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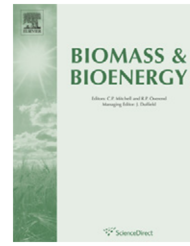

Development of sap compressing systems from oil palm trunk

Yoshinori Murata[a,*], Ryohei Tanaka[b], Kiyohiko Fujimoto[b], Akihiko Kosugi[a], Takamitsu Arai[a], Eiji Togawa[b], Tsutomu Takano[b], Wan Asma Ibrahim[c], Puad Elham[c], Othman Sulaiman[d], Rokiah Hashim[d], Yutaka Mori[a]

[a] Japan International Research Center for Agricultural Sciences (JIRCAS), Biological Resource and Post-Harvest Technology Division, 1-1 Ohwashi, Tsukuba, Ibaraki 305-8686, Japan
[b] Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan
[c] Forest Research Institute Malaysia (FRIM), 52109 Kepong, Selangor Darul Ehsan, Malaysia
[d] Universiti Sains Malaysia (USM), 11800 USM, Penang, Malaysia

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A B S T R A C T

In an attempt to utilize felled palm trunks, we found that they contain a large quantity of sap, and that abundant glucose and other fermentable sugars exist in the sap. In this study, we developed a prototype system for compressing the sap from oil palm trunks; it is composed of a rotary lathe, a shredder, and a compressing mill. A high compression efficiency of the mill was maintained (a sap recovery of ~80%) by properly preparing the trunks, which included peeling the bark and the outer layer of the trunks. In addition, a higher compression efficiency was obtained with a relatively slow rotation of the mill. Consequently, the net energy ratio (NER) reached 4.8 when the sugar concentration in the sap was 79 kg m^{-3}. This is the first paper about new developed systems for sap compressed from oil palm trunk.

1. Introduction

The oil palm (*Elaeis guineensis*) has become one of the most rapidly expanding equatorial crops in the world. The oil palm tree has an economic life, and the trees are replanted at an interval of 25 years due to decreased oil productivity [1]. In Malaysia, at least 120,000 ha of oil palm plantation was estimated to be replanted annually from 2006 to 2010 [2]. In Indonesia, 450,000 ha of oil palm plantation area is expected to be replanted annually during the next 25 years [3]. Palm trunks are not appropriate as lumber due to their high moisture (70–80% on the basis of the total mass), which leads to large warping after drying [4]. There is no available method to practically utilize felled oil palm trunks, except in plywood factories [5]. A small percentage of the felled trunks are utilized as plywood, but nearly all of the old felled palm trunks are discarded and burned at the plantation site. The stems of the oil palm tree that are left on the floor of the plantation without further processing serve as a breeding ground for insect pests, such as rhinoceros beetles, and sources of

* *Corresponding author*. Tel./fax: +81 29 838 6623.
E-mail address: muratayo@affrc.go.jp (Y. Murata).
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infection by *Ganoderma* sp., white rot fungus [6–11]. Therefore, the old felled palm trunks are a troublesome waste material, and a beneficial use for the felled trunks is strongly desired for environment preservation.

In our previous studies, it was found that a felled trunk contains large amount of sugars in its sap such as glucose and sucrose. These sugars can be converted easily to ethanol and to lactic acid, so that the trunk was found to be a significant resource for the production of fuel ethanol, biochemical and bioplastics [3,12]. However, an efficient technology has not been established yet for obtaining a large amount of the sap from oil palm trunks. Therefore, a bench-scale equipment composed of a shredder and a compressing mill has been developed in this study, which is the first system for obtaining the sap from the trunk efficiently. In this paper, we showed the details of this system, the results of compressing trials in Malaysia, and the estimation of the net energy ratio (NER) for efficient ethanol production from palm sap.

