3. Harvesting

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3.1. Introduction

The harvesting of the jatropha seeds is a difficult process due to the ripening characteristics of the jatropha fruit. Due to these ripening issues, the harvesting of jatropha is mainly done by hand. The harvesting process becomes a very labour-intensive process, and has a high impact on the production costs of jatropha oil. Harvesting, therefore, is an important aspect to consider in the entire production process. There have been many attempts to improve this process by mechanisation. These mechanical improvements are still under development, however, and have been applied only in pilot projects.

To provide insight into the major issues of the harvesting process of jatropha, this chapter discusses the following aspects: the harvesting and drying of fruit, the dehulling and storage of seeds, and the basic planning issues of a plantation[1]. The appendix provides practical tips and rules of thumb regarding the harvesting practice.

3.2. Harvesting technologies

One of the main impediments to producing bio-oil from the jatropha plant, is the relatively high cost of harvesting. These high costs, compared to other oil-producing crops, have a number of causes:

- The jatropha fruit ripens over a long period, requiring weekly picking for weeks up to many months a year.
- The uneven ripening of the fruit means only some of the fruit of a bunch can be harvested at one time: (i.e. yellow, brown and black fruits are ripe and can be picked).
- The jatropha fruit can *so far* only be hand-picked. This requires a lot of time, as each fruit is small (e.g. three seeds in a fruit weigh about 2 grams).
- The production of jatropha fruit on a hectare basis is moderate: i.e. the density of fruits in the field is low, requiring more transport distances in the field.

All in all, there is a relatively low yield per hectare, a long harvesting season, a small fruit size that requires a lot of hand picking and transport of the pickers, and thus is very labour intensive.

This section first elaborate on the actual picking rates and a labour cost threshold. Next the possible mechanical harvesting solutions are discussed, followed by the ongoing technology developments.

3.2.1. Manual picking of jatropha seeds

It is good to first know that the definition of picking is not always well defined. For example, is it the picking proper? Or does it also include bagging to the drying area? And transport to the pressing plant? It also is not always clear if it concerns dry seed or fresh seed. Data of general picking rates

[1] The term plantation is used for field with jatropha, not in the connotation of Estate plantation. We refer to the previous chapters on how jatropha can be grown as single crop as hedge or intercropped.

are found in a number of studies. The individual data show a large variation, but an average of all these figures however, provides useful indications, as shown below:

- Nicaragua 50 kg/day to 80 kg. The best pickers in Nicaragua harvest up to 30 kg of fruit/ hour, which would mean approximately 18 kg of seeds/hr, or 144 kg/day.
- Tanzania assumption: Picking seeds. Between 2 and 10 kg of seeds can be picked per hour, (it depends on the density of the plants).
- Tanzania: collection of seeds: 2 kg of dry seeds in 1 hour.
- Tanzania 52 kg/dry seed per day.
- India assumption: Hours necessary to harvest the seeds 125/MT This comes to 64 kg dry seed/day
- India: 8 kg of dry seeds/I hr work
- Sudan: 12 kg of dry seeds/ 4 hr work
- Indonesia: 60 kg of dry seeds/ 8 hr day (model based)
- Congo: 40-50 kg of dry seeds/ day
- Brazil: ca 48 kg dry seed /day
- Nicaragua: 64 kg dry seed/day
- Honduras: 40 kg dry seed/day

The examples show that the picking rates vary considerably by country and within a country. Low figures might be measured in areas of field hedges or low yield plantations, where seed density might be low and picking difficult because of height. If all the data are analyzed it becomes clear that 1) there is a large variation in picking efficiency, 2) that picking efficiency varies between wild stands (low yielding – harvests of 20-30kg per person per day) and well-managed plantations (high yielding – from 40-70 kg per person per day).

How does this affect costs? In a number of case studies where relatively high picking rates were used (60kg dry seed/day), the operating costs of a jatropha plantation of approx US$600 per ha per year, include roughly US$200 in harvesting, more than 30% of the operating cost. Currently, under the presumption that only manual harvesting is possible, it appears that jatropha is not a good choice for planting for a country where the labour costs exceed approximately US$4/day. This rule of thumb is based on experience in several projects over the period 1996-2009. The alternative is mechanical picking, and although not fully developed, this might bring down costs in the future.

