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Tropical waste biomass potential for solid biofuels production

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Abstract. Subsequent utilization of waste biomass in developing countries occurs at poor level, despite the fact, that it has great potential in solid biofuel production. Densified waste biomass is utilized for direct combustion, therefore, its suitability (energy potential, chemical composition) must be determined in attempt to protect environment and reduce air pollution. Main aim of present research was to determine suitability of waste biomass originating from production of rice (*Oryza sativa*), Date fruit (*Phoenix dactylifera L.*) and Jatropha fruit (*Jatropha curcas*) for solid biofuel production. Within a moisture, ash and volatile matter contents, major chemical elements (C, H, N, O) and net calorific value (NCV) were determined. Rice waste analysis proved low NCV (14.33 MJ kg^{-1}) and high ash content (20.74%), which presented problems during combustion. Jatropha fruit waste (cake) analyses exhibited outstanding NCV (24.44 MJ kg^{-1}) caused by residual oil content. Within major elements analysis a low content of oxygen (26.61%) was proved (recommended). Date fruit waste exhibited average NCV (16.40 MJ kg^{-1}). However, high oxygen content (44.01%) was defined as limiting factor. Overall evaluation proved greatest suitability for Jatropha fruit waste (cake), followed by Date fruit waste and lowest potential was determined for Rice waste. However, investigated plants are not cultivated for energy production purposes, thus, observed results achieved satisfactory level of their suitability for solid biofuel production.

Key words: briquettes, renewable energy, calorific value, Jatropha curcas, rice husk.

INTRODUCTION

The impact of intensive form of agriculture production, as well as extensive form (in many cases), leads to production of uncontrollable amount of various waste materials, in other words a waste biomass. If considered, such large amount of produced waste biomass its subsequent utilization is necessary and cannot be overlooked. Increasing popularity of intensive agriculture production is presented to public as a key to improve human living standards, but the side effect of establishment of such agriculture production represents serious negative impact on environment (Goldemberga & Coelho, 2004; Fullerton et al., 2008).

According to United Nations Environment Programme (UNEP) the agriculture sector produces approximately 5 billion metric tons of waste biomass every year. The equivalent of mentioned amount of waste biomass is 1.2 billion tons of oil, which represents approximately 25% of global production nowadays (UNEP, 2017). In this light, our challenge is to reduce dependence on petroleum as a source of energy. Our society requires food and energy independence so that the area, either at national, regional or local level, can become independent both materially and in terms of energy usage (Osaki, 2011) and therefore it is important to use waste biomass for further energy purposes. Because unused and irresponsibly stored waste biomass can cause spontaneous production of leachate and methane (CH_4), also carbon dioxide (CO_2) and other pollutants due to open burning of waste biomass, thus, contributes to soil, air and water contamination (United Nations, 2017). Also, the impact of using carbon based fuels for energy generation leads to environmental degradation and climate changes (Suzuki et al., 2016). Thus, it is time to consider waste, in general, as a choice for sources of fuel for further power generation. In view of these facts, the effort and obligation of subsequent utilization of waste biomass should represent major goal of agriculture sector. Moreover, several of the United Nations Sustainable Development Goals (SDGs) are related to environment conservation, thus, overall protection of planet Earth within sustainable development agenda. Specifically, Goal 7: 'Ensure access to affordable, reliable, sustainable and modern energy for all' focused on global expansion of clean renewable energy (biomass) and its fossil fuels substitution (United Nations, 2017).

It is essential to realize that developing and emerging economies are facing a two-fold energy challenge in the 21st century, as they need to meet needs of billions of people who still lack access to basic, modern energy services while simultaneously need to participate in a global transition to clean, low-carbon energy systems (Ahuja & Tatsutani, 2009). Of course, a much debated question is how to achieve this challenge. However, with rising demands for clean energy and recurrent fuel scarcity there is need to diversify fuel supply and maximize use of natural resources and reuse of waste materials. Furthermore, progress toward increased efficiency, de-carbonization, greater fuel diversity and lower pollutant emissions needs to be accelerated (Ben-Iwo et al., 2016; Suzuki et al., 2016). Approximately 80% of energy production in developing countries is accounted for biomass (UNEP, 2017). Focused on Asian countries a cultivation of rice (*Oryza sativa*) represents major part of local agriculture production which implies also great amount of herbaceous waste biomass production in the form of husks and straw (Lantin, 1999). Waste is a serious and growing problem throughout tropical Asia, as waste management technologies and policies are not keeping up with the rapid increase of waste production (MacRae, 2012). Both waste materials are commonly burned by farmers in order to clear their fields without any energy purposes, see in Fig. 1 (Author's data), nevertheless, utilization of rice straw for heating purposes was investigated by previous authors with satisfactory energetic results (Chou et al., 2009; Eissa et al., 2013).

