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 the 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% 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 this 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 logarithmical 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 uncrushed seeds. The data showed that only 20% of oil was extracted with uncrushed 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 to 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.