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Physical and Chemical Characteristics of Agricultural-Plastic Wastes for Feasibility of Solid Fuel Briquette Production

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Abstract: In recent years, the world has witnessed an enormous effort to find a replacement energy source that is more environmentally friendly and renewable. Face masks that contain plastics lead to another management problem as they are non-biodegradable. Thus, by turning agricultural waste with plastic waste as an additive into beneficial products like briquettes, a solid waste problem can be minimized. In this study, *Imperata cylindrica* and mango peel commonly found in Malaysia were anticipated to boost the properties of solid fuel briquettes. Thus, the characterization of *Imperata cylindrica*, mango peel, and face mask waste as raw materials for the production of solid fuel briquettes is discussed in this paper. Proximate and ultimate analyses as well as Fourier transform-infrared (FTIR) were conducted to obtain the properties of the raw materials. FTIR results showed that face mask waste contained a methyl type group (CH₃), and both agricultural wastes contained an oxygen type group (C–O–H). Based on the proximate analysis, face mask waste, mango peel, and *Imperata cylindrica* had low moisture contents, where mango peel had the highest moisture content (5.2%) followed by *Imperata cylindrica* (<1%) and face mask waste (<1%). *Imperata cylindrica* had the highest volatile matter content (94.6%) and the lowest ash content (2.3%), while mango peel contained the highest fixed carbon value, which was 16.1%. From the analyses conducted, face mask waste had the highest calorific value (26.19 MJ/kg⁻¹). Face mask waste contained 63.6% carbon and 10% hydrogen. Meanwhile, *Imperata cylindrica* and mango peel contained 44% and 40% carbon and 6.15% and 6.95% hydrogen, respectively. The characteristics and properties of face mask waste, mango peel, and *Imperata cylindrica* are significant for the contribution of the optimal ratio of these materials to form solid fuel briquettes.

Keywords: *Imperata cylindrica*; mango peel; plastic face mask; proximate analysis; ultimate analysis

1. Introduction

Currently, fossil fuels make up the bulk of today's global energy consumption [1]. Traditional briquettes were made only from charcoal, with wood being the main material. However, due to increasing energy demands in city areas, especially in commercial areas and for urban households, there is a growing concern regarding deforestation and the burning of forest biomasses for wood fuel [2]. Briquettes with other constituents can be an alternative for wood charcoal. Such briquettes can have high material density and higher calorific values per volume compared to wood, which means they require less storage space and are easily transportable [3]. In addition, by turning wastes such as plastic

and agricultural waste into beneficial things like briquettes, the use of landfill for waste disposal can be minimized [4]. The mismanagement and excessive production of solid waste including face masks has contributed to microplastic pollution in the ecosystem [5].

Many scientists and researchers are interested in finding new renewable energy sources as alternatives to fossil fuels. Historically, people used coal as the main energy source, for cooking, laundering, for boilers, barbecues, and for heaters [6]. However, coal pollutes the environment as it has a high carbon content and limited sources. Coal is commonly used together with charcoal briquettes to increase the energy density. Charcoal is widely used as an energy source and for other purposes, especially in developing countries [7]. It is a blackish substance and contains impure carbon. Charcoal is produced by a process called pyrolysis—heating of wood and other agricultural substances. The decreasing supplies of wood can affect briquette supplies. An overwhelming demand over supply can affect the cost of briquettes. Therefore, biomass solid fuel briquettes can be a good way to balance the increasing gap between the demand and supply of energy [8]. By using biomass residue as fuel, hopefully both wastage and environmental impacts can be minimized by obeying the 3R concept (reuse, reduce, recycle) [9].

Face masks are made from plastic that can pollute the environment and is not biodegradable [10]. Undeniably, plastic makes our daily lives easier. Almost everything we use consists of plastic. Disposable face masks contain plastics such as polypropylene (PP), polyethylene, polyurethane, and polystyrene [10]. In fact, about 70% of masks are made up of plastic [10]. Forbes [11] reported that polypropylene is widely used in food packaging and is also considered “food safe”. This adds to the existing plastic waste problems. Plastic waste releases chemical materials that contain toxins. In addition, used face masks contain germs. The spread of COVID-19 has impacted not only human health and economies but also the number of face masks used [10]. The negative impacts of plastic waste on the Earth have been well-explored, confirmed, and illustrated by various researchers in their publications [12,13]. Climate change is one of the effects of the excessive use and uncontrolled disposal of plastic waste [10]. A study showed that surgical face masks can be the source of microplastic contaminants in water systems [5]. Thus, converting this waste into briquettes could be a good solution for existing plastic problems. Over the last 10 years, numerous studies on the production of briquettes from plastic recycling have been conducted due to its high heating value and long combustion time [14–17]. Nevertheless, the use of face masks in the production of solid fuel briquettes is still limited because this type of plastic waste category has only recently emerged due to the COVID-19 spread at the end of 2019.

