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Agricultural residues in Indonesia and Vietnam and their potential for direct combustion: with a focus on fruit processing and plantation crops

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Abstract. Energy consumption in Indonesia and Vietnam has grown rapidly in recent decades. To meet the energy needs of both countries, a higher utilisation of waste biomass sources may represent an adequate solution. Investigated samples represent major crop residues (waste biomass) originating mainly from the agriculture sector of the selected countries. Herbaceous waste biomass from Indonesia is, namely, cassava stems and root peelings (*Manihot esculenta*), coffee leaves (*Coffea arabica*), cacao leaves (*Theobroma cacao*), banana leaves (*Musa acuminata*), bamboo leaves (*Bambusoideae* spp.) and aloe vera leaves (*Aloe vera*). Furthermore, fruit and aquatic waste biomass originating from Vietnam is, specifically, sugarcane bagasse (*Saccharum officinarum*), durian peelings (*Durio zibethinus*), rambutan peelings (*Nephelium lappaceum*), banana peelings (*Musa acuminata*), water milfoil (*Myriophyllum spicatum*) and water hyacinth (*Eichhornia crassipes*). All mentioned types of waste biomass were subjected to proximate and calorimetric analysis: moisture, ash and volatile matter contents (%) and higher and lower heating values (MJ kg^{-1}). Obtained values indicated the highest level of ash content in fruit biomass samples in the case of sugarcane bagasse (0.84%), in herbaceous biomass in the case of cassava stems (3.14%) and in aquatic biomass in the case of water hyacinth (14.16%). The highest levels of lower heating values were achieved by following samples (best samples from each biomass type): cassava stems (17.5 MJ kg^{-1}); banana peelings (17.3 MJ kg^{-1}) and water hyacinth (12.8 MJ kg^{-1}). The overall evaluation of all observed samples indicated that the best suitability for energy utilisation by direct combustion of investigated representatives is fruit waste biomass, followed by herbaceous waste biomass and then aquatic waste biomass.

Key words: renewable energy, waste management, biological residues, waste biomass, calorific value, energy potential.

INTRODUCTION

Energy is generally considered a crucial component for ensuring sustainable livelihood, and the world needs an enormous amount of energy to support future economic developments. A reliable energy supply is essential in all economies for heating, lighting, industrial equipment, transport etc. (IEA, 2014). However, almost one quarter of the world's population, most in developing countries, have basic energy needs that are not being adequately met (Mendu et al., 2012).

Therefore, there are efforts to increase the use of renewable energy resources in the developing world (Ahuja & Tatstani, 2009), especially from waste biomass (Brunerová et al., 2017b). Biomass energy is an important source of energy in most Asian countries (fuelwood, charcoal and other biomass energy such as agricultural residues), which is used by households and small-scale farms (Koopmans & Koppejan, 1998). One option of renewable energy resource utilisation is to extend the use of agricultural residues as potential energy sources because agricultural residual biomass can be used to produce energy (Li & Hu, 2003; Lozano & Lozano, 2018). As papers by Picchi et al. (2013), Obi et al. (2016), Romallosa & Kraft (2017) or Rezania et al. (2016) indicate, not only solid biofuels from wood waste biomass provide satisfactory energy potential, but also different waste biomass types (herbaceous, fruit, mixed) can represent a suitable source of renewable energy that can compete with fossil fuels. The current subsequent utilisation of waste biomass in developing countries occurs at a low level (Brunerová et al., 2017a).

It needs to be stated that knowledge about the current use of crop residues is very limited (Bentsen et al., 2014) as very few countries are collecting data on residue production and use (Bentsen et al., 2018).

Using biomass as an energy source is generally considered an option to mitigate greenhouse effects (Owusu & Asumadu–Sarkodie, 2016; Lozano & Lozano, 2018) and such biomass can be from agricultural residues. Crop residues represent more than half of the world's agricultural phytomass (Lozano & Lozano, 2018). That amount of residue is large and may have a significant energy potential (Nonheber, 2007). But it has to be mentioned that a significant amount of residue is also being used as livestock feed (Nonheber, 2007), and it should not be forgotten that a certain amount of residue is being left onsite to protect soil productivity (Bentsen et al., 2018). According to Scarlat et al. (2010), the amount left on site should usually be between 15% and 60% for most crops; however, the remaining amounts still leave potential for further processing and use.