2. Material and methods

2.1. Oil palm trunk and compressing sap system

Twenty-six oil palm (*E. guinensis*) trees that were 23–25 years old (height 12 m, diameter 30–45 cm) were felled, and their felled trunks were collected from some areas that located in Johor province (1° 28′ 0″ North, 103° 45′ 0″ East), Malaysia. Deli Dura x Yangambi, URTA or URTC as major cultivar, was used in this study. The palm trunk contains the sap; the end and top of the trunk, however are easily contaminated by fungi and bacteria. Therefore, approx. 50 cm of the butt and the top of the trunk were removed before peeling the outer layer, and the remaining wood was processed into smaller logs (1.2 m). The bark and outer layer of the trees were then peeled off using a rotary lathe. Consequently, the inner part of the palm trunk, or the palm trunk core (15–20 cm in diameter, 1.2 m in length), was prepared for pressing. The compressing system is composed of an existing rotary lathe, a new shredder, and new mills. The equipment (shredder and mills) in this study was designed and manufactured by MATSUO Inc. (Kagoshima, Japan) for testing purposes. The flow chart for compressing the sap from palm trunks was shown in Fig. 1A–C and the blueprints of shredder and mill were shown in Supplement Data (the blueprints in Supplementary Data). The bark and outer layer are peeled by the rotary lathe, the palm trunk core is ripped into small chips by the shredder. The chips are compressed by the mill in order to squeeze out the sap. The compressed residues are discharged from the mill via a chute. The processing capacities of the shredder and the mill in this system were approximately 550 kg of trunk per hour and 745 kg of shredded chips per hour, respectively. The power consumption was measured throughout the process, and the energy consumption was calculated on the basis of 1 h of through put trunk since these have a uniform mass of 30 kg.

2.2. Shredder

The newly developed shredder for the palm trunk core is composed of two parts; a stage component and a cutting component (Fig. 2-1A and B). The trunk core is laid on the ripping part of the shredder, and it is stably supported by the receiving roller and the rotary cutter. The palm trunk core is then shredded into small chips by the rotary cutter. Three types of rotary cutter blades were developed for shredding the palm trunk core for efficient compression of the sap from the shredded chips: cutters with 12 mm wide and 100 mm wide blades, and a polylayer blade (Fig. 2-2A).

2.3. Compressing mills

The compressing mill comprises two mills (Fig. 3), and each mill is composed of three rotary hydraulic compressed rolls (Fig. 3A and Supplementary Fig.). The rate of turning of the rolls ranges from 0.22 rad s^{-1} to 0.76 rad s^{-1}, and the pressure ranges from 2.9 MPa to 32.5 MPa for compression. The small chips from the shredder enter into a slot in the mill and are compressed in both the first and second mills. The compressed sap is collected in pans located under each mill, and the weight of the sap is determined immediately (Fig. 3B).

We modified the roller press that is used sugar cane milling. As the fibers are both shorter and thicker than those of sugar cane, we changed the roll to increase the size of the groove, while reducing the angle of the chevron to reduce slippage of the chips and the loss of sap. Because the texture of fiber of oil palm trunk was quite different with ones of sugar cane, we needed to develop the systems for compression from oil palm trunk. The conditions (roll rotation and pressure) were optimized for the most efficient compression through trial runs.

2.4. Sap yield and energy assessment

The weight of the shredded chips was determined immediately, and then the moisture of the shredded chips was measured using a moisture analyzer (MOC-120H, Shimazu). The sap yield was calculated on the basis of the mass of juice expressed relative to the moisture content of the trunk. The moisture in chips was estimated on basis of total mass. The water content of the trunk is surprisingly high at a mass fraction of 70–80% which is much higher than that of freshly harvested wood species that most frequently have around 50–60%. The major sugar in the sap from oil palm is glucose [3]. Therefore, the sugar concentration in the sap was estimated as glucose from the refractive index using the Brix scale (Refractometer Spittz; ATAGO CO LTD., Tokyo, Japan) and a standard glucose curve. The input energy was calculated from the consumed power during operation of the equipment, including the rotary lathe, the shredder, and the mill (Power: kWh, Supplementary Table 2). The power consumed from start to finish during the operation of each apparatus (i.e., the rotary lathe, shredder, and compressing mill) was determined using an electric power meter (Clamp on Power Hi Tester 3169-01, HIOKI E. E. CORPORATION) (Power, kWh in Supplementary Table 2). The input energy was then converted into thermal terms using the following equation: