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To cite this article: Anna Brunerová *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **345** 012007

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Sustainable management of coffee fruit waste biomass in ecological farming systems at West Lampung, Indonesia

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Abstract. Present study focuses on fruit waste biomass generated during the postharvest treatments of coffee cherries (*Coffea* spp.) and its subsequent utilization within the waste-less, sustainable and ecological farming systems. Investigated samples were collected at the organic shaded multi-culture coffee plantations in West Lampung, Indonesia. Within the determination of most suitable subsequent utilization, the samples were subjected to the analysis of their basic chemical parameters, energy potential and ash composition. Three samples kinds were defined: I. CP (outer skin, pulp), II. CH (husk, silver skin, parchment) and III. CA (burned mixture of previous two waste materials). Obtained values proved following results; CP: Mc - 79.21%, Ac - 2.05%, CV - 17.19 MJ/kg; CH: Mc - 21.08%, Ac - 6.50%, CV - 18.14 MJ/kg; CA: Mc - 30.79%, Ac - 28.11%. Measured values proves the suitability of tested materials for combustion processes as a renewable source of clean energy (high energy potential), but also for the composting purposes (Potassium content K₂O - 10.946%). A great potential of tested materials within their subsequent reuse was proved, as well as the fact that they represent a commodity suitable for further valorization. □

1. Introduction

Indonesia is one of four biggest coffee producers; together with Brazil, Colombia and Vietnam produce approximately 50% of world production [1, 2]. *Coffea arabica* L. and *Coffea Robusta* L., the members of Rubiaceae family, represent the world well-known and favorite agriculture crops.

Postharvest treatment of raw coffee cherries contains primarily the de-pulping of green beans, i.e. removing of the outer skin, pulp and other internal layers. Whereas, such treatment generates a large quantity of biological residues (fruit waste biomass) [3]. In general, more than ten million tons of various agriculture residues in solid and liquid forms are generated every year within the coffee agroindustry [1, 2]. According to previously published data, approximately one ton of fruit waste biomass is generated from two tons of raw



coffee cherries [4]. If consider the current amount of coffee production in Indonesia (see table 1.), it can be concluded, that coffee agroindustry participates in waste biomass production in large-scale.

Table 1. Cultivation of coffee beans in Indonesia [5]

Year	Harvested area (ha)	Yield (hg/ha)	Production (tonnes)
2014	1,230,500	5,233	643,900
2015	1,230,001	5,198	639,412
2016	1,228,512	5,204	639,305
2017	1,253,796	5,333	668,677

Thus, subsequent reuse of mentioned fruit waste biomass must be well managed and secured in effort to keep the proper waste management principals and to avoid to possible environmental damages. The necessity of such activities is undeniable and highly recommended within the reduction of the negative impact of the agriculture waste on the environment [1, 2]. Moreover, subsequent reusing of waste biomass do not represent only the proper waste management, it also offers the possibility of its financial valorization, because waste biomass also represents the valuable commodity [2].

Nowadays, a several different production sectors make an effort to find the most suitable and efficient strategies, how to reuse coffee fruit waste biomass [6]. The possibilities are very wide. Coffee pulp is occasionally used as a feedstock for livestock animals; however, the content of caffeine limits its utilization for such purposes due to the impacts on the animal health [7-9]. By using of the fermentation processes can be coffee pulp converted into the compost [10], as well as it can be used as a natural food colorant [11]. Antioxidants contained in the coffee pulp neutralize the free radicals, thus, can be uses as a prevention of various diseases [12-16].

Regarding to the biofuel research field, the bioethanol can be produced from coffee pulp by using of a digestion method [6, 17]. Biochemical characterization of investigated fruit waste biomass proved also its suitability for the production of first generation solid biofuel intended for direct combustion [1]. All of selected mentioned techniques seems attractive and relevant within the valorization and adding-value to investigated waste within the "Waste to energy" principles and strategies. Due to large-scale interest of human population in coffee products consummation, the knowledge about large-scale practical utilization of waste biomass from coffee industry is still in process. It is no exception that generated waste biomass and other by-products are left behind as an unused agriculture residue without further utilization, despite its great potential was proved [11].

Regarding to all facts mentioned above, the main aim of present paper was to investigated the chemical parameters of fruit waste biomass (coffee outer skin, pulp, silver skin and parchment) originated from ecological farming plantations and state the most efficient way of its sustainable utilization within the principal of materials return in to the environmental life cycle.