Very little information is available on how the farmers themselves see their situation regarding the use of agricultural residues in developing countries (Koopmans & Koppejan, 1998; Winkler et al., 2018). However, the farmers' opinions will determine the adoption and increased use of agricultural residues on a farm scale level. Furthermore, as a study by Bilgili et al. (2017) shows, the use of agricultural residues can also be an efficient policy tool for sustainable development. In the issue of waste biomass (herbaceous or fruit) generation of an agricultural crop investigated in the present research, the area of their cultivation in target countries was monitored; detailed values are noted in Table 1.

Energy consumption in Indonesia and Vietnam has grown rapidly in recent decades. To meet the possibilities and needs of both countries, higher utilisation of waste biomass sources may represent an adequate solution. Therefore, this study covers the energy potential from various agricultural residues from major crops in Indonesia and Vietnam.

Table 1. Harvested areas of specific agriculture crop cultivation in 2016

Country	Plantation plant	Cultivated area, ha
Indonesia	Banana tree	139,964.0
	Cassava plants	867,495.0
	Cacao tree	1,701,351.0
	Coffee tree	1,228,512.0
	Sugar cane plants	472,693.0
Vietnam	Banana tree	120,041.0
	Cassava plants	579,898.0
	Coffee tree	597,597.0
	Sugar cane plants	256,322.0

ha – hectares (Source: FAO, 2018).

MATERIALS AND METHODS

All investigated materials were produced as agricultural residues, thus, they were characterised as a waste biomass (renewable source of energy) because of their biological origin and the nature of their origin. As a result, performed experimental methods were defined by technical standards related to the bio-briquette fuel production and its subsequent quality testing, namely, by the technical standards EN 14918 (2010), EN 15234–1 (2011), EN ISO 16559 (2014), EN 18134–2 (2015), EN ISO 17225–1 (2015), ISO 17225–7 (2014), EN ISO 18122 (2015), EN ISO 18123 (2016), whose requirements must be followed and achieved in biofuel commercial production. Each standard is described in the following text related to the biofuels' specific quality indicators, and their full names are noted in the References.

Materials and samples

Investigated waste biomass samples originated from Southeast Asia, namely, from the Socialist Republic of Vietnam and the Republic of Indonesia, as shown in Fig. 1. The specific areas of sample collection in each country are identified by red frames.

Figure 1. The areas of sample collection in the Republic of Indonesia and the Socialist Republic of Vietnam (Adopted from: Wikipedia Commons, CC BY-SA 3.0).

The official administrative division of sample collection target areas in each visited country is noted in detail in Table 2.

Table 2. Administrative division of target areas of sample collection

Country	Province	District	Capital city
Republic of Indonesia	Sumatera Utara	Toba Samosir	Balige
Socialist Republic of Vietnam	Thừa Thiên - Huế	Huế	Huế

Research activities in the Republic of Indonesia were done in the summer of 2016, and the investigated waste biomass samples were collected from July to September. Collection of investigated waste biomass samples in the Socialist Republic of Vietnam were done in January and May 2017. All chosen waste biomass samples were collected in rural areas of districts listed in Table 1, were properly processed directly after their collection and were preserved for subsequent experimental analysis in Prague, Czech Republic (see the subchapter 'Experimental measurements').

Table 3. Characteristic description of investigated waste biomass types

Name of plant species	Biomass type	Country of origin	Plant part
Bambusoideae spp.	Herbaceous	IDN	Leaves
Coffea arabica	Herbaceous	IDN	Leaves
Musa acuminata	Herbaceous	IDN	Leaves
Theobroma cacao	Herbaceous	IDN	Leaves
Aloe vera	Herbaceous	IDN	Leaves
Manihot esculenta[1]	Herbaceous	IDN, VN	Stem
Manihot esculenta[2]	Herbaceous	IDN	Root peel
Saccharum officinarum	Fruit	VN	Stem
Durio zibethinus	Fruit	VN	Peel
Nephelium lappaceum	Fruit	VN	Peel
Musa acuminata	Fruit	VN	Peel
Myriophyllum spicatum	Aquatic	VN	Stem, leaves
Eichhornia crassipes	Aquatic	VN	Stem, leaves

VN – Socialist Republic of Vietnam; IDN – Republic of Indonesia.