Researchers mention that the conversion of face masks into biofuels is the best environmental solution to tackle the plastic waste problem generated by the pandemic [10,18,19]. Fadere and Okorro [10] described disposable face masks as containing hydrocarbons and can be converted into bioproducts such as syngas, bio-oil, and bio-chars. Compared to lignocellulosic wastes, polymeric materials such as face masks contain a low moisture content (0–0.8%), low ash content (0–1.4%), and high volatile content (87–99%) [19]. The pyrolysis of polypropylene produced bio-oils has been reported to have high calorific values [18]. A study conducted by Song et al. [17] suggested that polypropylene (PP) plastic was suitable for biomass briquetting and has many characteristics suitable for forming a good quality briquette. The use of disposable plastic can help to increase the calorific value of the briquette. Harussani et al. [16] converted disinfected PP-based isolation gown waste (PP-IG) into an optimized amount of char yields and discovered that low-temperature pyrolysis of PP-IG resulted in higher char yields (2.27 wt%), with the significant proportion of the char consisting of aliphatic and carbonaceous alkene structures. Kumar et al. [15] investigated the co-pyrolysis of lignocellulosic biomass, plastic (polypropylene (PP) and polystyrene (PS)) with spent FCC catalyst at 10 wt% in a semi-batch reactor and found 49% aromatic selectivity with PP and 82% aromatic selectivity with PS at 0.5 feed ratio.

Perennial grasses such as Switchgrass (*Panicum virgatum*) and Miscanthus (*Miscanthus giganteum*) have been used as fuel substitutes in several countries, such as the United States

and Brazil [20]. Cogon grass or Spear grass (*Imperata cylindrica*) is categorized as a diploid C4 grass and is a widespread harmful weed and a significant threat to global ecology and sustainable agriculture [20]. This grass can be converted thermally or biochemically into energy to produce heat, electricity, liquid fuels, or gases. Studies have shown that *Imperata cylindrica* was found to have properties similar to those of Switchgrass and Miscanthus [21]. *Imperata cylindrica* is categorized as a weed and is a common grass in west, east, and south Africa, Australia, some parts of America, and south-east Asia especially Malaysia [21]. It can be found in frequently disturbed soil, such as roadsides, borrow pits, and also construction sites. It is known by various names such as Lalang, spear grass, cogon grass, kunai grass, or Japanese blood red grass [22]. Traditionally it was used as a roofing material, mats, for animal grazing, and erosion control. However, for decades it has been an inconvenience to farmers and is ranked in the top ten of the most troublesome weeds worldwide [21], so it would be helpful to make use of this plant.

Population growth, combined with technological advancements, has resulted in an imbalance in commodity demand and supply, resulting in increased food waste globally [23]. The consumption of several agricultural products has frequently resulted in the waste or disposal of the tree stems, leaves, and peels. Therefore, the exploitation and use of these biomass resources can prevent possible environmental degradation and the disposal problems that arise with the vast volume of agricultural and forestry waste produced each year. Current agricultural waste applications include briquetting, waste to energy conversion, enzymatic degradation, and adsorption, as well as emerging opportunities in nutraceuticals, packaging, flavoring agents, and waste induced nanoparticles. Fruit waste, including peels, is categorized both as municipal waste and agricultural waste. This waste material contains bacteria and yeasts that can be harmful, hence adding to environmental problems [24]. Every fruit generates half of its total weight as waste globally. Mango (*Mangifera indica* L.) is one of the most significant tropical fruits in terms of production and consumer acceptance worldwide. Mango peel, which makes up about 15–20% of the fresh fruit when processed industrially, is discarded and becomes a source of pollution because it is disposed of in an unsustainable manner [25]. Mango peel is a valuable by-product of industrial mango processing and is high in phytochemical compounds and lignin. As a result, it seems to have a high potential for recovering in the form of bio-products and biofuels, and can also be used as a binding agent to improve the handling properties of densified solid fuel.