Focused on fruit waste biomass, a cultivation of Date palm (*Phoenix dactylifera L.*) is mainly located in North Africa, Middle East and China and plays important role in local agriculture sector. Date fruit production and consumption is considered as an inherent part of nutrition dietary in many cultures (Said et al., 2014). After processing of Date fruits a wastes biomass in the form of fruit pits or skins are left behind (fruit biomass) having minimal economic value and only in small quantities are used for combustion purposes or occasionally as fillers in composite systems (Said et al., 2014; Ruggiero et al., 2016). A Gravalos et al. (2016) have proved possibility of reusing of fruit pits, seeds and kernels for combustion purposes, namely, the olive pits, cherry seeds, apricot kernels, peach kernels, watermelon seeds or grape seeds.

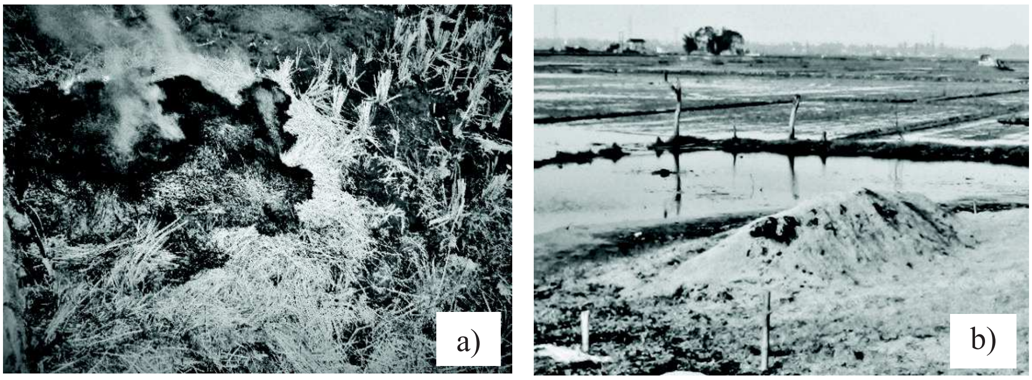

Figure 1. Burning pile of a) rice straw and b) rice husk on the rice fields in Socialist Republic of Vietnam.

Oil production sector situated in tropical and subtropical countries purposely cultivates different plants as a source of vegetable oil; *Jatropha Curcas L.* is one of mentioned plant (Samsuri et al., 2014). This crop is cultivated on large plantations and the oil from seeds is widely used throughout the world; in small scale is used as fertilizer and for soap or local medicine production but the larger utilization is in biofuels production (biodiesel). Jatropha seeds are pressed for the oil extraction purposes and during this process also a by–products (i.e. de-oiled press cake or pomace) are generated (Joshi & Khare, 2011). Subsequent utilization of such secondary raw material for solid biofuel energy generation purposes was investigated previously by Singh et al. (2008) with positive results.

In the view of these facts, present study deals with the issue of reusing of specific waste biomass for solid biofuel production. Main aim of experimental testing of present study was to determine the energy potential of specific waste materials originating from production of Rice, Jatropha oil and Date fruit products, and therefore, state the suitability of investigated waste materials for combustion purposes in case of use as feedstock materials for solid biofuel production.

MATERIALS AND METHODS

All process of experimental testing of present research was conducted to regulations and recommendations in accordance to related mandatory technical standards. Detail information about specific procedures are described below.

Material preparation

Two different types of waste biomass originating from agriculture sector were investigated for the purposes of present research. Firstly, (i) herbaceous biomass represented by rice husks and secondly, (ii) fruit biomass represented by Date fruit skins and pits and Jatropha press cakes and shells. All chosen waste materials were produced during technological processing of specific agriculture crops or products in different countries of origin. Namely, waste materials from rice production originated from Socialist Republic of Vietnam (SRV), Date fruit waste materials originated from People's Republic of China (CN) and Jatropha wastes originated from Republic of Indonesia (ID). Initial preparation of investigated materials performed before experimental testing consisted materials drying by using of laboratory drier LAC (Rajhrad, Czech Republic) for 20 hours at 105 °C. Secondary, all investigated samples were milled by hand knife mill working with 20,000 rpm min^{-1}.