Different parts of bodies or fruits of the following plants were investigated: bamboo (*Bambusoideae* spp.), coffee tree (*Coffea arabica*), banana tree (*Musa acuminata*), cacao trees (*Theobroma cacao*), aloe vera (*Aloe vera*), cassava (*Manihot esculenta*), sugarcane (*Saccharum officinarum*), durian tree (*Durio zibethinus*), rambutan tree (*Nephelium lappaceum*), water hyacinth (*Eichhornia crassipes*) and aquatic weed (*Myriophyllum spicatum*). These plants were selected because they represent commonly cultivated agriculture crops in the target areas and their cultivation covers extensive areas, thus, a great amount of unutilised waste biomass originates from this cultivation. The characterisation of collected waste biomass samples is described in Table 3, the main focus of the present research was the production of waste biomass originating from plant cultivations at plantations and from processing plantations of crops or fruits. Moreover, the Socialist Republic of Vietnam has been struggling with water pollution issues for decades; entire populations of invasive aquatic plants are occupying water areas, which results in their removing, thus, production of great amount of aquatic waste biomass. Therefore, the aquatic waste biomass produced when cleaning polluted water areas was investigated, namely, water milfoil *Myriophyllum spicatum* and water hyacinth *Eichhornia crassipes*.

The collection of herbaceous waste biomass samples was performed in close proximity to the plantations, where the redundant and unwanted agriculture residues were mainly stored in the open field. Fruit waste biomass samples were collected near the processing plants or factories where the agriculture crop or fruits were processed. The location of these agriculture residues in practice is shown in Fig. 2.

Figure 2. Investigated agriculture residues left as waste without any subsequent utilisation: a) cassava stems (VN); b) banana tree residues (IDN); c) cacao tree residues (IDN); d) cassava root peels (IDN); e) durian peels (VN); f) sugar cane stems (VN).

Fig. 3 illustrates the reality of water pollution, which resulted in aquatic waste biomass production. Aquatic waste biomass samples were collected in the places they grow-directly from the water surface.

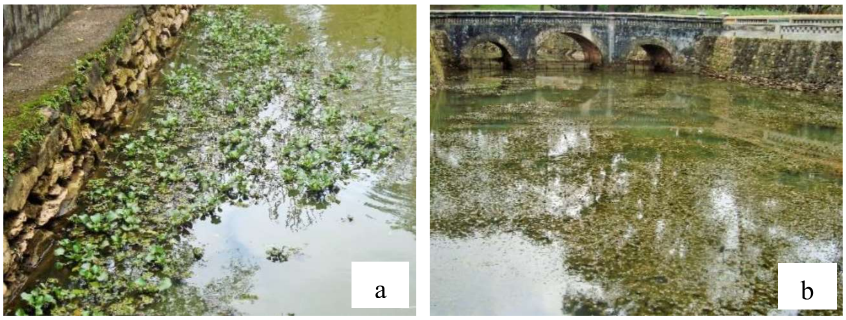

Figure 3. Water pollution results in the production of aquatic waste biomass of: a) water hyacinth (VN); b) aquatic weed (VN).

Experimental measurements

The aim of all experimental tests was to find the suitability of investigated waste biomass samples for direct combustion for energy utilisation. The following methods were chosen in an attempt to determine the samples' safety and efficiency during burning processes, with special emphasis on environmental conservation and competition with fossil fuels.

Initial sample preparation

Collected waste biomass samples were initially crushed and dried in a laboratory drier (at 105°C for 24 hours) in an attempt to stabilise their properties. Processed samples were stored in hermetically sealed laboratory vessels for transportation to the laboratory located in Prague (Czech Republic). The form of waste biomass samples after initial processing is shown in Fig. 4.