Recent studies have also focused on the production of solid fuel briquettes from agricultural waste. For example, Hosseinzadeh et al. [26] discussed a detailed characterization of slow pyrolysis fractions obtained from three major agricultural wastes with different origins and compositions at temperatures ranging from 300 to 550 °C, namely pistachio shell, bitter orange peel, and saffron petals. Mibulo et al. [27] utilized pineapple peel, banana peel, and water hyacinth to render both carbonized and uncarbonized briquettes. The highest calorific value was to be found in pineapple peel carbonized briquettes (25.08 MJ kg⁻¹), then followed by a composite of banana peel and pineapple peel (22.77 MJ kg⁻¹). Water hyacinth produced briquettes with lower calorific values (16.22 MJ kg⁻¹), but the calorific values then increased when combined with banana (20.79 MJ kg⁻¹) or pineapple peel (20.55 MJ kg⁻¹). Alvarez et al. [28] performed citrus waste valorization via fast pyrolysis in a conical spouted bed reactor. The findings demonstrated that the char yield (33–27 wt%) was high across the entire temperature range investigated, and that its high carbon content (71–73 wt%) and high heating value (27 MJ kg⁻¹) are suitable for use as fuel. Brunerova et al. [29] investigated the bio-briquette production from the following tropical fruits: durian (*Durio zibethinus*), coconut (*Cocos nucifera*), coffee (*Coffea arabica*), cacao (*Theobroma cacao*), banana (*Musa acuminata*), and rambutan (*Nephelium lappaceum*). Fruit biomass wastes with the highest energy potentials were found in coconut (18.22 MJ kg⁻¹), banana (17.79 MJ kg⁻¹), and durian (17.60 MJ kg⁻¹), while fruit biomass wastes with the lowest ash content were found in rambutan (3.67%), coconut (4.52%), and durian (5.05%). Rosas et al. [30] carbonized orange peel and partially gasified it with CO₂ to produce activated carbons for environmental

uses such as CO₂ extraction. The previous studies demonstrated that bio-briquettes made from fruit waste biomass can provide a potentially appealing energy source with numerous benefits, particularly for the residues of fruits and plants that are removed or disposed of at landfills or burned widely. However, the previous researchers put more emphasis on the bio-briquettes' characteristics while research on the characteristics of raw materials for solid fuel briquettes is scarce.

Biomass briquettes made from biomass waste products that are naturally abundant can provide a substitute for the use of fossil resources [31]. They are eco-friendly and cost effective as the materials required are waste products. Briquetting low density biomass can save storage and transportation costs. The briquetting process is commonly used to counter the low bulk density problem in solid fuel [32]. Traditionally, people used lump charcoal as a source of energy for cooking, heating, etc. Briquettes made from plastic waste are not a new invention. However, producing briquettes using disposable face masks is a mainly new concept. A binder needs to be added to increase the internal strength of the briquettes. Starch, such as corn starch, wheat starch, maize, or rice flour, is the typical binder, although it is pricy [23]. Only a small amount of binder is added to the mixture to improve the strength of the briquette; around 4–8% starch is needed to produce briquettes, which is negligible [23]. There was not much information available about *Imperata cylindrica* and fruit waste such as mango peel used as briquettes. Therefore, the purpose of this article was to study the characterization of *Imperata cylindrica*, mango peel, and face mask waste as raw materials for the production of solid fuel briquettes.

2. Materials and Methods

2.1. Sampling and Pre-Treatment

This study was conducted mainly at the main campus of Universiti Kebangsaan Malaysia (UKM) located in Bandar Baru Bangi, Malaysia. The used disposable face masks were collected from Menawar Resources Sdn. Bhd., and *Imperata cylindrica* was collected from Laman Duta, Putrajaya. Meanwhile, the mango peel was collected from the Manga asamboi supplier in Puchong. Each waste obtained underwent a pre-treatment process before it could be used for laboratory tests. Mango peel was washed using tap water to remove foreign substances (1 washing), dried under the sun for about 6 h, cut into small pieces with scissors, ground (coffee grinder 200 W) into a fine powder (0.212 mm), and sieved (US standard mesh no 70), then kept in zip lock bags. Face masks were disinfected under ultraviolet (UV) light (Type: UV germicidal disinfection lamp, 8 W, 220 V with a wavelength of 254 nm) for 30 min in a closed room. The face masks were then disassembled, and only three layers of the face masks were used for this study (without the nose strap and ear straps). An office paper shredder was used to shred face masks into smaller pieces and then the pieces were ground (Panasonic 1L blender) into a cotton-wool-like fabric. *Imperata cylindrica* was dried under the sun for 6 h and cut into smaller pieces (garden secateurs, 8 inches). A blender was used to grind it into a fine powder (mesh no 70, 0.212 mm). The physicochemical analyses were carried out in three replicates for each raw sample.