2. Methodology

Current chapter is divided into several sub-chapters ordered chronologically according to the sequences of performed research activities.

2.1. Materials and samples

Three different types of samples originating from the coffee cherry's (*Coffea* spp.) postharvest treatment were collected; namely, I. CP samples - outer skin and pulp (pericarp, exocarp and mesocarp), II. CH samples - husk, parchment and silver skin (endocarp and epidermis) and III. CA samples - burned mixture of previous two waste materials (CP samples + CH samples). For better visualization, see figure 1, which express the specific parts of coffee cherry.

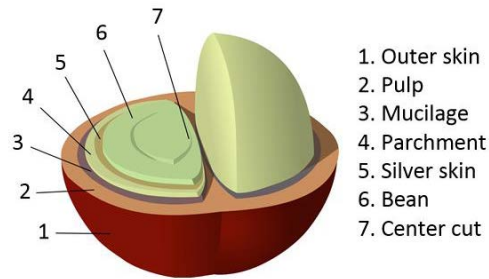


Figure 1. Cross-section of investigated coffee cherries

Samples were collected during the rainy season in February 2019 at organic shaded coffee plantations placed in mountain areas of Hanakau city, Sukau district, West Lampung Regency, South Sumatra, Republic of Indonesia, as expressed in figure 2.



Figure 2. Target area of collection.

Collected samples of fruit waste biomass represented agriculture residue generated within the coffee agroindustry during the raw coffee cherries and green coffee beans treatment. Figure 3 visualizes the harvested unprocessed coffee cherries and figure 4 represents the fruit waste biomass removed from raw coffee cherries in practice in the form of the agriculture residue left behind.



Figure 3. Investigated samples: ripe raw coffee cherries.



Figure 4. Investigated samples: fruit waste biomass.

Collected CP samples were removed from the raw coffee cherries by using of pulping machine (see figure. 5) directly after harvest and CH samples were collected after the process of green coffee beans natural sun drying (see figure. 6) and removing of skin remains. Thus, CP samples occurred in their initial moisture content, while CH samples were already sundried during drying process.



Figure 5. Postharvest treatment equipment: pulping machine.



Figure 6. Postharvest treatment equipment: solar sun dryer.

2.2. Experimental measurement

All measuring procedures described in present chapter were conducted to the mandatory technical standards, namely, ASTM International standards. Such standards define all details and specific steps of performed measurements, thus, they ensure their correctness and safety.

The laboratory experiments were performed within 7 days after the samples collection. Until then, the samples were hermetically preserved and stored in a cold place to prevent the change of their composition.

Primarily, all samples were subjected to the determination of their basic chemical parameters, namely, moisture content Mc (%) and ash content Ac (%). Determination of Mc was performed by using of Laboratory oven Memmert, model UN55 (Schwabach, Germany), whereas, samples were dried for 24 hours at 102°C until their weight was constant. Determination of Ac was performed by using of Laboratory muffle furnace oven ISUZU, model EPTR-13K (Sanjo, Japan), while samples were dried at 600°C for 6 hours until the weight of ash was constant. Obtained values represented the differences between samples weight losses before and after experimental testing and were basis for the calculations of final results.

Further, the energy potential of CP and CH samples was stated by the determination of their calorific value CV (MJ/kg). Experimental measurements were performed by using of Oxygen Bomb Calorimeter, model CAL2K (Northcliff, South Africa), thereby, the samples were burned in the presence of Oxygen and CV was stated.

Finally, last part of the experiments was related to the coffee ash (CA samples) parameters, thus, the analysis of its mineral composition was performed by using of multi-functional instrument X-ray fluorescence (EDXRF) spectrometer PANalytical, model Epsilon 3XLE (Westborough, USA). The samples were burned in the presence of Oxygen, while the energy necessary for their burning was measured.

3. Results and discussion

The results, which are described in present chapter, are expressed as an average values of several performed measurements due to their repetition ($n=3$). Parameters discussed in the chapter also represent quality indicators, which defined the suitability of samples for specific purpose.

Next part of the chapter is dealing with the cultivation procedures at target shaded multi-culture plantation due to its ecological, zero waste and sustainable principles. Specifically, the potential contribution of investigated fruit biomass materials in such ecological farming systems.