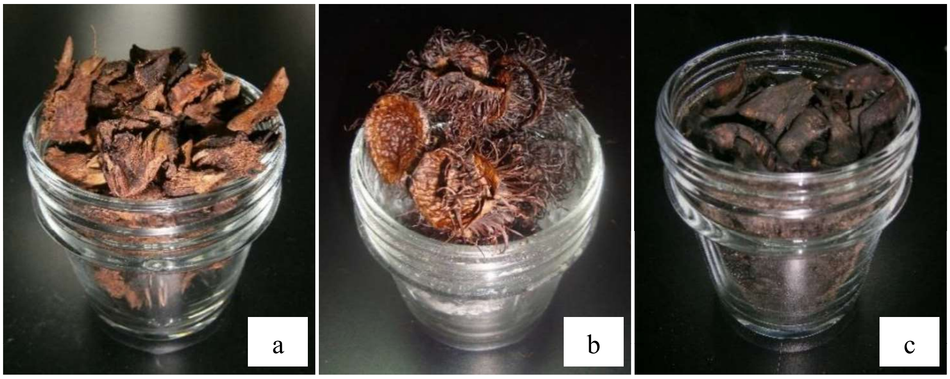

Figure 4. Investigated waste biomass samples prepared for preservation within their transport: a) durian fruit peels; b) rambutan fruit peels; c) banana fruit peels.

Fuel analysis

Proximate analyses and calorimetric measurements were performed in laboratories in Prague, Czech Republic. A set of chosen tests described the basic fuel properties of samples in the statement of their suitability for direct combustion purposes. Primarily, all samples were milled by a cutting mill into a particle size suitable for subsequent testing, i.e. particle size < 0.1 mm. The speed of the equipment was set to 20,000 rpm·min^{-1}. Subsequently, moisture content M_c (%), ash content A_c (%), volatile matter content VM_c (%) and higher heating value HHV (MJ kg^{-1}) of the samples were measured; while lower heating value LHV (MJ kg^{-1}) was estimated. Within each specific test in the case of all tested samples, several measurements were performed; prevalently, two or three suitable measurements and supporting software were used for the statement of final values.

The methodology of measurements of moisture content M_c (%), ash content A_c (%) and volatile matter content VM_c (%) was performed in respect to the ordinance of technical standards EN ISO 18122 (2015), ISO 18134–2 (2017) and EN ISO 18123, (2015). In the first step, a tested sample was dried at 107 °C until constant weight was reached to measure moisture content M_c (%). Subsequently, the dried samples were subjected to the ash content A_c (%) determination. The samples were burned in the presence of oxygen at 550 °C until their weights were constant, which indicated the end of the test. Both of the described tests were performed using a laboratory oven and laboratory thermogravimetric analyser.

The evaluation of energy potential of investigated waste biomass samples, and thus their suitability as an efficient biofuel, was expressed by determining their higher heating value HHV (MJ kg^{-1}). This indicator was determined by an isoperibol calorimeter, and the whole methodology of measurement was conducted according to the technical standard EN ISO 18125 (2017). Before testing itself, milled samples were densified into small pellets of 0.7 g weight. Subsequently, the pellets were burned, and obtained result values were sorted and analysed by the analyser's software. An estimate of lower heating value LHV (MJ kg^{-1}) was calculated from the higher heating value by the same technical standard, assuming hydrogen content at 6% wt. and combined oxygen and nitrogen content at 43% wt. in dry ash free state in all samples. These values were chosen as typical for many types of biomass.

RESULTS AND DISCUSSION

The obtained results of the experimental measurements performed in the present study primarily described the suitability of investigated waste biomass samples for direct combustion for energy generation purposes. Such information was combined with the statistical data of production (harvested areas and production quantity) of several investigated crops, which can indicate the amount of their produced waste biomass. By combining these factors (chemical analysis combined with the theoretical amount of produced waste biomass), the overall monitoring of such waste biomass potential within the energy generation was evaluated.

Materials and samples

Data published by statistical databases of Food and Agriculture Organization of the United Nations (FAO) provided information about agriculture production in specific countries, inter alia, in the Socialist Republic of Vietnam and the Republic of Indonesia (noted also in Table 1). As mentioned in the Introduction, due to the extensive areas of specific crop plantations, the greatest theoretical potential for waste biomass generation can be estimated for the plantation of cacao trees and coffee trees, followed by plantations of cassava plants. Because of the diversity of investigated waste biomass samples, the theoretical production quantity of specific fruits was monitored (expressed in Table 4) in the fruit waste biomass production.

