td>4. Cetane Number</td>
<td>40 – 49.15</td>
<td>51</td>
</tr>
<tr>
<td>5. Carbon Residue (Mass-%)</td>
<td>0.34 – 0.64</td>
<td>0.02</td>
</tr>
<tr>
<td>6. Iodine Number (g/100g)</td>
<td>96.5</td>
<td>-</td>
</tr>
<tr>
<td>7. Sulfur Content (mg/kg)</td>
<td>&lt;1</td>
<td>-</td>
</tr>
<tr>
<td>8. Total Contamination (mg/kg)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9. Acid Value (mg KOH/g)</td>
<td>0.92</td>
<td>-</td>
</tr>
<tr>
<td>10. Oxidation Stability (h) at 110 °C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11. Phosphorus content (ppm)</td>
<td>290</td>
<td>17.5</td>
</tr>
<tr>
<td>12. Ash Content (Mass-%)</td>
<td>0.007</td>
<td>-</td>
</tr>
<tr>
<td>13. Water Content (ppm)</td>
<td>935</td>
<td>-</td>
</tr>
</tbody>
</table>

APPENDIX 9

Contradictory recommendation on jatropha harvest time base on high seed oil yield at day after anthesis and it fruit characters cited in various literatures.

<table>
<thead>
<tr>
<th>Harvesting time recommendation (days after anthesis - fruits characters)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 days (dry fruits)</td>
<td>(Heller 1996; Wiesenhutter 2003; Nurcholis and Sumarsih 2007; Priyanto 2007 and Hambali 2007)</td>
</tr>
<tr>
<td>55 days (fully yellow fruits)</td>
<td>Santoso (2008)</td>
</tr>
<tr>
<td>45 days (yellow fruits)</td>
<td>Wanita and Hartono (2006)</td>
</tr>
<tr>
<td>37 days (before dry)</td>
<td>Annarao et al. (2008)</td>
</tr>
</tbody>
</table>
General optimum ripening conditions for different fruits.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>18-25°C</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>90-95%</td>
</tr>
<tr>
<td>Ethylene concentration</td>
<td>10-100 ppm</td>
</tr>
<tr>
<td>Duration of treatment</td>
<td>24-72 h depending on fruit maturity stages</td>
</tr>
<tr>
<td>Air circulation</td>
<td>Sufficient to ensure uniform distribution of ethylene, but will reduce its effectiveness.</td>
</tr>
</tbody>
</table>

Source: Reid (1992)
APPENDIX 11

Schematic drawing and photo of Modified Hydraulic Presser used in the research.

<table>
<thead>
<tr>
<th>Legend</th>
<th>Components</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steering pressing</td>
<td>Tool to steer of screw</td>
</tr>
<tr>
<td>2</td>
<td>Screw</td>
<td>Hold back of powers for hydraulic jack</td>
</tr>
<tr>
<td>3</td>
<td>Disk of pressing</td>
<td>Push down of samples</td>
</tr>
<tr>
<td>4</td>
<td>Pressing chamber</td>
<td>Samples receiver</td>
</tr>
<tr>
<td>5</td>
<td>Bearing of pressing</td>
<td>As a bearing of pressing chamber</td>
</tr>
<tr>
<td>6</td>
<td>Fame of equipment</td>
<td>Protecting all of equipment components</td>
</tr>
<tr>
<td>7</td>
<td>Hydraulic jack</td>
<td>As a power supply</td>
</tr>
<tr>
<td>8</td>
<td>Heater</td>
<td>As a heat supply</td>
</tr>
</tbody>
</table>
APPENDIX 12

Rainfall and number of day raining throughout the year in 2010 at the Jatropha pilot project belong to Agro-Biotechnology Institute, Ministry of Science, Technology and Innovation Malaysia located at Luanti Baru village, District of Keningau, State of Sabah, Malaysia.

Source: Department of Metrology, Ministry of Science, Technology and Innovation Malaysia.
APPENDIX 13

Relationship between the jatropha seed moisture and drying time with several drying conditions (room temperature, sunrise, 80°C/20%RH, 80°C/40%RH, 60°C/20%RH and 60°C/40%RH).

![Graphs showing the relationship between moisture content and drying time under various conditions.](image-url)
APPENDIX 14

Temperatures of fruits at different environments and times of measurement.
APPENDIX 15

Photos of multiple fruit bunches in a single branch of *J. curcas* Linn

The photos showed occurrence of multiple bunches in a single branch of jatropha tree. Mature fruits per bunch were confirmed at the bottom but a young immature fruit per bunch at the middle. Potential buds are confirmed at the tip of the branch and flowers mixed with just become a fruit (fruit bloom) is confirmed sometime occurred within the tips and the young fruit bunch.
APPENDIX 16

Photos of fruit maturity uniformity per bunch of *J. curcas* Linn

The photo shows (1) 100% uniform in green colour, (2) 11% of fruits are ripe, (3) 5% of fruits are ripe, (4) 50% ripe 20% senescence but still has 20% unripe fruits, (5) 30% ripe and 70% senescence and (6) 100% dry fruits.
APPENDIX 17

Photos of off-tree fruit ripening of *J. curcas* Linn

The photos showed (1) the harvested mature green jatropha fruit used for off-tree ripening treatment, (2) normal ripening appearance, (3) abnormal ripening in unventilated packaging, (4) abnormal ripening of exposure to 24 hours with calcium carbide (CaC$_2$), (5) appearance or ripening uniformity after 24 hours with different exposure duration with CaC$_2$, no exposure to CaC$_2$ (5a), 3 hours exposure with CaC$_2$ (5b), 6 hours exposure with CaC$_2$ and 24 hours exposure with CaC$_2$. 
5. Pendekatan kajian agribisnis di Universitas Bogor.
APPENDIX 18

Photos showed appearance of seed germination during prolong processing of harvested matured green *J. curcas* Linn.

The photos showed (1) multiple fruit ripening maturity at day 5th of storage at storage temperature (27±3°C), (2) germination on the seed of senescence black wet fruit at day 5th of storage and (3) different stage of seed germination.