IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 8, Issue 8 Ver. II (Aug. 2015), PP 13-20
www.iosrjournals.org

Some aspects of carbohydrate physiology in sugar palm (Arenga pinnataMerr.)

Julius Pontoh[1], W.Th.M. Smits[2]
[1]*Department of Chemistry, Sam Ratulangi University, Manado. Indonesia.*
([2]Masarang Foundation, Tomohon, Indonesia

Correspondent Author: *Julius Pontoh, Department of Chemistry, Sam Ratulangi University, Jalan Kampus Unsrat, Bahu Manado, 95115, Indonesia; email address: pontohjulius@yahoo.com*

Abstract: *The sugar palm (Arenga pinnata Merr.) is one of the emerging important economic plants in South East Asia, producing sugar, fibers, wood, starch and fruit. The main product of this plant is the sap containing 10 to 15 percent sucrose produced by tapping from the stalk male inflorescence. The question investigated here is whether the tapping practice changes the carbohydrate metabolic balance (source sink balance) of the palm. The research was using two trees. The first tree was used to measure the starch content and the second one to measure the sugar production. The results of the research show that an eight-year-old small sugar palm can produce about 2.5 kg sugar per day for at least 135 days from a single tapping period. This productivity amounts to about 30 tons of sugar per hectare per year that can be derived from a mixed sugar palm forest. The research demonstrates that the sugar in the tapped juice originates both from the stored starch and directly from the leaves. The tree can be considered a photosynthetic factory that allows the direct harvest of photosynthetic production without destroying or harvesting the tree itself.*
Keywords: *sugar palm, Arenga pinnata, sugar production, metabolism, transportation.*

I. Introduction

The sugar palm (Arenga pinnata Merr.) is one of the still lesser known economic plants in the tropical areas of South East Asia used to produce sugar, starch, alcoholic beverage, fiber and fruit amongst many other local uses. All of these products generate income for the farmers and can supply the needs of local people, especially food security and environmental protection. The plant grows naturally on landslide areas, in mixed secondary forests and in semi cultivated lands.

Up to now this palm was often still considered as a less important species. This may be due to the inadequate information about the production potential of this palm and how to maximize the utilization of its various products of economic value. From observations on the sugary sap production it is evident that this plant holds a very good potential for large-scale sugar and energy production. It has been estimated before that the sugar palm can produce about 25 tons of sugar per hectare per year from a mixed forest [1].

The principle of daily tapping the palm sap from the male inflorescences of this palm to produce sugar without destroying the palm and without the need for fertilizer or pesticides is very compatible with forest sustainability. This is the main reason why the Masarang Foundation is using these palms in reforestation programs all over Indonesia.

Various field observations have shown that individuals of this species can produce vast amounts of sap containing a high percentage of sugar. The sugar is mainly made up of sucrose with a very low amount of reducing sugars (glucose and fructose, [2]). The sugar concentration (Brix) of the juice varies from 10-17% but is mostly in the range 12-15 % depending upon amongst others altitude; the higher the altitude the lower the sugar concentration [3].

The sugar palm is a tall solitary hapaxanthic plant species with basipetal inflorescence production [4]. The tree can reach heights of up to 20 m. The age at which the tree starts to produce flowers varies from 7 to 15 years depend on the place where the tree grown. In the shaded place the tree will grow much longer and taller and the start of flowering will be much delayed compared to those individuals that are growing in more exposed locations. In the latter instances some individuals, especially at lower altitudes can already start flowering after only 5-6 years.

The growth of a plant can be divided into two phases, the so-called vegetative and generative phases. The vegetative phase is dominated by the development of vegetative organs such as stem and leaves, while the reproductive phase is dominated by the development of generative organs such as flowers and fruits. The energy produced by the plants during the vegetative phase is used to support the formation of vegetative organs, while the excess is stored in storage organs such as stems and roots. After that phase the energy is redirected to the reproductive organs, especially the fruits.

In the case of the sugar palm, the vegetative phase is marked by the development of the leaves each next one occurring higher on the stem. The start of the generative phase can be noticed from the development of a shorter last vertically oriented leaf followed shortly thereafter by the formation of female flowers near the top of the palm. After this periodically one by one male flower will appear beneath the female inflorescences appearing from the top to the bottom until the tree dies or the last small male inflorescence develops at the base of the palm.

The accumulation of starch in the trunk starts during the vegetative phase after the end of the rosette stage of the sugar palm and continues during the initial period of the reproductive phase. During the reproductive phase the stored starch along with direct photosynthetic products is mobilized to support the development of the reproductive organs. However, this source-sink system is still less well understood for the sugar palm. This research attempts to provide some insights in how the system functions.

