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Fruit processing residues as an alternative fuel for drying in Northern Thailand

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In this study, the fuel potential of residues from local fruit processing facilities in Northern Thailand was assessed. Facilities were surveyed to determine current processing and waste disposal strategies. In facilities handling large amounts of these fruits particularly, residues are currently disposed of in municipal dumps. Fresh processing refuse such as peels and seeds was sampled and analyzed for fuel properties. The results of proximate analysis showed mean moisture content of wastes were 35–75% wb with ash contents of about 2.2–7.1 wt.% db and high volatile matter ranging 67–73 wt.% db. Higher heating values ranged between 18.3 and 19.3 MJ kg^{-1}. Therefore, wastes showed good fuel potential, but high moisture (>60% wb) and nitrogen (>0.6 wt.% db) contents require attention when considering potential fuel applications.

1. Introduction

Thailand is a major agricultural producer with a growing demand for energy and a large potential of biomass resources, especially those related to agriculture. Government policy has been established and research is being conducted to develop alternative energy sources. Much of the respective research in this area has focused on biomass residues produced by dominating agro-industries such as paddy rice, palm oil, rubber, and sugarcane [1]. The current share of biomass in total energy consumption for Thailand is about 20%, two-third of which is used in the domestic sector [2,3]. While household applications mainly involve cooking and heating, biomass provides large amounts of energy for many industrial applications such as kiln firing, metalworking and textile processing. More recently, biomass combustion has also started to be utilized for large-scale power generation [4].

Currently, little has been documented concerning small-scale, decentralized applications of available biomass resources. Energy requirements for drying of agricultural crops are becoming a major problem in Thailand [5]. For fruit crops, typically dried on a small-scale, considerable reductions in moisture content require high temperatures (60–80 °C) and thus, demand significant amounts of energy. Liquefied petroleum gas is generally used for heating drying air, but concern is growing over the increasing price of this fuel, thus, efforts to save energy and incorporate alternative energy technology are self-evident. Among various promising renewable energy sources in the country, biomass residues from processing industries are noteworthy since these materials are readily available and currently underutilized [6]. Wastes from fruit processing are especially unexploited with a large majority of these materials ultimately becoming landfill. With ample biomass availability, the burners at drying facilities could be hypothetically adapted to utilize various forms of bio-energy to substitute fossil fuels.

Along with many tropical fruits produced in Thailand, longan (*Dimocarpus longan* Lour.) and litchi (*Litchi chinensis* Sonn.) are mainly grown in Northern regions. This area is the leading world exporter of longan, producing about 230,000 tons per annum, and also is a major production area for litchi with more than 25,000 tons harvested annually [7]. Mango (*Mangifera indica* L.) is equally important in the country, as Thailand is the main producer in Southeast Asia. Some research has already been conducted on the fuel properties of fruit processing residues [8–10], but little is known about the residues of these particular fruits, especially with respect to potential as biomass fuels. While direct combustion is the most widely practiced biomass conversion method accounting for a majority of global bio-energy production, a common alternative is the digestion of biomass to produce biogas. These processes are highly affected by the physical properties and chemical composition of the feedstock [11,12]. Knowledge of biomass fuel

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properties is necessary to realize adequate efficiency during the conversion processes as well as limiting production of undesired byproducts [13]. Investigations are required to typify local biomass resources and suggest appropriate technologies. Meanwhile, localized assessments of biomass potential provides a better understanding for the development of energy supplies [14,15]. In this context, the aim of the study was to investigate the availability and fuel properties of processing residues from mango, litchi and longan as a source of alternative energy for drying operations in Northern Thailand. A further intent was to assess in which form of bio-energy the residues might be best utilized and form a basis for further research in practical applications of local biomass resources.

2. Materials and methods

The present study was conducted around the greater Chiang Mai area, Thailand and focused on the availability and fuel properties of residues discarded by local fruit processing facilities handling mango, litchi and longan. A sampling of 13 facilities was surveyed and interviews were conducted to document current quantities and handling procedures of processing residues. The criterion for selecting facilities was the processing of at least one of the aforementioned fruit crops for at least one part of the annual cycle. A selection of larger and smaller processing facilities was surveyed, where large-scale fruit processors were defined as having a daily handling of more than 10 tons of raw materials. A semi-structured questionnaire was used to obtain information from facility operators. Facility residues were collected onsite for the three investigated fruit crops, where approximately 5 kg of waste was collected by randomly sampling fresh refuse heaps. Varieties collected included 'Daw' for longan, 'Hong Huay' and 'Chacapat' for litchi and 'Chok Anan', 'Khiew Sawoey' and 'Maha Chanok' for mango. Mixed seed and peel materials were later sorted into individual constituents prior to sample preparation. For laboratory experiments, each sample was portioned into two fractions. One part was used for moisture content (MC) determination and the other was prepared for fuel property investigations by drying at 60 °C until constant mass, dry-milled under cooled conditions, hermetically sealed and kept at 4 °C until further analysis. Whole fruits were also purchased from local markets and fruit proportions were evaluated in the laboratory for comparison with survey values.