Primarily, analysis of basic chemical parameters of investigated samples defined their moisture content Mc (%) (noted in table 2.).

Table 2. Analysis of coffee waste samples parameters

Parameter	Biomass sample		
	CP	CH	CA
Mc (%)	79.21 ± 0.31	21.08 ± 0.06	30.79 ± 0.12
Ac (%)	2.05 ± 0.004	6.50 ± 0.24	28.11 ± 0.07
TS (%)	20.79 ± 0.31	78.92 ± 0.06	69.21 ± 0.12
VS (%)	18.74 ± 0.03	72.43 ± 0.30	41.10 ± 0.19
CV (MJ/kg)	17.19	18.14	-

Mc - moisture content (%), Ac - ash content (%), TS - total solids (%), VS - volatile solids (%), CV - calorific value, \pm - standard deviation

All samples proved higher moisture content Mc (%) than is suitable for waste biomass intended for combustion processes (within potential solid biofuel conversion). High amount of moisture in sample (biofuel) leads to loss of energy output during burning, because energy is consumed by process of moisture vaporizing.

Thus, such results represent limitation in mentioned process. Nevertheless, countries like Indonesia have a great potential for sun drying technology due to their geographical location and climate conditions. The advantages of such technology can provide environmental friendly the solution within the waste biomass high moisture content issue; moreover, without the investment of other energy sources (electricity) by using only renewable energy form of sun power [18].

Next quality indicator was ash content Ac (%), which defined the amount of ash in burning device after combustion. Thus, lower level of such indicator is required. Observed data proved satisfactory level ($Ac < 10\%$) of ash content in case of CP and CH samples which is desired within combustion purposes. The CA samples were already burned at the plantation, thus, the result is not unbiased and were not be considered.

Energy potential of investigated samples was represented by the calorific value CV (MJ/kg) indicator. Both, the CP and CH samples, high level of calorific value, which is recommended for feedstock materials intended for solid biofuel production ($CV > 14.5$ MJ/kg). Due to the characteristics of AC samples (previously burned), there were not use for the determination of calorific value CV (MJ/kg).

A comparison of observed data with results of other authors is expressed in table 3. As visible, the results of moisture and ash content occur at similar values as was investigated in present research. Results of calorific values CV (MJ/kg) from literature review ranges from 11.60 to 24.07, while measured data correspond approximately to the average of reported values.

Table 3. Analysis of coffee waste samples parameters

Ac (%)	Mc (%)	CV (MJ/kg)
8.90 [19]	81.40 [19]	11.60 - 12.50 [21]
1.50 [20]	76.70 [20]	17.67 [22]
8.68 [21]	90.00 [21]	17.40 [25]
5.47 [22]	85.00 [16]	23.72 - 24.07 [26]
3.00 [23]	77.00 [24]	18.34 [27]

Result values of last investigated measurement (see table 4.) described the mineral composition of samples ash (CA samples). Such analysis described the suitability of samples for several sustainable utilization; defines the suitability for composting technology or for utilization as a natural fertilizer. Moreover, describe possible problems during combustion process related to samples burning abilities and possible damages of burning device.

The inorganic content in biomass normally act as nutrients for living biological plants. The composition of ash strongly dependent on the plant species, growth and soil conditions. The data in table 4. showed that concentration of CaO is dominated and higher than K₂O and SiO₂. High concentration value of alkaline earth such as Ca, Mg and K act as a soil liming agent and neutralize soil acidity, thus, it is advantageous to reuse such materials as a forest fertilizer, plant nutrient and soil conservation agent.

Table 4. Mineral composition of coffee waste biomass ash

MgO (%)	Al ₂ O ₃ (%)	SiO ₂ (%)	P ₂ O ₅ (%)
5.328	2.483	5.779	7.830
SO ₃ (%)	K ₂ O (%)	CaO (%)	TiO ₂ (%)
2.596	10.946	60.191	0.358
V ₂ O ₅ (ppm)	MnO (%)	Fe ₂ O ₃ (%)	CuO (%)
108.6	0.342	3.150	0.235
ZnO (%)	As ₂ O ₃ (ppm)	Rb ₂ O (%)	SrO (%)
0.108	11.6	0.137	0.396
ZrO ₂ (ppm)	SnO ₂ (ppm)	TeO ₂ (ppm)	PbO (ppm)
49.1	705.3	251.9	69.1

% - percentage, ppm - parts per million

Knowledge about coffee fruit waste biomass chemical composition is necessary, if the material should represent commodity intended for subsequent valorization purposes. Therefore, table 5. express other detail analysis (and comparison) of ash content and mineral composition of coffee pulp of other author.

Table 5. Analysis of coffee waste samples parameters

Ash (g%)	Ca (mg%)	P (mg%)	Fe (mg%)	Na (mg%)
8.3	554	116	15	100
K (mg%)	Zn (ppm)	Cu (ppm)	Mn (ppm)	B (ppm)
1765	4	5	6.25	26

mg% - milligram per cent, ppm - parts per million

Another aspect which must be considered, if evaluate the parameters and composition of investigated samples, are the cultivating conditions of their own growth. As was mentioned before, the samples originated from organic shaded coffee plantations. In general, coffee trees were not nourished or treated by any chemical fertilizers or agents (insecticides, herbicides, fungicides), which plays important role in ecological cultivation of coffee trees, further in composition of their fruit. Specifically, the waste biomass and ash, both originating from the plantations, were used as a natural fertilizer. Moreover, the specialized “shaded” method of cultivations represents ecological way of coffee trees preservation. Such method uses the principles of multi-culture farming when specific plants are used for preservation of other specific plants conditions. Selected plants live in symbiosis and support each other within the nutrient, shade or insect repellent issues and create a stable network of mutualistic interactions between each other [29-31].

Target plantations were cultivated by using of the intercropping principle; an Areca palm (*Areca catechu* L.) specie was grown there as an intercrop intended to protect coffee trees against to abundance of sunshine and prevent of the water vaporization [32], see figure 7.

**Figure 7.** Intercropping principle at target plantation.**Figure 8.** Cover crops principle at target plantation.

Within the soil conservation were plantations protected by two cover crop species of Pinto Peanut (*Arachis pintoii*) of family *Fabaceae* and Black Pepper (*Piper Nigrum*) of family *Piperaceae*, which were cultivated under the coffee trees. Pinto Peanut is in ecological farming systems occasionally used as a living mulch. Which is related to its ability to fix nitrogen from the atmosphere and to grow in a shade of other cultivated plants [33]. Described multi-culture ecosystem is expressed in figure 8. Such interactions between specific cultivated plants are necessary and plays important role in specific ecosystem conservation and functionality of ecological farming systems without chemicals [28]. Using of such knowledge can replace the using of chemical substances in such ecosystems. The suitable composition of waste biomass originating from ecological plantations is very important, due to it represents the main source of plants nutrient, which is used in closed waste-less farming systems.

4. Conclusion

In the end, it can be concluded that coffee fruit waste biomass originating from postharvest treatments represents commodity with great potential within the ecological farming systems and returning into the nature life cycle (zero waste agriculture principles). To achieve such statement, the samples were subjected to the determination of their suitability for sustainable technologies and renewable energy production. Due to the results of basic chemical parameters, the ash content prove required low level, while moisture content proved undesired high level. Higher level of moisture content can represent the limitation within such waste biomass utilization, nevertheless, it can be easily improved solar drying technology. Energy potential determination proved suitability for direct combustion processes (solid biofuel production). Analyses of mineral composition proved advantage of investigated waste biomass for plant nutrient and soil conservation. In consequence, the ash from investigated fruit waste biomass is full-featured natural fertilizer. Such knowledge about sustainable multi-culture organic farming and intercropping principles can leads to better understanding of mutualistic interactions between each crops, which can directly leads to decreasing of chemical fertilizers and agents utilization, which is highly recommended within the environmental conservation and consumers health issues.

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Acknowledgments

The performed research was funded by the EUROPEAN UNION (EU), managing authority of the Czech Operational Programme Research, Development and Education within the project “Supporting the development of international mobility of research staff at CULS Prague”, reg. no. CZ.02.2.69/0.0/0.0/16_027/0008366. Further, research was supported by the Internal Grant Agency of the Czech University Life Sciences Prague, grant number 20173005 (31140/1313/3108) and by Internal Grant Agency of the Faculty of Engineering, Czech University of Life Sciences Prague, grant number 2019:31140/1312/3103.