Moisture, ash and volatile matter determination

Within performance of actual experimental testing all investigated samples (n = 5), namely Rice husk, Date skin, Date pits, Jatropha press cake and Jatropha shells, were primarily ground into fine powder with particle size < 0.1 mm. Subsequently, investigated samples were analysed for moisture content, ash content, volatile matter content, elemental composition and calorific value. The first three parameters were analysed by using of thermogravimetric analyser LECO TGA 701 (Saint Joseph, United States). The temperature programme was set at 107 °C and samples were dried to constant weight at first, within what its moisture content was determined. Further, the volatile matter content of samples was determined after seven minutes lasting drying at 900 °C; correction was performed against a coal standard with 41.4% volatile matter content. As the last, the ash content was determined after samples burning in oxygen at 550 °C until constant weight.

Elementary composition determination

Elemental composition (carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) contents) of investigated waste materials was analysed in laboratory instrument LECO CHN628+S (Saint Joseph, United States) working with helium as carrier gas. Within present testing the investigated samples were burned in oxygen and resulting flue gases were analysed. Contents of C, H and S were measured in infrared absorption cells and content of N was measured in a thermal conductivity cell. For determination of C, H and N contents a 0.15 g of sample was wrapped into a tin foil and burned at 950 °C; the EDTA (ethylenediaminetetraacetic acid) and rye flour were used as a calibrating standard. Within S content determination the samples weighing 0.2 g were poured into a crucible and burned at 1,350 °C; calibrating standards for S module were rye flour and coal. Every investigated sample was analysed repeatedly in attempt to get at least three good measurements of each element during present experimental testing.

Calorific value determination

Gross calorific value of specific selected waste material was measured in an isoperibol calorimeter LECO AC 600 (Saint Joseph, United States). Investigated samples were primarily pressed into pellet form (or let in powder form, if practicable) and subsequently burned. Gross calorific value was determined using the supplied software and least three reliable results were acquired for every sample. The relationship between gross calorific value Q_s (MJ kg^{-1}) and net calorific value Q_i (MJ kg^{-1}) was expressed according to ISO 1928 (2010). For complete calorific value determination, the following measurements and calculations described in Equations (1), (2), (3) and (4) were performed:

The theoretical amount of oxygen O_{min} ($m^3\ kg^{-1}$) was stated by the equation (real molar volumes were used):

$$O_{min} = \frac{22.39}{12.01} \cdot C + \frac{22.39}{4.032} \cdot H + \frac{22.39}{32.06} \cdot S - \frac{22.39}{31.99} \cdot O \quad (1)$$

where: C – carbon content in wet basis (%), H – hydrogen content in wet basis (%), S – sulphur content in wet basis (%), O – oxygen content in wet basis (%).

The theoretical amount of dry air L ($m^3\ kg^{-1}$) was determined by equation:

$$L = O_{min} \cdot \frac{100}{21} \quad (2)$$

where: O_{min} – theoretical amount of oxygen ($m^3\ kg^{-1}$).

The theoretical amount of dry flue gases $v^s_{sp_{min}}$ ($m^3\ kg^{-1}$) was based on the equation:

$$v^s_{sp_{min}} = \frac{22.27}{12.01} \cdot C + \frac{21.89}{32.06} \cdot S + \frac{22.40}{28.013} \cdot N + 0.7805 \cdot L \quad (3)$$

where: C – carbon content (%); S – sulphur content (%); N – nitrogen content (%); L – theoretical amount of dry air ($m^3\ kg^{-1}$).

The theoretical amount of emission concentrations of CO_2 ($m^3\ kg^{-1}$) was based on the equation:

$$CO_2 = \frac{\frac{22.27}{12.01} \cdot C}{v^s_{sp_{min}}} \cdot 100 \quad (4)$$

where: C – carbon content (%); $v^s_{sp_{min}}$ – theoretical amount of dry flue gases.

RESULTS AND DISCUSSION

Considering the fact that investigated waste materials differed from a taxonomical point of view the evaluation of obtained result values were performed individually with focus on waste materials originated from each plant.