Table 4. Production quantity of specific agriculture crop in 2016

Country	Crop	Production quantity, t
Indonesia	Bananas	7,007,125.0
	Cassava	20,744,674.0
	Cacao (beans)	656,817.0
	Coffee (green beans)	639,305.0
	Sugar cane stem	27,158,830.0
Vietnam	Bananas	1,941,935.0
	Cassava root	11,045,184.0
	Coffee (green beans)	1,460,800.0
	Sugar cane stem	16,313,145.0

t – tonnes (Source: FAO, 2018).

Data noted in Table 4 can also help upgrade the knowledge about the production of fruit waste biomass, which can also be a renewable source for energy generation. The ratio (expressed in percentage of the whole fruit mass) of the used part of fruit and the unused fruit waste biomass of specific exotic fruits was published in the research of Brunerová et al. (2017b). This research proved an extremely high ratio of fruit waste biomass in fruit like cacaos, bananas or coffee fruits. Using data published in the mentioned study (amount of waste biomass from specific fruit types in g and %), the following theoretical production of specific fruit waste biomass (t) was calculated; see Table 5.

Table 5. Estimated potential of specific fruit waste biomass production

Country	Fruit	Mass from one fruit sample, g	Mass proportion of fruit waste biomass*, %	Theoretical production of fruit waste biomass, t
Indonesia	Banana	23.8 ± 6.1	39.4 ± 8.8	2,760,807.3
	Cacao	523.7 ± 176.7	83.8 ± 8.9	550,412.6
	Coffee	0.7 ± 0.1	43.4 ± 9.9	277,458.4
Vietnam	Banana	23.80 ± 6.05	39.4 ± 8.8	765,122.4
	Coffee	0.7 ± 0.1	43.4 ± 9.9	633,987.2

*proportion of fruit waste biomass mass of total fruit sample mass in percentage; ± – standard deviation (Source: Brunerová et al., 2017b).

Experimental measurements

The chemical analysis and related experimental measurements were performed for all investigated waste biomass samples equally. Unfortunately, several samples occurred in a form unsuitable to perform experimental measurements (too heterogeneous), thus, all defined tests in the case of several samples were unable to be performed. Nevertheless, the obtained result values of successfully tested waste biomass samples are expressed in Table 6.

Table 6. Chemical parameters of investigated agriculture waste biomass kinds (in w.b.)

Biomass sample	M_c, %	A_c, %	VM_c, %	HHV, MJ kg^{-1}	LHV, MJ kg^{-1}
Bambusoideae spp.	7.38	12.50	81.79	16.71	15.5
Coffea arabica	9.33	9.42	<u>88.37</u>	17.82	16.5
Musa acuminata	4.56	9.16	<u>88.41</u>	17.18	15.9
Theobroma cacao	8.73	<u>13.50</u>	84.23	16.34	15.1
Aloe vera	4.01	<u>13.53</u>	85.82	16.90	15.7
Manihot esculenta[1] (IDN)	6.31	**3.14**	–	**18.55**	**17.2**
Manihot esculenta[1](VN)	5.93	**2.75**	–	**18.81**	**17.5**
Manihot esculenta[2]	1.52	<u>32.15</u>	**59.15**	12.68	11.8
Saccharum officinarum	7.00	**0.84**	–	17.84	16.5
Durio zibethinus	8.53	5.13	–	16.61	15.3
Nephelium lappaceum	7.55	**3.21**	–	17.03	15.7
Musa acuminata	8.27	12.02	–	**18.56**	**17.3**
Myriophyllum spicatum	5.18	<u>53.31</u>	**42.48**	<u>8.63</u>	<u>7.9</u>
Eichhornia crassipes	7.48	<u>14.16</u>	81.59	<u>13.97</u>	<u>12.8</u>

[1] – stem; [2] – root peel; VN – Socialist Republic of Vietnam; IDN – Republic of Indonesia; M_c – moisture content; A_c – ash content; VM_c – volatile matter content; HHV – higher heating value; LHV – estimated lower heating value; w.b. – wet basis.

Outstanding values, both good and bad, are highlighted in Table 5, bold font indicates good results, while underlined values indicate bad results. The result values of moisture content M_c (%) noted in Table 6 represented the moisture content of the samples processed and prepared for experimental testing. The initial moisture content of investigated samples was not measured because of the limited local conditions during sample collection and transportation. As other research papers indicate, the moisture content of aquatic waste biomass ranges between 85.3%–89.6%, while fruit waste biomass ranges between 63.4%–84.5% (Brunerová et al., 2017b; 2017c).