Carbohydrates produced by photosynthesis in the leaves are used for structural and non-structural compounds. The structural carbohydrates including cellulose, hemicellulose and lignin function to support the plant mechanically, while non-structural carbohydrates including simple sugars and starch are used for respiration and some is saved as stored energy. Mialet-Serra, at al. [5] proposed also that the non-structural carbohydrate acts as a buffer for any sink-source imbalances.

The diurnal metabolism of carbohydrates in plants is as follows: during the day, the photosynthetic production in the form of sucrose in the source organ (mature leaves) is transported to the various sinks in the plant (meristems and young leaves to support growth, and storage organs such as seeds, stem and tubers to be stored as starch). During night time starch is remobilized as sucrose for the various carbohydrate sinks [6]. Sucrose is the major component in the transport liquid in the capillaries of the plant that is moved from the source organs to the sink organs. Up to 80 percent of the photosynthetic production is normally exported from the mature leaves [7]. The transportation takes place through phloem tissues and is highly regulated [8].

The rate of photosynthesis is determined by the CO_2 concentration in the air, the surrounding temperature and light intensity. In addition the system of photosynthesis (e.g. C3 vs. C4) can influence the rate of photosynthesis. The concentration of sucrose in the sink organ can also influence the rate of photosynthesis. Ainsworth and Bush [8] reviewed various literature sources that indicate that activities between the carbohydrate source (photosynthesis) and sink are tightly interrelated.

The sago palm (Metroxylon sp.) has a similar flowering behavior as the sugar palm being a hapaxanthic species (plants producing flowers only once followed by death). Therefore this palm will be discussed here as comparison to the sugar palm that besides this special flowering behavior also has starch as storage organ. Flach [9] discussed the physiology of this tree. He states that it is during the trunk development that the starch is accumulated and that this process reaches its maximum at the start of the flowering. The accumulated stored starch is then utilized to support the flower formation. This leads to a significant reduction in the trunks starch content. Some starch is used for the development of suckers after which the plant dies.

The sugar palm has a slightly different growth pattern when compared to the sago palm. The palm does not produce suckers and continues to live and produce over time many increasingly smaller male inflorescences, sometimes even after the fruits have fallen and when the last leaves near the top have died. Also the older the palm gets the woodier the lower part of the trunk becomes. So the trunks starch supply not only supports the energy need for the flowering and fruiting but also part of it is utilized to fortify the trunk by continually adding lignin.

Sugar palms are harvested for the production of sugar by tapping the male inflorescences [1]. The stalk of the male inflorescence is first beaten and swung several times over an extended period of 2-7 weeks, then cut at a very precise moment after which the cut of stem is sliced twice daily to keep the sap flowing from the open wound. The sap contains mainly sucrose in concentrations varying widely from 10 to 17 percent. Depending upon its genetics, growing location, light exposure, size, number of inflorescences already tapped, etc. a single individual can produce 5 - 50 liters sap a day from a single inflorescence stem. Some individual trees produced even more than 100 liters per day but this then originated from two or three simultaneously tapped inflorescences, something that can occur in a very small percentage of the sugar palms.

What this research tries to establish is what the source of the sucrose in the tapped juice is and what the potency of this plant to produce sugar. Whether it originates either directly from the photosynthetic leaves or from the built up starch supply in the stem or from a combination of both processes as postulated by Van Die and Thammes [10]. An interesting question that remains is whether the practice of tapping influences the photosynthetic rate in the leaves.

II. Materials And Methods

Two sugar palm trees were selected in the area of Tomohon, North Sulawesi, Indonesia. The first one was grown from a seedling planted in an andosol soil type in relatively exposed condition. The original seed was collected from a high producing sugar palm from a nearby tapper. The second individual was grown from a seed from another mother tree in slightly more shaded condition in a mixed secondary forest condition and was the same age as the first individual, both trees being 8 years old. The latter tree had just started to produce the female inflorescences near the top of the tree. Both trees had a stem of 8 meters high and a trunk diameter of around 50 cm but varying with height. The first tree was used to monitor the production of sugary juice that was tapped from two male inflorescences that were started at about the same time, while the second tree was used to analyze the starch content.

2.1. Sap Production [1] and measurement.

The male inflorescences were first cleaned from the scales surrounding the stems, about two months after their appearance from in between the leaf petioles. Then the inflorescence stems were systematically beaten by means of a wooden rounded mallet from the base of the stalk to the part where the strings carrying the male flowers were located (here in after referred to as top of the stalk). The beatings were repeated five times over a period of six weeks. At the time of the opening of the flowers the stalks were cut near the top. The open wound of the inflorescence stem was left for a day before the start of regular twice a day slicing of about 1-2 millimeters from the end of the stalk, which quickly lead to a steady flow of juice dripping from the wound.

The sap was collected into a plastic container using funnels to direct the sap into the containers and the funnels were wrapped with sugar palm fibers to prevent insects getting to the freshly dripping sugary juice. The sap was collected twice a day (in the morning between 7-8 am and in the afternoon between 5-6 pm). Each time after sap collection the surface of the wounded stalk was cut again taking away a slice of 1-2 mm thickness to keeps the sap flowing.

The sap volume was recorded for each collection using the plastic containers that had been marked with lines to indicate known volume heights. In addition the Brix of the juice in the container was measured by either an electronic refractometer or a simple handhold device (Brix meter, Ataco, Pocket Refractometer PAL-3). The refractometer was calibrated once a week using distilled water. In addition to this the weather conditions were recorded during the whole process.

2.2. Assessment of the starch content

2.2.1. Weight of the trunks

The weight of the trunks was approximately calculated by measuring the pith diameter and the length of the various stem parts. From these measurements the total weight of the trunk was calculated based on the specific gravity of the pith being 0.90, using the following formula:

Weight of trunk = pith volume (length (m) x $\pi r^{2\,(M)}$) x specific gravity (0.90 kg/liter) x 1000 kg.

2.2.2. Components analysis

The tree assessed for starch content was cut down at ground level and cut into 6 pieces, each measuring 1.25 meters. The small top remnant was not collected. For each trunk piece the length, thickness of the bark and diameter of the pith were measured. Pith samples were taken by grinding the pith material from the middle of the split trunk parts using a commercial machine. The sample was taken over the 1.25 meter length of the trunk part. For each trunk part a sample of 6 kilograms was collected. The water content for each sample was determined using the oven drying method. Fresh samples of each part were weighed with milligram precision on a dry aluminum sample plate. These samples were then dried in an oven at 105 ^{o}C during a 12 hour period after which the water content was calculated as follows:
Wet Weight – Dry Weight)/Wet Weight X 100%.

Starch content was determined using a water extraction procedure. The 5 kg fresh grinded samples were weighed individually and washed in draining water using a plastic screen (with holes diameter 1 mm) as filter to remove the fibrous parts of the pith. The starch was washed two times and collected in a big basket. The starch precipitated on the bottom of the basket while the overflowing water removed any non starch floating particles. After about 30 minutes the excess water in the basket was decanted and the starch was collected to be dried under the sun until the water content reached less than 5 percent. The starch content was calculated as follows:
Weight of dried starch / Weight of fresh sample) X 100 %.
Total starch content was calculated as follows:
Weight of pith material x Percentage starch content.

III. Results

3.1. Starch content

The starch content of the sugar palm was calculated based upon the starch content of each log (Table 1). The starch content varied from 11.8 to 20.5 % between the different stem pieces and averaged 16.9%. The highest starch content was located in the higher part of the trunk. The starch content tended to increase from the bottom to the top of the stem; except that the very top part had much lower starch content. The starch content for the whole tree was 75 kg.

Table1. Pith Volume, water content and starch content of a sugar palm tree.

Log Number	Pith Volume (m^3)	Water Content (%)	Starch Content (%)	Total Starch Content (kg)
1	0.032	60.7	15.7	5
2	0.046	61.1	16.1	7
3	0.066	63.6	17.6	12
4	0.086	61.2	19.9	18
5	0.121	62.3	20.5	25
6	0.069	68.9	11.8	8
Total				75

3.2. Sugar production

The two inflorescences started to produce sugary juice at different times. The second inflorescence started to produce juice about a week after the first one (Fig. 1) but its juice production lasted longer than that of the first one (130 days vs. 100 days). When the second inflorescence started producing juice it was noticed that the productivity of the first one started getting slightly less as can be seen from Figure 1. From day 65 the productivity of the first inflorescence started to diminish while the second one slightly increased for a few weeks. From day 80 a sharp drop in juice production was noticed to a stable level of about 10 liters per day.