If focused on Date fruit waste biomass, obtained result values exhibited satisfactory level of energy potential expressed by Net calorific value in dry basis equal to 16.40 MJ kg^{-1} for Date skin samples and equal to 17.84 MJ kg^{-1} for Date pits samples. Previous study of Nasser et al. (2016) focused on energy potential of different parts of Date palm (*Phoenix dactylifera L.*) proved Gross calorific value of Date fruit pits equal to 19.85 MJ kg^{-1} which corresponds to the result value obtained from experimental testing of present paper. According to other study made by Gravalos et al. (2016) fruit pits are suitable for combustion purposes within what a calorific value of olive pits (*Olea europaea*) was stated 17.97 MJ kg^{-1}. However, overall evaluation of present waste materials suitability for combustion purposes indicated undesirable high oxygen content, specifically 44.01% for Date pits and 45.06% for Date skins (bolded in Table 1). This observation was defined as a limiting factor of Date biomass because elementary composition of biofuels affects both its calorific value and behaviour during combustion.

Especially high content of oxygen in biofuel will change the combustion air consumption and amount of flue gas.

Table 1. Composition analysis of waste biomass from Dates, Jatropha and rice plants

Sample / Average values	Water Content (% wt.)	Ash content (% wt.)	Volatile matter content (% wt.)	Gross Calorific Value (MJ kg^{-1})	Net Calorific Value (MJ kg^{-1})	Carbon (% wt.)	Hydrogen (% wt.)	Nitrogen (% wt.)	Sulphur (% wt.)	Oxygen (% wt.)
	W	*A*	*VM*	Q_s	Q_i	*C*	*H*	*N*	*S*	*O*
Date skin, os.	6.88	2.65	75.71	16.52	15.10	42.20	5.72	0.52	0.08	41.97
Date skin, db.	–	2.84	81.30	17.74	16.40	45.31	6.09	0.55	0.08	**45.06**
Date pits, os.	5.90	1.18	79.31	18.13	16.65	44.24	6.13	1.04	0.10	41.42
Date pits, db.	–	1.25	84.29	19.26	17.84	47.01	6.52	1.11	0.10	**44.01**
Rice waste, os.	6.06	**19.48**	64.65	14.43	13.32	37.28	4.43	0.38	0.06	32.32
Rice waste, db.	–	**20.74**	68.82	15.36	14.33	39.68	4.71	0.41	0.06	34.40
Jatropha press cake, os.	4.94	4.36	83.96	24.83	**23.12**	54.83	7.32	3.05	0.21	25.30
Jatropha press cake, db.	–	4.58	88.33	26.12	**24.44**	57.67	7.70	3.21	0.22	26.61
Jatropha shell, os.	7.39	1.45	69.58	19.59	18.29	49.77	5.15	0.49	0.04	35.71
Jatropha shell, db.	–	1.57	75.12	21.16	19.94	53.73	5.56	0.53	0.05	38.56

(os. – original sample, db. – in dry basis).

Results observed within Jatropha fruit waste analyses exhibited Net calorific value in dry basis at outstanding level for Jatropha press cake samples (24.44 MJ kg^{-1}) and at high level for Jatropha shell samples (19.94 MJ kg^{-1}) which was caused by residual oil content (bolded in Table 1). According to Ružbarský et al. (2014) the calorific value of Jatropha fruit differs in accordance to different parts of fruit. Following values were stated by their previous research: seeds coat – 18.21 MJ kg^{-1}, seeds kernel – 29.27 MJ kg^{-1}, seeds – 24.88 MJ kg^{-1}, oil-cake from kernel – 20.38 MJ kg^{-1}, oil-cake from seeds – 19.63 MJ kg^{-1}. Focused on energy consumption (financial input) of Jatropha fruit processing (oil production) it was proved that energy required to pressing of different parts of fruit was equal to 147,052 J for seeds and equal to 76,849 J for kernels, thus, difference between investigated samples was approximately 50%. This observation must be considered within evaluation of Jatropha waste efficiency (Müller et al., 2015).

Such high level of calorific value was observed also for waste materials of other agriculture crops cultivated for oil production such as the Sunflower and Rapeseed which exhibited calorific value equal to 21.23 MJ kg^{-1} and 21.57 MJ kg^{-1} (Gravalos et al., 2016). Husain et al. (2002) also proved calorific value of oil palm shells equal to 16.4 MJ kg^{-1} which is lower level in compare with Jatropha shells (19.94 MJ kg^{-1}) tested in present research. Subsequent utilization of waste biomass originating from Jatropha technological processing was proved as a suitable and advantageous previously (Jingura et al., 2010) and the possibility of reusing of Jatropha waste biomass as a feedstock for briquette production was also proved (Singh et al., 2008).