Waste biomass from aquatic weed (*Myriophyllum spicatum*) resulted in extremely high ash content A_c, which is unwanted. In addition, the ash content of cassava root peels (*Manihot esculenta*) was also very high. In both cases, such results could be caused by admixtures, which is highly arguable in the case of cassava root peels. Those are removed from the root with a certain amount of earth impurities. Focusing on energy potential, the cassava stems (*Manihot esculenta*) from both target countries of origin exhibited a high level of quality indicators, as did the banana peels. Very low values of high heating value were achieved by the aquatic waste biomass (both samples, *Myriophyllum spicatum, Eichhornia crassipes*) and cassava root peel (*Manihot esculenta*). Here, the relation between ash content and high heating value is apparent. The energy potential is lower in the case of samples that exhibited high ash content.

The high energy potential of such agriculture residues (fruit waste biomass) intended for combustion processes was also proved in the research of Brunerová et al. (2017b); namely, it found lower heating values LHV ($MJ \cdot kg^{-1}$) in the dry basis (d.b.) of fruit waste biomass originating from the processing of: banana – 17.79 MJ kg^{-1}, cacao – 16.73 MJ kg^{-1} and coffee – 17.37 MJ kg^{-1}.

Table 7. Calorific value of investigated agriculture waste materials in dry ash free state (d.a.f.)

Biomass sample	HHV, MJ kg^{-1}	LHV, MJ kg^{-1}
Bambusoideae spp.	20.62	19.3
Coffea arabica	21.70	20.4
Musa acuminata	19.82	18.5
Theobroma cacao	20.70	19.4
Aloe vera	20.36	19.1
Manihot esculenta[1] (IDN)	20.49	19.2
Manihot esculenta[1](VN)	20.60	19.3
Manihot esculenta[2]	18.98	17.7
Saccharum officinarum	19.36	18.1
Durio zibethinus	19.24	17.9
Nephelium lappaceum	19.09	17.8
Musa acuminata	23.29	22.0
Myriophyllum spicatum	19.49	18.2
Eichhornia crassipes	17.59	16.3

[1] – stem; [2] – root peel; VN – Socialist Republic of Vietnam; IDN – Republic of Indonesia; HHV – higher heating value; LHV – estimated lower heating value; d.a.f. – dry ash free state.

In respect to the fact that heating value is one of the most important indicators of fuel energy potential, the conversion to a dry ash free state was performed. The result values noted in Table 7 express the exact values of such indicators without the presence of ash, which should be influenced by the contamination of samples, thus, they can sometimes be misleading. The waste biomass samples were collected in the original form to reflect the waste management reality, thus, the contamination of samples was not removed.

Within the overall evaluation of specific biomass types (herbaceous, fruit and aquatic), the average values from all investigated samples were calculated and used to create charts in Figs 5, 6 and 7.

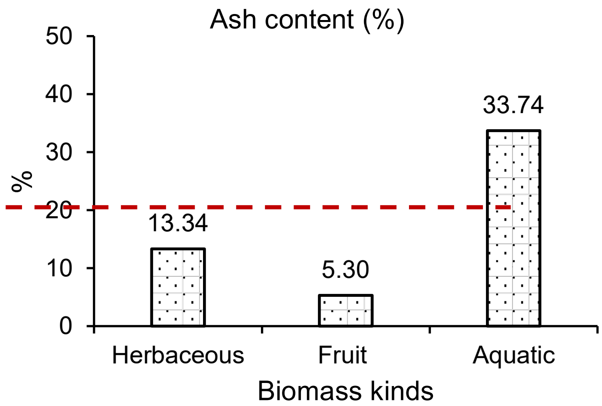

Figure 5. Comparison of ash content of specific investigated biomass types.

Based on the requirements of technical standard ISO 17225–7 (2014), the allowed level of ash content A_c (%) in the case of commercially produced bio–briquette fuel should be lower than 10%. This level is expressed by the dashed line in Fig. 5.