3.2.2. Mechanical harvesting solutions

At the inception of most crop developments, picking was done by hand. But with increasing labour costs, mechanical systems were developed and allowed for substantial expansion of areas. For jatropha, this development is also taking place. The obvious way of looking at the problem is comparing plants with similar size of fruit and ripening patterns and how they are mechanically harvested. The next step is to try to adapt the technology to jatropha. Plants with similar-sized fruit are a number of nut trees, like walnut, and fruit trees like apricot and cherry. Also olive and grapes can be compared, but to a lesser extent.

Jatropha fruit are best harvested when yellow. Seeds from dried fruits have slightly lower oil content, while green fruit are low in oil. Jatropha seeds build up Free Fatty Acids (FFA) once they have ripened and lie on the ground. Several mechanical harvesting techniques for plants with a similar fruit size and shape as jatropha exist. These techniques are discussed below, together with the suitability for harvesting of the jatropha fruits:

- **Tree or stem shakers** - A mechanical grip system is put to the stem and then it is shaken so that all ripe fruits fall down. For jatropha this might work if the grip/tool has the ability to open the fruit when drying, or when the yellow fruit will fall down when shaken. Experience tells that shaking does not always provide the expected result.

- **Nets to prevent fruits falling on the ground** - These nets prevent the fruit from bruising and rotting on the ground. For jatropha, such nets can be interesting if the yellowing or ripe fruit would easily be shaken off while the green ones would not. Jatropha fruit, once on the ground, will lose their seeds. Seeds do not easily decay on the ground. Nets need to be relatively small gauge as the fruit/seeds are of small diameter of less than 6 to 8 mm. The disadvantage of nets is the collection of leaves and other debris that concentrate especially when the season of fruiting is long.
- **Strippers** - In this case the branches are raked and all fruit are stripped off the branches. This poses a problem in the ripening of the Jatropha fruit. If the fruit ripen over a longer period, the stripping of the branches is not adequate. The stripping also would require the branches to be strong and flexible enough not to break. Unless jatropha plants can be designed such that the ripening is concentrated in one period, this method is not feasible.
- **Robots with picking arms** - R&D in robots is moving fast and in high-yielding fruit they can be feasible as the product price allows. For jatropha, robots with picking arms are unlikely to be successful due to 1) low density of yield over the surface and in time 2) low costs of the end product.
- **Vacuum cleaners** - One can also choose to forego the best oil content. In this case, it's possible to vacuum clean the soil of the seeds on a regular basis. In this method one should design the machine such that the suction force allows only the seeds to be lifted and taken, leaving the soil aggregate behind. Next, using a separator like a cyclone might separate the seeds from other debris. This method might work for jatropha, if the variety really drops the fruit.
- **Other options** - There are chemicals that might allow fruit to be less fixed on the terminal. These might be sprayed, but again the costs might be prohibitive.
- **Combinations of these systems** - Of the above methods, combinations can be made. These options might also include the use of handpicking, in which the pickers would be moving on a chariot along the jatropha bush lines.

It is too early to say what the best methods are and what combinations might work best. If plants are not selected or modified to concentrate ripening in a short period, it is likely that a manual picking with tractor chariots might be a step, vacuum cleaning might also develop, or carefully stripping. Below the recent developments are highlighted.

3.2.2.1. Technologies under development

Research & development into mechanical harvesting has advanced with companies rushing to develop mechanical harvesters. At JatrophaWorld Miami 2008, a presentation was given by a group of companies like Viridas PLC and DreamFuels Ltd. DreamFuels Ltd has developed a prototype of a mechanical harvesting machine for Jatropha plantations, which they plan to use in their newly established plantation in La Belle, Florida.

Viridas PLC, a Brazilian company, has developed a prototype mechanical harvesting for jatropha plantations based on the "shakers" used in the olive industry. Based on statistics for the olive industry, one worker can hand pick just over 4 kilos per hour .With a mechanized “shaker” picker, one worker can pick 635 kilos per hour. Once mechanical harvesting has been developed, it holds a tremendous promise to reduce labour intensity and cost.
Recently, at the Hamburg Jatropha seminar, Nov 2008, neither company announced any news, so the status of their mechanical harvesting developments is unknown.