If compare all result values of investigated samples (see in Table 1), the highest ash content was stated for waste biomass from rice production (rice husks), namely, equal to 20.74% (bolded in Table 1). Likewise, unsatisfactory result of rice husks ash content equal to 19.2% was proved by Vassilev et al.(2015). On the contrary, other authors dealing with rice waste chemical composition issue proved level of ash content of rice straw equal to 15.6% (Thy et al., 2006) and equal to 11.25% (Chou et al., 2009). In general, non-woody biomass contains more ash (Gürdil et al., 2009) in compare with woody biomass (Johansson et al., 2004). Nevertheless, such high level of ash content observed in present research represented problems during combustion. This phenomenon was reflected in low level of Net calorific value of rice husk samples which was stated 14.33 MJ kg^{-1}. Previous studies of Chin (2000) and Gravalos et al. (2016) proved similarly low level of rice husk calorific value, namely 14.77 MJ kg^{-1} and 15.97 MJ kg^{-1}, however, the ash contents of investigated samples were not mentioned. Apart from low calorific value, high level of ash content also causes the clog of combustion devices grates by bottom ash, thus, obstructing the way for combustion air (Malaťák & Passian, 2011). Other authors, however, point out the possibility of subsequent reusing of rice husk ash as a cleaner and novel adsorbent of Methylene Blue and Congo Red in Aqueous Phases (Chowdhury et al., 2009; Foo & Hameed, 2009). This fact adds a value to produced waste material (rice husk ash) and support its subsequent utilization.

Biomass elementary composition influences result level of calorific value as well as biomass behaviour during combustion. Within major elements analysis a required low content of oxygen was proved for Jatropha waste samples (see in Table 1). During experimental combustion of Jatropha press cake and shell were observed a different amounts of combustion air resulted in different flue gas concentrations. This phenomenon can be seen in Table 2 within the comparison of result values of Jatropha press cake samples with the rest of analysed materials. The resulting high combustion air intake and high flue gas production might require specific setting of combustion device (Skanderová et al., 2015; Malaťák et al., 2016) as it hinders the energy use.

Table 2. Result values of combustion air intake and flue gas production

Sample / Average values	Theoretical amount of combustion air $^{(2)}$		Theoretical amount of dry flue gases $^{(3)}$		Theoretical concentration of carbon dioxide in dry flue gases $^{(4)}$	
	(kg kg^{-1})	(m^3 kg^{-1})	(kg kg^{-1})	(m^3 kg^{-1})	(% wt.)	(% vol.)
Date skin, os.	5.02	3.86	7.34	3.80	21.08	20.58
Date pits, os.	5.42	4.09	7.72	4.09	21.00	20.08
Rice husk, os.	4.42	3.4	6.71	3.35	20.37	20.62
Jatropha press cake, os	7.74	5.97	9.89	5.70	20.33	17.84
Jatropha shells, os.	5.96	4.59	8.33	4.51	21.91	20.46

(os. – original sample).

In general, knowledge based on observation of present parameters and their result values represent important step within setting and optimal performance of combustion devices. Moreover, using of such a knowledge can positively influence and improve technologies for processing of waste biomass into solid biofuels (Jourabchi et al., 2016).

CONCLUSIONS

Overall evaluation of observed result values indicated suitability of investigated materials for combustion purposes, thus, proved their suitability for possible solid biofuel production. Specific parameters of tested samples exhibited satisfactory level.

In general, these results indicate that even though all selected plants are not commonly cultivated for energy production purposes, they proved high level of energy potential (especially in case of Jatropha wastes). In case of rice wastes a high content of ash was detected, nevertheless, the potential of rice husk ash reusing as a cleaner and novel adsorbent was proved by previous authors. Undesirable higher oxygen content of Date wastes can negatively influence combustion properties of materials, but the calorific value achieved satisfactory level, hereby, it can be concluded that a balance between the positives and negatives of this material was achieved. Taken together, reusing of all present waste materials is highly recommended, as well as all kinds of waste materials (especially the biological ones) in attempt to keep the main key factors of proper waste management 'Reduce – Reuse – Recycle'. A natural progression of this work is to analyse further tropical waste biomass in order to extends our knowledge of appropriate waste materials for further energy purposes.

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