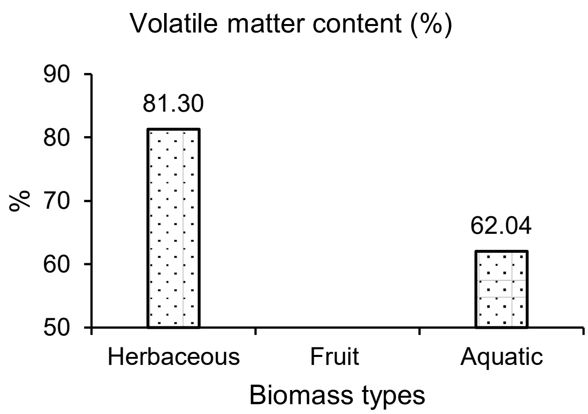

Figure 6. Comparison of volatile matter content of specific investigated biomass types.

The results of aquatic biomass volatile matter content VM_c (%) were not obtained due to the problematic behaviour of samples during testing. The acceptable level of volatile matter content in bio–briquette samples is not strictly stated, but it should be approximately 80%. In the case of wood biomass, the results will always be higher than

80%, but these results do not indicate bad properties of the fuel; they indicate that fuel will burn differently than, for example, coal (EN ISO 18123, 2015).

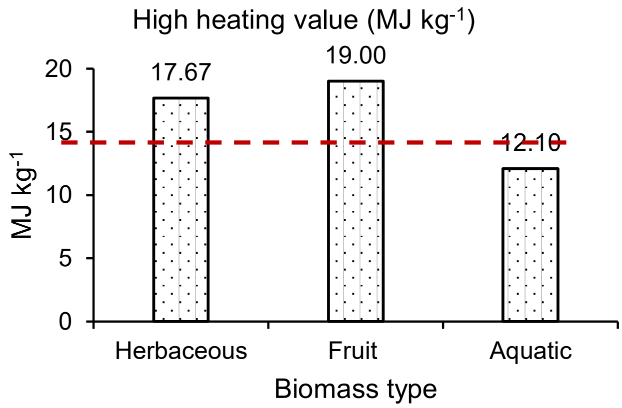

Figure 7. Comparison of higher heating values of specific investigated biomass types.

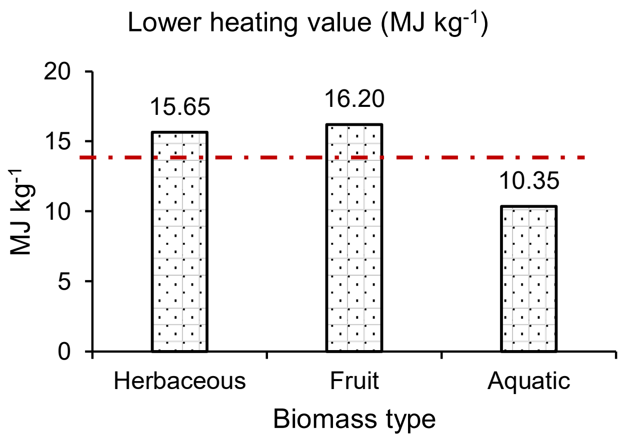

Figure 8. Comparison of lower heating values of specific investigated biomass types.

The required level of lower heating value LHV (MJ kg^{-1}) is expressed in Fig. 8 by the dashed line, thus, LHV > 14.5 MJ kg^{-1} (ISO 17225-7, 2014). This clearly shows which biomass types fulfilled the required levels and which were not suitable for investigation purposes. In both cases, the aquatic biomass samples exhibited unsatisfactory results, thus, proved their inappropriateness for energy utilisation by direct combustion.

CONCLUSIONS

As considerable quantities of agricultural residues remain unused in the developing world, there is potential to use energy from those waste sources. However, the current utilisation of waste biomass in developing countries occurs at a low level. Experimental analysis of fuel parameters of investigated waste biomass samples proved suitability of herbaceous and fruit waste biomass for energy utilisation by direct combustion, while values of aquatic waste biomass showed very low fuel quality indicators. These results could, in practice, cause low energy efficiency of biofuel or could be detrimental to the environment. In the future, having a database system on residue generation and utilisation at a national level could be beneficial; however, there is a need to be cautious and not to lose sight of the implications of social aspects, such as using agricultural residues as domestic fuel. In addition, future studies should focus on the possible effects of an increased use of residues at the farm level, for example, on soil conservation and degradation, income generation, effects on the environment and local communities.

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