3.3. Seed extraction from fruits

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The next activity after harvesting is dehulling of the jatropha fruit, which is the process of removing the fruit shell from the seeds. Considering the shape, texture and size of jatropha fruit it can be concluded that no complicated technology is needed to separate the fruit shells from the seeds inside. The description given hopefully provides some ideas to handle the dehulling issue with local solutions. Dehulling can be done manually, semi-mechanized or fully mechanized. Manually dehulling is a time-consuming activity that can be mechanized easily. The process exists out of two steps: crushing and separation.

Dehulling can be done with fresh (yellow) fruits or with dry (brown) fruits. The shell of a fresh jatropha fruit is approximately 5 mm thick, while the shell of the dried fruit is approximately 1 mm thick. Dehulling the larger sized fresh fruit has the advantage of provoking more friction, which results in a higher dehulling efficiency than dehulling of dry fruit. The fruit shells come out of the dehuller mixed with the seeds and they need to be separated.

A few methods are known and discussed below. At this time there is a scope for further development of technologies in relation to logistics.

3.3.1. Dehulling

The dehulling principle is based on provoking slight pressure and friction on the fruits within the dehuller that results in the opening and coming loose of the fruit shells. There are different kinds of dehullers; from manual driven to motor driven. Most of the existing dehullers are designed for industrial uses and large volumes. Similar dehullers are used for coffee and peanuts. There are also small, locally made types in use, which are made of local available materials, using manpower.

3.3.1.1. Small size dehuller of "full belly project": Universal Nut Sheller (UNS)

The first interesting example of a semi-mechanized dehuller is a hand-driven bell shape device made of concrete and steel designed by Joost Brandis of the Full Belly Project. The friction is provoked by the vertical turning mill and the outer bell shaped hollow concrete shell. With the adjustable lock nut on the top of the vertical axe, the UNS can be adjusted to every desired fruit size. The UNS is made with glass fibre malls, which are to be filled with concrete and upright metal rods. The metal parts are made in standard sizes and can be found in most developing countries. This simple but effective device has a capacity of 250 kg of fresh fruit per hour, which is equivalent to 125 kg of dry seeds. It is about 60 centimetres high and 35 cm. wide and weighs about 40 kilograms

This dehuller can be connected to a pedal-forced or motorized transmission of 1 HP.

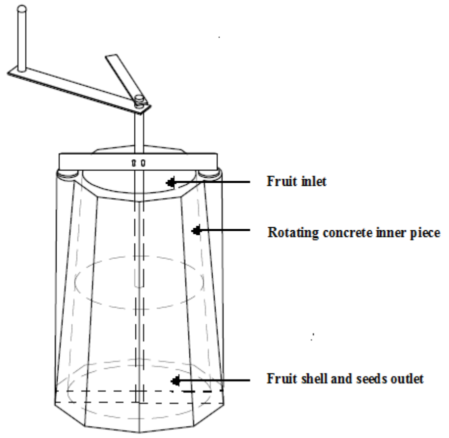

Figure : side view of the Universal Nut Sheller **Figure 2: Universal Nut Sheller [1]**

The cost of the materials of this dehuller is about US$30 in the Full Belly Project.
Two days of labour are needed to prepare the metal pieces, poor the cement in the moulds and assemble the dehuller. If assembled correctly, no maintenance is required for this Universal Nut Sheller. One disadvantage of the UNS is that it can break easily if it falls

The supplier of this decentralized nut sheller is BYSA, Yoro, Yoro (Honduras). A more detailed description on the Universal Nut Sheller assembling can be found on the Gota Verde website: www.gotaverde.org.

In Mali, these simple hand dehullers were also built and used for jatropha fruit dehulling. It is claimed that this improves the manual hand labour by 5 times. They are simple to make locally as can be seen in the figure 1. (http: www.malibiocarburant.com) The Mali Bio Carburant Company, active in Mali with small farmers, has obtained the technology from the Full Belly Project group (USA), which designs appropriate technology.

3.3.1.2. Large size “industrial” dehuller

An existing example of a large size industrial type dehuller for jatropha is the one designed by the ‘projector tempate’ in Leon Nicaragua. It works with a horizontal rotating cylinder (100 rotations per minute) of mesh, which provokes the friction in the fruit against the fixed mesh on the upper side. This mesh can be adjusted to the fruit size to optimize the dehulling process. An 8 HP diesel engine drives the dehuller and the separator simultaneously. It has a capacity of 1000 kg of fresh fruit per hour (yielding up to 500 kg of seeds per hour) and consumes 0,75 litres of fuel per hour.
The machine costs about US$2000, Its overall dimensions are 70 x 100 x 150 cm and weighs about 120 kg.