2.2. Proximate Analysis

The moisture content, volatile matter, fixed carbon, ash, and calorific value for the raw materials of *Imperata cylindrica*, mango peel, and face mask blend were analyzed. The proximate analysis refers to BS EN 1016-104 (BS 1998). The summarized methodology of the proximate analyses is reported below.

2.3. Determination of Moisture Content

The moisture content (MC) was determined by calculating the loss in weight of material using the oven drying method at 105–110 °C for 1 h until a constant weight loss was reached (BS 1998).

$$\text{Moisture content (\%)} = \frac{w_2 - w_3}{w_2 - w_1} \times 100\% \quad (1)$$

where,

w_1 = weight of the empty crucible (g)
 w_2 = weight of empty crucible + sample (g)
 w_3 = weight of the crucible + sample after heating (g)

2.4. Determination of Volatile Matter

The dried sample left in the crucible was covered with a lid and placed in an electric furnace (muffle furnace) and maintained at a temperature of 900 ± 15 °C for 7 min. The crucible was first cooled in air, then placed inside a desiccator and weighed again. The loss in weight was reported as volatile matter (VM) on a percentage basis (BS 1998).

$$\text{Volatile matter (\%)} = \frac{w_5 - w_6}{w_5 - w_4} \times 100\% \quad (2)$$

where,

w_4 = weight of the empty crucible (g)
 w_5 = weight of empty crucible + sample (g)
 w_6 = weight of the crucible + ash (g)

2.5. Determination of Ash Content

The residual sample or ash content (AC) in the crucible was heated without a lid in a muffle furnace at a temperature of 815 ± 15 °C for 3 h. The crucible was then taken out, cooled first in the air, then in a desiccator, and weighed. The residue was reported as ash on a percentage basis (BS 1998).

$$\text{Ash content (\%)} = \frac{w_9 - w_7}{w_8 - w_7} \times 100\% \quad (3)$$

where,

w_7 = weight of the empty crucible (g)
 w_8 = weight of empty crucible + sample (g)
 w_9 = weight of the crucible + ash (g)

2.6. Fixed Carbon Determination

The fixed carbon (FC) followed BS 1998, where the percentage was calculated using the following equation:

$$\text{Fixed carbon (\%)} = 100 - \% \text{ of (MC + VM + AC)} \quad (4)$$

2.7. Ultimate Analysis

The ultimate analysis was conducted in order to obtain the elements present in the biomass [33]. The analysis was conducted according to ASTM D5373-02 [33]. The combustibility depends on the amount of carbon and hydrogen [34]. A high carbon content means that the material is a good burning agent. Minimal sulfur and nitrogen oxides released into the atmosphere indicate that burning the biomass will not cause environmental pollution [35]. For each type of waste, the amount of moisture content before and after drying was weighed. A mixer was used to blend the samples for 15 to 20 min.

2.8. Calorific Value

The calorific value is known as the energy content and can be measured using a bomb calorimeter or calculated using thermodynamical values. It can be expressed in kcal/m³ or MJ/kg⁻¹. The oxygen bomb calorimeters, which are the industry standard for determining the calorific values of solid and liquid combustible samples using procedures like BS EN ISO 1716 and/or ASTM D240, are the most often used equipment. They determine the heat

quantity produced during combustion. Water vapor is released during the combustion process and, by condensing the vapor using specific techniques, the heat can be recovered. The two types of calorific values are the gross and net calorific values. Gross calorific value is that used to measure heating value when water is present as a liquid. The heating value is known as the net calorific value if there is water present as vapor. For the purposes of calculating energy efficiency, the net calorific value is more significant.

The calorific value (CV) of the briquetted solid fuel was determined by using a bomb calorimeter model A500. The calorific value of the briquetted fuel was determined using the following formula (ASTM 2000).

$$\text{Calorific value (MJ/kg)} = \frac{(W + w) \times (T1 - T2)}{x} \quad (5)$$

where,

W = weight of water in calorimeter (kg)

w = weight equivalent of apparatus

$T1$ = initial temperature of water ($^{\circ}\text{C}$)

$T2$ = final temperature of water ($^{\circ}\text{C}$)

x = weight of fuel sample taken (kg)

2.9. Carbon and Hydrogen

Generally, both elements are estimated simultaneously. An accurately weighed coal sample is heated in a tubular furnace in an excess of oxygen. Hydrogen is converted to water and carbon to carbon dioxide. The gases are then absorbed in a U-tube containing anhydrous calcium and a U-tube containing potassium hydroxide, respectively.

2.10. Nitrogen

Nitrogen present in a coal sample is estimated by Kjeldahl's method. The basic principle is to convert nitrogen to the ammonium salt. The ammonium salt on treatment with NaOH liberates ammonia which is estimated by back titration, using a standard acid solution. Concentrated H_2SO_4 was added and boiled with the organic samples for about 1–2 h to produce ammonium sulphate solution. Here any nitrogen present in the coal is converted to ammonium salts. The contents are transferred to a round bottomed flask, concentrated NaOH is added, and the flask is heated. Ammonia is distilled into a measured amount of acid. The residual acid is back titrated with standard NaOH. The percentage of N is calculated from the amount of acid consumed.

2.11. Sulfur

Sulfur is determined from the bomb washings obtained due to the combustion of a known quantity of material in the bomb calorimeter experiment. The washings contain sulfur in the form of sulfate, which is precipitated as BaSO_4 . The weight of sulfur present in the material is then calculated.

2.12. Fourier Transform-Infrared Spectrophotometry (FTIR)

FTIR gives basic information on the polymeric type. The face mask was shredded using a shredder and ground with a blender. The FTIR spectra were acquired using a compact infrared spectrometer (Alpha II Bruker, Bruker Corporation, Billerica, MA, USA) equipped with a deuterated triglycine sulfate (DTGS) detector. Each powder sample was scanned by placing the sample on the platinum ATR with a durable magnetic diamond interface. FTIR can collect high spectral resolution data, usually ranging between 5000 and 400 cm^{-1} . The frequency range obtained from the absorption collected for this study was 5000 to 500 cm^{-1} . Thus, the spectrum was verified in transparent mode from 500 to 4000 cm^{-1} , with a resolution of 4.0 cm^{-1} . Each IR spectrum was validated with reference standards.

3. Results and Discussion

3.1. Characteristics of Mango Peel

The compositional analyses of mango peel and other fruit peels are presented in Table 1 based on previous studies [24]. According to Jahid et al. [24], mango peel contained the highest lignin and cellulose content compared to papaya peel, pineapple peel, and banana peel, with lignin content (27.9%) and cellulose content (38.4%). Lignin composition is one of the important factors in producing a good briquette as it acts as a binding agent. Lignin can affect the strength of the briquette [36]. Hardianto et al. [32] stated that the interlocking effect of lignin increases the mechanical strength of briquettes made from biomass waste. The compressive strength increases simultaneously with the increase of the binder percentage [37]. Agricultural residue-based briquettes were said to have lower quality due to low lignin percentages [37,38].

Table 1. Compositional analysis of fruit waste by Jahid et al. [24].

Fruit Waste	Hemicellulose * (%)	Cellulose * (%)	Lignin * (%)
Banana peel	9.4	34.8	4.5
Pineapple peel	11.1	22.4	6.5
Papaya peel	24.6	20.4	2.7
Mango peel	13.9	38.4	27.9

* All percentages on a dried basis.

3.2. Proximate Analysis

Proximate and ultimate analyses were conducted to determine the physical and chemical properties of the briquettes. Proximate analysis was used to determine the moisture content, ash content, volatile matter, and fixed carbon content [4]. Proximate analysis was conducted in accordance with the standard ASTM D3172. The moisture content is the amount of water expressed as a percentage of the total weight of the material. The moisture content is a significant parameter that influences the burning characteristics of biomass and the durability of the briquette [9]. According to the Thailand Industrial Standards Institute, the moisture content for solid fuel briquettes must not exceed 8% [4]. Table 2 shows the results of the proximate analysis of the raw samples, i.e., mango peel, *Imperata cylindrica*, and face mask waste. The moisture content for face mask waste obtained in this study was less than 1%, which was close to the study conducted by Yulinah et al. [39] on polypropylene materials, where the moisture content obtained was 0.42%. In this study, face mask waste had a high volatile matter value of 72.1%. However, the residue from the combustion was slightly higher. Nonetheless, from the data obtained, disposable face mask waste is suitable to be used as a control material as the fixed carbon value was high, which means a higher heating value, while the moisture content was low. A lower moisture content gives a higher quality briquette. The moisture content of mango peel powder was 5.2%. Based on the results, the value obtained did not exceed the limit set for good briquette production and was within the maximum limits of 15% moisture content recommended by Wilaipon [40] and Grover et al. [41]. Jayalaxmi et al. [25] reported that the moisture content of mango peel powder in their study was 3.4%, while the ash moisture content was 2.9%. Meanwhile, *Imperata cylindrica* contained less than 1% moisture, which is good, as moisture content influences the calorific value of briquettes. The moisture content greatly affects the quality [41] and strength of the briquettes [42]. According to Aina et al. [43], the moisture content is one of the main parameters that determines briquette quality, and a moisture content of 5% for charcoal briquettes creates a durable briquette. A moisture content of 5.7% for charcoal briquettes is acceptable for storability and combustibility [43].

Table 2. Proximate analysis of the raw samples, i.e., mango peel, *Imperata cylindrica*, and face mask waste.

Parameter	Mango Peel	<i>Imperata cylindrica</i>	Face Mask Waste
Moisture content (MC), %	5.2	<1	<1
Volatile matter (VM), %	72.1	94.6	82.3
Ash (AC), %	7.5	2.3	6.75
Fixed carbon (FC), %	16.1	3.1	10.95
Calorific value (CV), (MJ/kg)	18.1	17.8	26.19

The heating value increases when the moisture content decreases [44]. There are two types of moisture content: intrinsic, also known as bound water, and extrinsic. Intrinsic is the moisture from the biomass itself, while extrinsic is the moisture from the surroundings, which can change. The maximum moisture content for cellulosic biomass ranges between 8% and 12% [45]. A previous study showed that briquettes with the highest calorific value (17.688 MJ kg⁻¹) had around 14% moisture content [9]. In this study, face mask waste had the highest calorific value, 26.19 MJ kg⁻¹, followed by mango peel with 18.1% and *Imperata cylindrica* with 17.8%. Overall moisture content decreases the efficiency of briquettes produced as the higher moisture content reduces the calorific value of the briquette [45]. Thus, briquettes with lower moisture content are preferable.

In this study, the ash value for mango peel (7.5%) was higher compared to *Imperata cylindrica* (2.3%), while the volatile matter value for *Imperata cylindrica* (94.6%) was higher than the value for mango peel (72.1%). The fixed carbon value for mango peel was the highest among the three materials, with a value of 16.1%, compared to 10.95% for face mask waste and 3.1% for *Imperata cylindrica*. A high amount of fixed carbon produces better charcoal because the corresponding calorific energy is usually high [46]. A low fixed carbon value tends to prolong cooking time when using briquettes due to the low heat release. Ash has a significant influence on the heat transfer to the surface of a fuel as well as the diffusion of oxygen to the fuel surface during char combustion. As ash is an impurity that will not burn, fuels with a low ash content are better suited for thermal utilization compared to fuels with a high ash content. Higher ash content in a fuel usually leads to higher dust emissions and affects the combustion volume and efficiency. It can be concluded that *Imperata cylindrica* is suitable to be used as a heating agent and mango peel is more suitable to be used as a natural and more eco-friendly binding agent.

3.3. Ultimate Analysis

The ultimate analysis was conducted in order to obtain the elements in the biomass. The analysis was conducted according to ASTM D5373-02. The combustibility depends on the amount of carbon and hydrogen present. A high carbon content means that the material is a good burning agent. Minimal sulfur and nitrogen oxides released into the atmosphere indicate that burning the biomass will not cause environmental pollution [35]. In order to make an eco-friendly briquette, sulfur and nitrogen values need to be low.