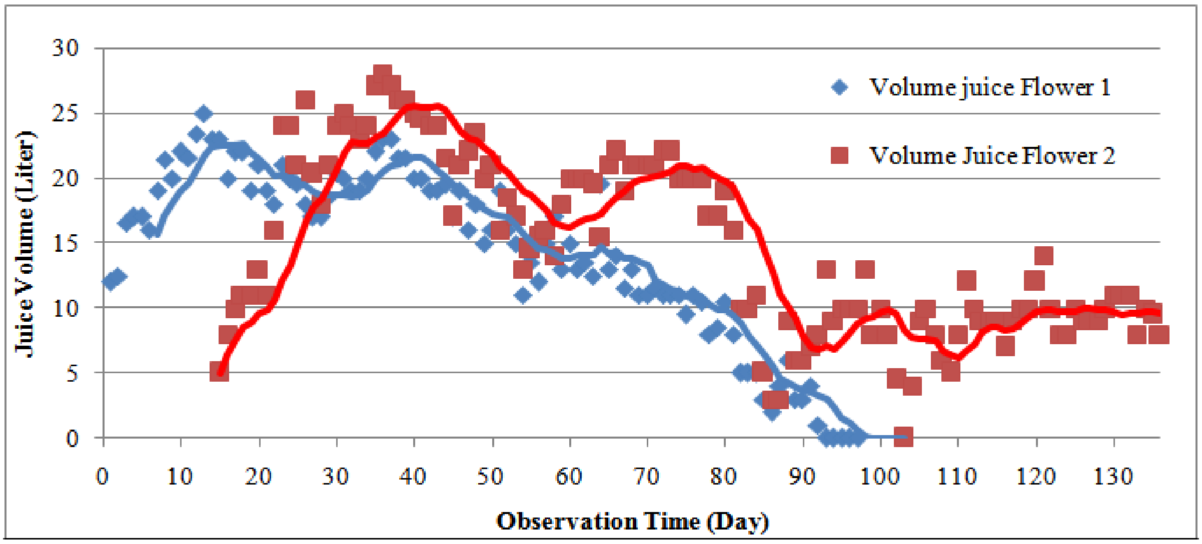

Figure 1. Juice volume (liters) produced by each of two inflorescences from a single tree during a 140 day tapping period (horizontal axis).

The total juice production in liters per day can be seen in the Fig. 2. The total volume started increased in the beginning of the tapping until it reached the maximum (about 50 liters a day) and then decreased slowly till around day 80 after which it dropped sharply until it reached a stable volume at about 10 liters a day until the experiment was stopped to prevent exhausting the palm. The palm continued to produce many more inflorescences that were tapped as well but those data were not included in the present report.

In the following figure (Fig. 3) the average Brix of the sugary juice is presented and how it fluctuated over time. The sugar content of the juice started at 13% Brix and then slowly decreased to 8% Brix at which time the palm tapper reduced the slicing of the inflorescence, thereby bringing down the amount of liters produced but raising the Brix of the juice again to about 11% Brix until the end of tapping period.

The total amount of sugar produced by this individual palm over the tapping period presented in Fig. 4. Initially the production increased steadily up to some 5 kg of sugar per day after which it decreased gradually to about1 kg per day. This lasted until the end of this tapping period.

The total sugar produced during this particular tapping period that lasted 136 days, was 325.2 kg (Fig. 5) or 2.39 kg per day on average.

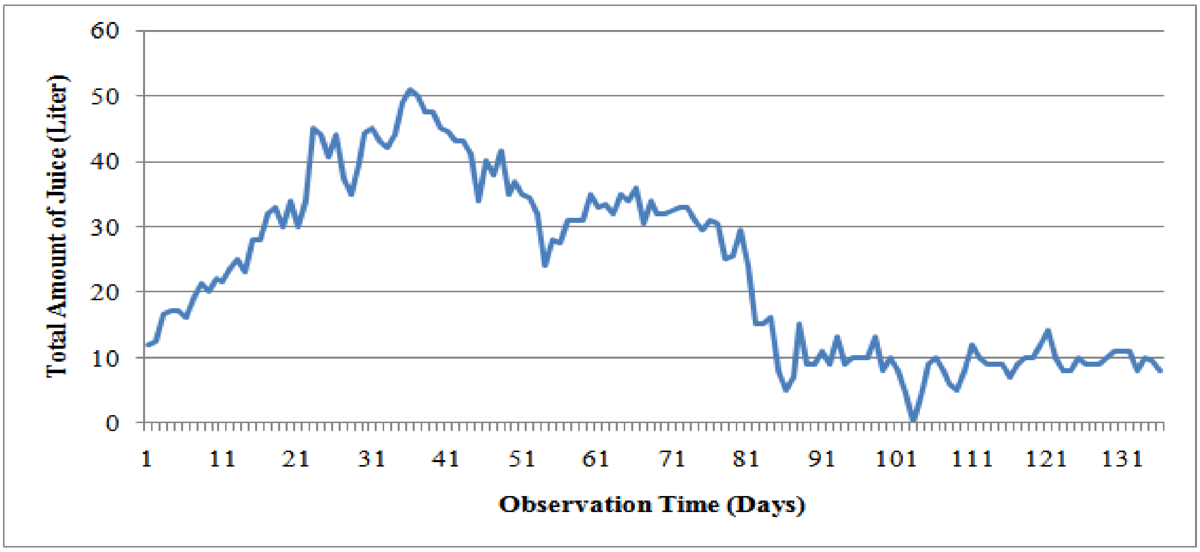

Figure 2. Total amount of juice produced by two inflorescences that were tapped during a single tapping period from a single tree.