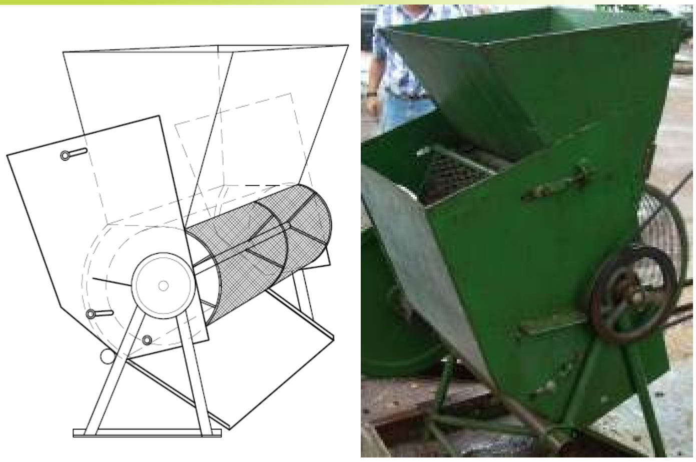

Figure 3:Dehuller “proyecto tempate”

For dehulling, mechanized versions are available in most countries. See example from Indonesia, (Eka Bukit [eka@kreatifgroup.com] http: wwwkreatifgroup.com

3.3.2. Separation of seeds and fruit shells

In practice there are two methods to separate seeds and fruit shells.

1. A simple way by hand
2. By using a mechanical separator

In both cases the principle of separation is based on the size difference between the seeds (small) and the fruit shells (yellow and large). The difference of fresh fruit shells and seeds is greater than of dried fruits (brown and shrunken) and seeds, making fresh fruit easier to separate.

3.3.2.1. Small scale (by hand)

When a manual-operated small dehuller is used, the mix of seeds and fruit shells can be separated by using a sieve, which is shaken by hand, to let the seeds pass trough the mesh while the fruit shells are retained. This allows the jatropha grower to dehull the fruit directly in the field where the shells can be used as a fertilizer without the need of drying areas and transport.

3.3.2.2. Large scale (mechanically)

With a mechanical separator, the seeds are separated from the shell by a rotating hollow cylinder of mesh that is in inclined position. The mesh size can be adjusted to the seed size. The shells fall out at the bottom end of the rotation cylinder and the fruit shells come out the lower end of the cylinder, which is inclined. Overall size of the separator is 100 x 200 x 300 cm and costs about US$700.

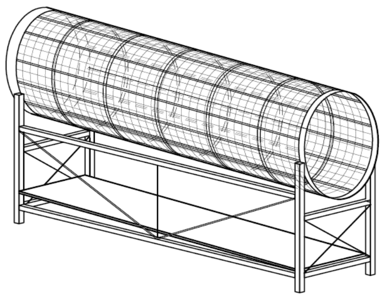

Figure 6: sketch and photograph of a separator in operation (used in the Gota Verde project in Honduras).

When shells and seeds of dry fruits cannot be separated easily, they should be separated with a blower or when no power is available in the field, by wind.

3.3.3 Drying fruit

For dehulling dry fruit, of course the fruit needs first to dry. In addition, transporting wet fruit, adds to the weight and costs, making drying even more beneficial. It has been reported that direct sun has a negative effect on sowing seed viability, and that kind of seeds should be dried in the shade.

The manual dehulling and first dying can be done on the field or in a central area. When fruit are packed without aeration they might rot and it might make the seeds dirty.

3.3.3.1. Drying area parameters

For the purpose of designing a system of solar drying and posterior storing some important parameters are discussed here.

The area for drying should ideally consist of a concrete floor or a simple agricultural plastic. A concrete floor has more solidity and can be worked on more efficiently. The floor should be slightly inclined so that rain will easily runoff and not stagnate. If dehulling machines are used on the floor, it might require a steel matting and minimum depth to hold the weight of small front loaders. Local contractors can provide the right design depending on the use of machinery.

3.4. Drying and storage of seeds

When the seeds are separated from the fruit shells they have to be stored for use. It is best is to transport the seeds from the field to the processing area. Transport modes are tractor carts, donkey carts, bikes or manual. The seeds require drying to a 6% moisture content (ideally) before pressing. The drying process takes place for the individual seeds, while storage takes place in sacks. This section elaborates more on how to dry and store seeds. It also discusses the storage conditions for different end-applications.