Four samples of each fruit residue type were subjected to proximate and ultimate analyses according to the methods described in Table 1. A laboratory oven (Memmert 100, Schwabach, Germany) was used to determine MC and calculation was made as percent wet basis (% wb). A muffle furnace (Carbolite 1100, London, UK) was required for other proximate analyses where values are expresses as weight percent, dry basis (wt.% db). Samples were selected for elemental analyses, namely seed and peel samples of 'Chok Anan' for mango and 'Hong Huay' for litchi and 'Daw' for longan. Analysis of mango endocarp was included as a separate sample. For sample preparation, 200 mg of the dried material was digested with 4 ml nitric acid and 1 ml distilled water in a pressurized microwave system (Ultra Clave III MLS 1200, Leutkirch, Germany) at 220 °C for 20 min. As indicated in Table 1, C, N and H contents were determined as using an elemental analyzer (Vario EL, Hanau, Germany). Other elements were measured by inductively coupled plasma optical emission spectrometry (ICP-OES) using a PS1000 system (Teledyne Leeman Labs, Hudson, NH USA) or inductively coupled plasma mass spectrometry (ICP-MS) using an Elan 6000 system (Perkin Elmer-Sciex, Concord, Canada) or atomic absorption spectrometry (AAS) using a Unicam 939 system (Offenbach, Germany). Chloride was extracted in hot water and determined by ion chromatography (Dionex ICS-4000, Sunnyvale, Cal. USA). Values are provided as wt.% db or milligram per kilogram (mg kg^{-1}). Higher heating value (HHV) of the biomass samples was measured using an oxygen bomb calorimeter (Parr 6100, Moline, Ill. USA) and values are give in megajoules per kilogram (MJ kg^{-1}). Significant differences between means were calculated by ANOVA and comparison between groups was done by least significant difference (LSD) using SPSS software (Chicago, USA). Proximate analysis data were fitted with six literature-based models for estimation of biomass energy content (Table 2) and compared against measured values. Linear regression analysis was performed using SPSS. Other statistical parameters such root mean square error (RMSE) and mean absolute percentage error (MAPE) were calculated to determine the quality of the fit and are defined as:

Table 1
Analyzed fuel parameters.

Analysis	Unit	Procedure	Method
Moisture content (MC)	% wb	Thermogravimetric (105 °C)	ASAE S358.2 [16]
Bulk density (BD)	kg m^{-3}	Gravimetric	ASAE S269.4 [17]
Ash content (AC)	wt.% db	Thermogravimetric (575 °C)	ASTM E1755–01 [18]
Volatile matter (VM)	wt.% db	Thermogravimetric (950 °C)	ASTM E897–88 [19]
Fixed carbon (FC)	wt.% db	Calculation	ASTM E897–88 [19]
C, H, N	wt.% db	Elemental analyzer	VDLUFA [20]
S, Na, Mg, K, Fe, Mn	mg kg^{-1}	ICP-OES	VDLUFA [20]
Cd, Cr, Cu, Co, Ni, Pb, Zn	mg kg^{-1}	ICP-MS	VDLUFA [20]
As, Hg	mg kg^{-1}	AAS	VDLUFA [20]
Cl^-	wt.% db	Ion chromatography	VDLUFA [20]
Higher heating value (HHV)	MJ kg^{-1}	Oxygen bomb calorimetry	ASTM D2016–93 [21]

$$\mathrm{RMSE} = \left[\frac{1}{n}\sum_{i=1}^{N}(\mathrm{HHV}_{\mathrm{exp},i} - \mathrm{HHV}_{\mathrm{pre},i})^2\right]^{1/2} \quad (1)$$

$$\mathrm{MAPE} = \frac{100}{n}\sum_{i=1}^{N}\left|\frac{\mathrm{HHV}_{\mathrm{exp},i} - \mathrm{HHV}_{\mathrm{pre},i}}{\mathrm{HHV}_{\mathrm{exp},i}}\right| \quad (2)$$

3. Results

Results of the processing facility survey showed while total waste outputs at large facilities are roughly half of inputs for all three crops (Table 3), smaller facilities were considerably more proficient at recovering edible parts. On average, small-scale facilities produce about 30 tons and large-scale facilities about 2200 tons of raw waste per year. These figures are a combination of waste generated from mango, litchi and longan. However, the annual processing schedule for these fruits is staggered over a time from March until August according to production season: March–May for mango, May–June for litchi and July–August for longan.

Table 2
Literature models used to estimate higher heating value (HHV) of fruit processing wastes based on proximate analysis values of ash content (AC), volatile matter (VM) and fixed carbon (FC).

No.	Model	Source
1	HHV = 0.3536 (FC) + 0.1559 (VM) − 0.0078 (AC)	[22]
2	HHV = 19.914 + 0.2324 (AC)	[23]
3	HHV = −3.0368 + 0.2218 (VM) + 0.2601(FC)	[23]
4	HHV = −10.81408 + 0.3133 (VM + FC)	[24]
5	HHV = 0.312 (FC) + 0.1534 (VM)	[25]
6	HHV = 0.196 (FC) + 14.119	[25]