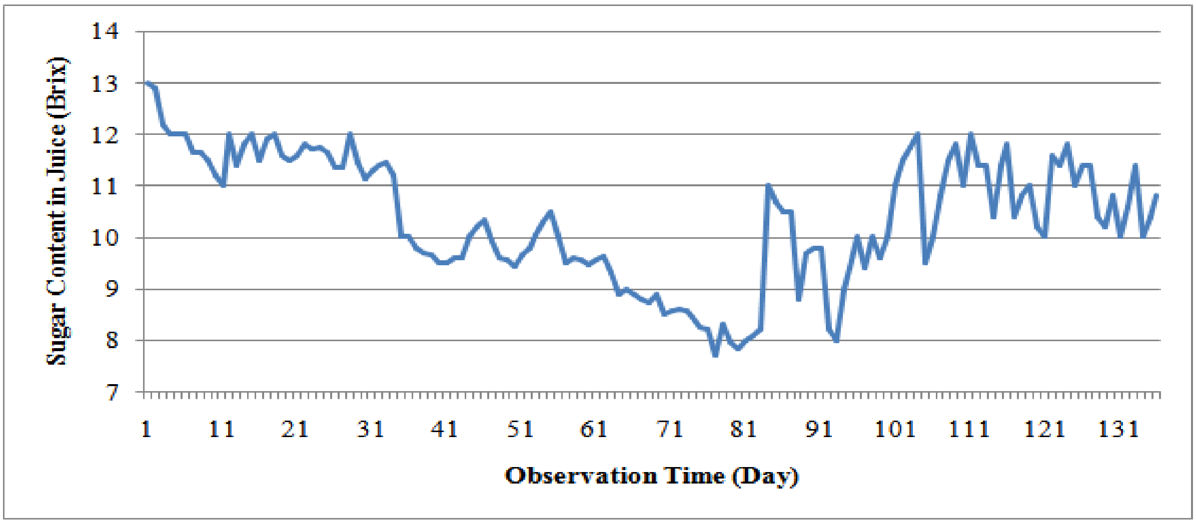

Figure 3. The average of the sugar content (Brix) of the two inflorescences during the observation period.

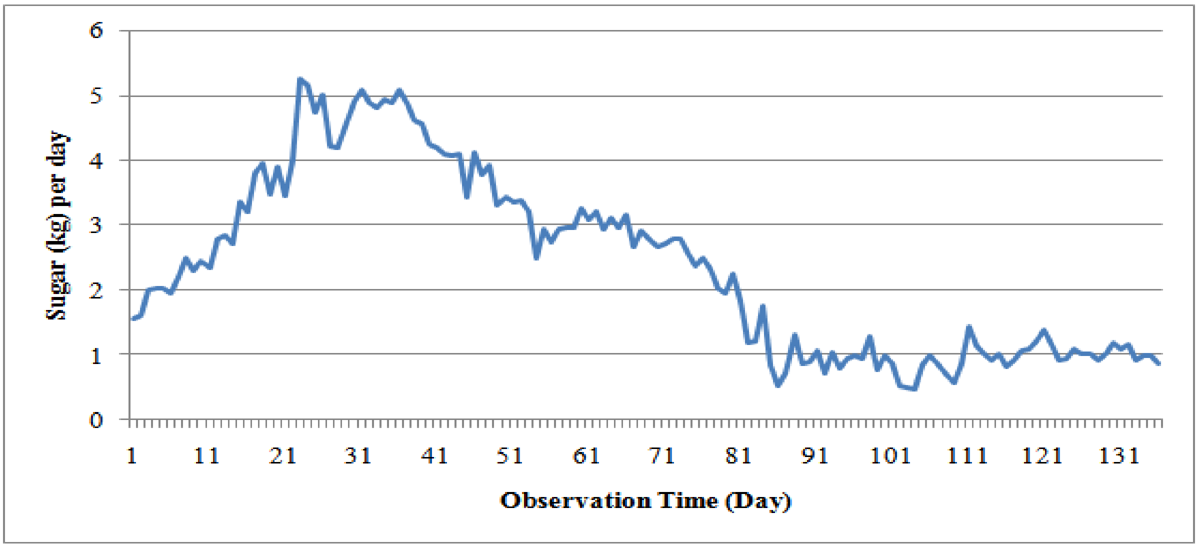

Figure 4. Total sugar (kg) produced per day by two inflorescences of a single tree over the tapping period.

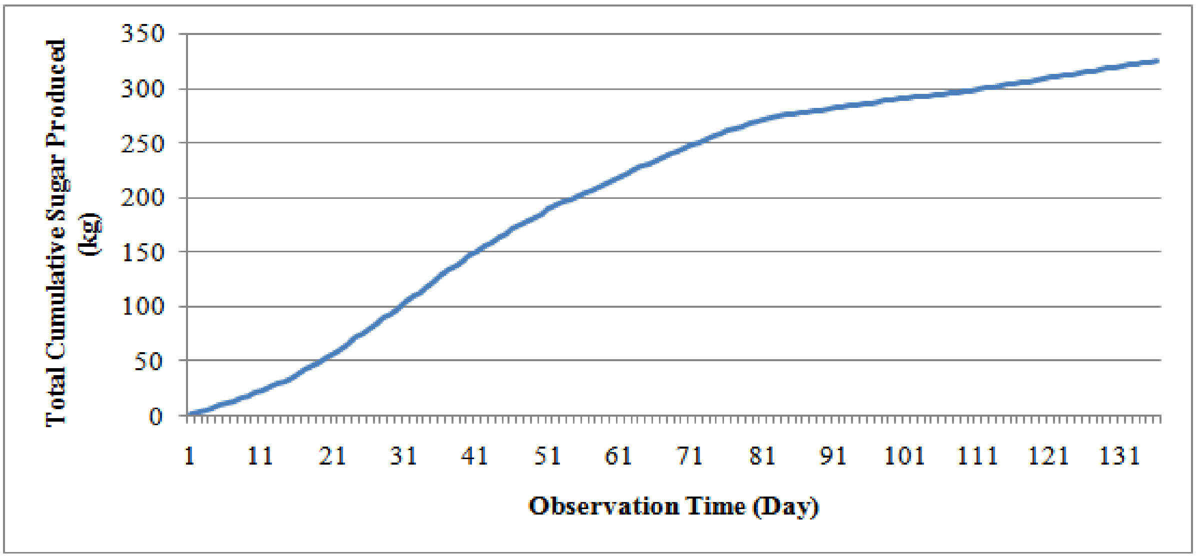

Figure 5. Cumulative sugar production by a single sugar palm during a single tapping period of 136 days.

IV. Discussion

The research shows that sugar palms store assimilates mainly in the form of starch, similar to the sago palm (Metroxylon sp.) which it resembles in many ways. In sago palms the starch content will reach maximum at the stage of flower formation [9]. The difference between these two palm species is that the sago palm only produces a single huge inflorescence followed by a quick death while the sugar palm initially produces several large female inflorescences and afterwards produces male inflorescences for many more years. Flach [9] hypothesizes that the sago palm stores the photosynthetic assimilate to be used for flowering and some for sucker formation. For sugar palms the starch seems to be used only for the production of female inflorescences and consequent fruiting. After the large quantities of big fruits have ripened the palm however continues to live and produce male inflorescences even when the last leaves have died. This means that there must be a post flowering store of starch in the stem to support this male flowering. Perhaps this is a strategy to support the year round pollination of sugar palms. The pollen is wind dispersed but bees come in large quantities to harvest the pollen but are never seen amongst the female flowers higher up in the tree.

The capacity to store starch in sugar palm trunks varies from 50 to 100 kg per palm trunk (pers. comm. with sago producers near Kulon Progo in Central Java) and the data in Table 1 fall well within this range. This number is significantly below that of sago palms that can amount up to150 to 250 kg per palm [9]. The distribution in starch content along the trunk is about the same between the two palm species, lower at the basal part of the trunk and increasing higher up the trunk and low again at the top.

The amount of starch stored in the sugar palm trunk is far lower than the amount of sugar produced during even a sugar palm tapping period (325 kg, Fig. 5). This fact shows that the sugar produced during tapping cannot just be derived from the remobilization of stored starch but has to have come for the major part directly from the photosynthetic activity in the leaves. This is in agreement agreed with the opinion of Van Die and Thammes [10], who support the idea that the sugar tapped from the sugar palm comes simultaneous from the trunk and leaves.

The ability of the sugar palm to produce sugar is phenomenal. For instance if there are only about 40 trees continually producing sugar (at 2 kg per tree per day) in a single hectare of mixed sugar palm forest then in one year this hectare can produce about 30 tons of sugar each year. This productivity is already higher than that of any other known carbohydrate producing plant species such as sugar cane (10.5 tons) and sugar beet (10 tons) and also higher than the starch producing sago palm at some 20 tones starch per year per hectare [11].