3.4.1. Drying of seeds

The yield per ha, period of harvesting and the duration of drying determine the size of the drying area needed. If one looks at the area needed, it is estimated that one seed requires about 2 cm^2. Or 1000 seeds, which can weigh 550 to 800 grams, require 0.2 m^2 (average would be 1400 seeds/kg). Per kg of seed, this would be around 0.25 m^2. After drying the seeds can be stored in woven sacks (aeration) for further storage.

3.4.2. Storage area of sacks

The storage area needed depends on the volume to be stored, which is a function of both the production seasonality and the press operation period during the year. It is well understood that to reduce press capacity installation costs and operational costs for running the press, one can best have presses operating throughout the year. However with a need of a continuous supply, this requires normally some storage, especially if the jatropha harvest is seasonal.

In the example below, a first estimate is given on the max storage capacity for an area of 100 ha, with an annual production capacity of 500MT and continuous demand of 42 MT/month for the oil press.

The harvest season is from December to June. The yield varies over time. The minimum yield in MT/month is in December (30 MT) and the optimum is in March (120 MT). The demand is 42 MT/month. The required storage capacity is therefore the production per month minus the demand. The maximum required storage capacity is 220 MT (sum storage need January – June). In this example an oil press can operate approx continuously over the whole year.

Table 1 – Storage approximations for 100ha area of cultivation.

Parameter	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Production	MT/month (100ha)	50	80	120	100	70	50	0	0	0	0	0	30
Demand	MT/month	42	42	42	42	42	42	42	42	42	42	42	42
Storage need	MT/month	8	38	78	58	28	8	-42	-42	-42	-42	-42	-12
Max storage	MT/month			78									
Max storage	MT (Dec-Jun)						220						
Max depletion	MT/month							-42	-42	-42	-42	-42	

The bulk density of jatropha seed is estimated at ca 400 kg/m3. This is for air-dry seed of 0.8 gram/seed.

The design of a storage shed needs to have a large roof and an open or semi-open wall structure. It can be similar as one used to store maize. It should be well aerated and the containers should be open bins, just like those for maize. Yet jatropha seed is not eaten, so fumigation is not needed. Because some 400 kg per cubic meter can be stored, the net volume for this storage shed would be 220/0.4= 550 m^3. If one converts that to a gross area (for pathways, etc.) by a factor of 2 this would need 1100 m^3. With an average height of 3 m this would be about 366 m^2 or 19m x 19 m.

3.4.3. Storage conditions

Storage conditions certainly will affect the oil quality. Seeds for oil production require more dedicated storage conditions than seeds used as planting material. The storage conditions for both applications are explained below.

3.4.3.1. Seed storage for planting

Seeds are oily and do not store for long. Under tropical conditions seeds older than 15 months show viability below 50%. High levels of viability and low levels of germination shortly after harvest indicate innate (primary) dormancy.

Seeds for planting should be dried to low moisture content (5%-7%) and stored under dark and cool conditions in containers. As seeds breathe slightly they should not be packed air tight. At a temperature of 20°C the seeds can retain high viability for at least one year. However, because of the high oil content the seeds cannot be expected to be stored for as long as most common species. The seed stored in ambient conditions maintains viability for 7-8 months. Seed viability begins to deteriorate after eight months. Therefore, seed being used for plantation should be kept at low temperature to retain its viability and ability to effectively emerge.

3.4.3.2. Seed storage for oil extraction

The oil industry requires continuous supply of raw material for oil extraction and esterification. The seeds containing the oil must be properly stored and prepared for extraction, to maintain high quality in the final product. The long storage of seeds (more than 8 months) is reported to affect oil quality and quantity hence long storage should be avoided. Long exposure to sun will also degrade oil quality. For normal storage 5%-7% of moist air or sun drying is adequate, the period of which depends on a number of factors such sunshine hours, humidity, temperature, and wind.

The seed storage should be properly aerated. This can be done in silos similar to maize. The drying of seeds up to 4% moisture enhances storability. However, the dryer the seed the lower the efficiency of the press. Therefore it is recommended to press the seed at higher moisture content, e.g. between 7%-10%, and prevent long storage of the seed.

3.5 References

[1] www.malibiocarburant.com.