The sugar content of this tree varied from 8 to 13 Brix is relatively low compared to the average sugar content at this location (altitude higher than 500 m) that is 12.6 to 13.5 Brix [3]. They found an average production of more than 20 liters per day for slightly bigger naturally growing sugar palms. Those trees therefore produced on average almost 3 kilograms of sugar per day per tree. So the 30 tons of productivity per hectare is likely a lower estimate for the potential productivity of managed sugar palm forests.

Sugar production during tapping slowly increased at the beginning of the tapping period (Fig. 4). We postulate that this is caused by the mobilization of starch taking some time to increase as a result of the tapping taking away carbohydrates from the ripening fruits near the top of the palm. The decrease in sugar production after the peak may indicate the decrease in available starch to be converted into sucrose. The constant sugar production at the last period of tapping (during 50 days, starting after 85 days of tapping) indicates that the photosynthetic product is converted into sucrose and transported directly towards the wounded inflorescence stalk. This number shows that the photosynthetic rate is about one kg sugar per day for this small tree of only 8 years old.

The following scheme (Fig. 6.) demonstrates the overview of the carbohydrate flows in the sugar palm and what we know so far. From this scheme it is clear that the tapping of sugary juice must take away carbohydrates from the ripening fruits. And indeed this is what happens in the field. When a tapper is too "eager" and cuts thick slices from the sap-bleeding inflorescence the seeds start falling and even the top of the sugar palm can bend over and the tree dies. An experienced tapper will never let this happen and is more conservative in the amount of sugary juice he taps in order to prevent the tree from dying and to ensure many more years of tapping the same tree. Indeed the seeds of trees that have been tapped are significantly smaller and lighter than those of trees that were tapped. Also it takes up a much longer period for the seeds to ripen and fall naturally in tapped trees. This all goes to demonstrate that

This kind of phenomenon, where the photosynthetic product can be directly harvested from the plants without the need of harvesting plant parts is very rare indeed in nature. Maple syrup is different because it occurs only during the time that leaves are not yet fully developed and capable of contributing sugar to the syrup. The sugar palm tree can be seen as a photosynthetic factory, where the product (sugar) can be harvested on a daily basis from sunlight.

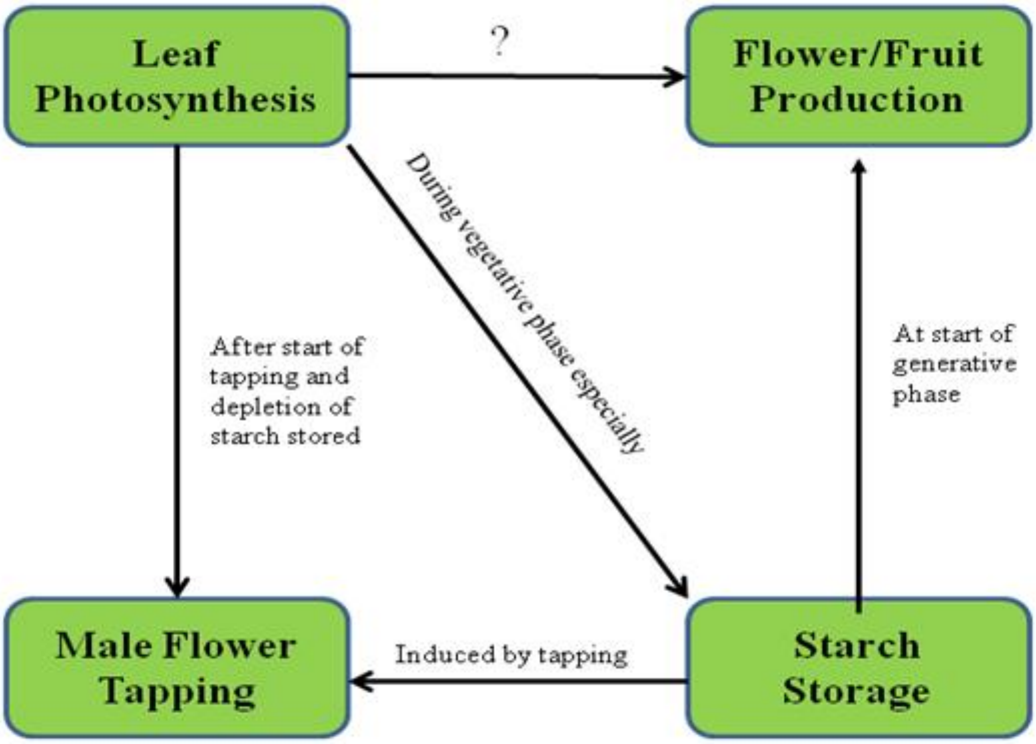

Figure 6. Carbohydrate streams in sugar palm as influenced by tapping.

The research showed that though the amount of juice varied much the amount of sugar harvested per day varied much less. Tapping should therefore focus on the health of the tree in order not to over exploit it and reduce future sugar production. For this particular tree a new male inflorescence appeared after some 3 months and started to be tapped after 6 months. It showed a similar production curve as the first tapping produced. First increasing to a steady level of 1.6 kg per day and after 80 days going down. It seems therefore that in the "resting" period, the palm was able to restore the starch in the trunk albeit not to the initial levels.

More research is needed to investigate the effect of tapping on the photosynthetic productivity. Also more work needs to be done on the exact capacity of buffering photosynthetic products in the form of starch and the speed at which it can be stored or remobilized.

V. Conclusion

Small sugar palms can produce sugar with an average of 2.5 kg per day for more than 3 months per tapping period. The sugar originates from both the starch storage in the trunk as well as directly from the palm leaves. The tree can be considered a photosynthetic factory that allows the direct harvest of photosynthetic production without destroying or harvesting the tree itself. Based on its ability to produce a significant amount of sugar in the order of at least 30 tons of sugar per year per hectare this promising palm should become an important source of sugar and energy in the near future.

Acknowledgements

We would like to thanks for Masarang Foundation, Tomohon, Indonesia for providing its facilities (Experimental Fields) and financial support to conduct the research.

References

[1]. W.T.M. Smits, Arenga pinnata (Wurmb) Merrill. In: M. Flach, F. Rumawas (Eds), Prosea: Plant resources of South-East Asia 9: Plants yielding non-seed carbohydrates. (Bogor, Indonesia, 1996) 53-59.

[2]. J. Pontoh, Analytical methods for chemical composition of sugar palm sap and palm sugar. Proc. Indonesian Seminar on Sugar Palm: Sugar palm for food and alternative renewable energy. Balikpapan 26-27 September 2012, 66-72.

[3]. H. Lantemona, A.L. Abadi, A. Rachmansyah, and J. Pontoh, Impact of altitude and seasons to volume, brix content, and chemical composition of aren sap in North Sulawesi. IOSR J. Environ. Sci. Toxicol Food Tech. 4 2014, 42-48.

[4]. J. Dransfield,and J.P. Mogea, The flowering behavior of arenga (Palmae: Caryotoideae). Bot. J. of the Linnean Soc. 88, 1984, 1-10.

[5]. I. Mialet-Serra, A. Clement, N. Sonderegger, O. Roupsard, C. Jourdan, J. Labouisse, and M. Dingkuhn, Assimilate storage in vegetative organs of coconuts (Cocos nucifera L.) Exp Agric 41, 2005, 1-14.

[6]. A. Pokhilko, O. Ebenhoh Mathematical modeling of diurnal regulation of carbohydrate allocation by osmo-related processes in plants, Royal Soc J Interface 12 2015 Issue: 105.

[7]. R. Lemoine, S. Camera, R. Atanassova, F. Dedaldechamp, T. Allario, N. Pourtau, J. Bonnemain, M. Laloi, P. Coutos-Thevonot, L. Maurausset, M. Faucher, C. Girousse, P. Lemonnier, J. Parrilla, and M. Durant, Source to sink transport of sugar and regulation by environmental factors, Front. Plant Sci. 4, 2013, 1-21.

[8]. E.A. Ainsworth, D.R. Bush Carbohydrate export from the leaf: a highly regulated process and target to enhance photosynthesis and productivity. Plant Physiol. 155, 2011, 64–69.

[9]. M. Flach, Sago palm from equatorial swamps: a competitive source of tropical starch. In: W. Stanton, and M. Flach, (Eds) Sago. The equatorial swamp as a natural resource. Proc. Second International Sago Symposium, Kuala Lumpur, Malaysia, 1979, 110-127.

[10]. J. Van Die, P.M. Thammes, Phloem exudation from monocotyledonous axes. In: N.H. Zimmermann, J.A. Milburn (Eds), Encyclopedia of plant physiology. Vol 1. Transport in plants I: phloem transport. {Springer-Verlag, Berlin, 1975) 196-222.

[11]. A. Ishizaki, Necfer's new technology for bioethanol from sago log. Proc. Workshop on Sago Development in Indonesia. Center for Estate Research and Development, Batam, Indonesia, 2007, 37-45.