Table 3 shows carbon content obtained from this study for the face mask waste, mango peel and *Imperata cylindrica* were 63.6%, 44%, and 40.8%, respectively. Meanwhile, for hydrogen the values were 10%, 6.15%, and 6.95%, respectively. Face mask waste contained the highest value of carbon and hydrogen as it is made from polymeric materials that have high heating and calorific values. For both agricultural wastes, the carbon and hydrogen content were still in the range of the standard ranges for agricultural waste, which are 4.5–7.5% for hydrogen and 40–53% for carbon [47]. Based on a study conducted for pure polypropylene, the carbon content was in the range 60–90% [48].

Table 3. CHNS values for face mask waste, mango peel, and *Imperata cylindrica*.

Samples	C (%)	H (%)	N (%)	S (%)
Face mask waste	63.6 ± 1.5	10.00 ± 0.5	0.11 ± 0.05	0.89 ± 0.03
Mango peel	44.0 ± 0.5	6.15 ± 0.2	0.52 ± 0.05	0.62 ± 0.04
<i>Imperata cylindrica</i>	40.8 ± 0.7	6.95 ± 0.3	0.83 ± 0.05	0.66 ± 0.01

Most of the time, biomass has less sulfur content compared to coal or a polymer [33]. This means that the higher the biomass content in a solid fuel, the lower the sulfur dioxide (SO₂) emissions [49]. From the data, the face mask waste had the highest sulfur content, 0.89%. Sulfur can be converted to sulfuric acid, which can cause corrosion of the furnace and equipment. The sulfur content for mango peel was 0.62% and *Imperata cylindrica* 0.66%, still below the maximum range (0.0–0.7%). The nitrogen content for all the materials was considered low, where the range was 0.1–8.0%.

3.4. Fourier Transform-Infrared (FTIR) Analysis

FTIR is a method used to determine the functional groups of materials before conducting flammability and thermal analysis [50]. For organic compounds, FTIR detects the infrared absorbance of molecules based on their vibrational modes and is sensitive and selective [51]. As a result, it is commonly used to study the degradation of polymers [51] or biomass [52]. An FTIR Spectrum 400 Perkin Elmer instrument was used to produce wavelengths and convert them into graphs. The functional group, compound, and group were then determined for each sample by referring to the values shown in Table 4.

Table 4. FTIR Spectrum correlation tables. Source: [Thermofisher.com](https://www.thermofisher.com).

Functional Group	Wavenumber (cm ⁻¹)
C–H	2850–3300
C=O	1680–1750
C–O	1000–1300
O–H (alcohols)	3230–3550
O–H (acids)	2500–3300 (very broad)

The FTIR graph for *Imperata cylindrica* vs. mango peel is shown in Figure 1, and FTIR graphs for disposable face mask waste of all three layers, and the outer, inner, and middle layers are shown in Figure 2. Based on the FTIR analysis, the inner and outer layers have a characteristic peak for polypropylene and high-density polyethylene [10]. The FTIR spectrum for mango peel consisted of major peaks at 3320, 2925, 1683, and 1031 cm⁻¹, corresponding to OH, CH, C=O, and C–O stretching. Meanwhile, for *Imperata cylindrica*, the major peaks were at 3450, 2982, 1051, and 1052 cm⁻¹, corresponding to OH, CH, C=O, and C–O stretching.

In this analysis, the ear straps of the masks were removed and not included. Four large bands in the wavenumber range 3000–2700 cm⁻¹ were due to CH₂ asymmetric deformation vibrations. The band at 2985 cm⁻¹ could be ascribed to the symmetric vibration of cellulose oxygen–hydrogen (O–H) groups. The C–H wagging vibration is characterized by a sharp and distinct peak at 2900 cm⁻¹ [53]. The C–O stretching within the polypropylene component of the mask waste was assigned to the peaks at about 1405 cm⁻¹ [19]. The inner layer had the highest peak for the C–H bond, with bands at 723 cm⁻¹ and 2823 cm⁻¹. The symmetry deformation of CH₃ on aliphatic hydrocarbons was assigned to the peak at 1454 cm⁻¹ [54]. All three layers of the disposable face mask waste, the outer layer, inner layer, and middle layer, indicated that each layer peaks around 1500–1300 cm⁻¹ in symmetry deformation of the methyl groups. It can be concluded that the face mask waste used was made up of polymeric materials, particularly polypropylene sheets.

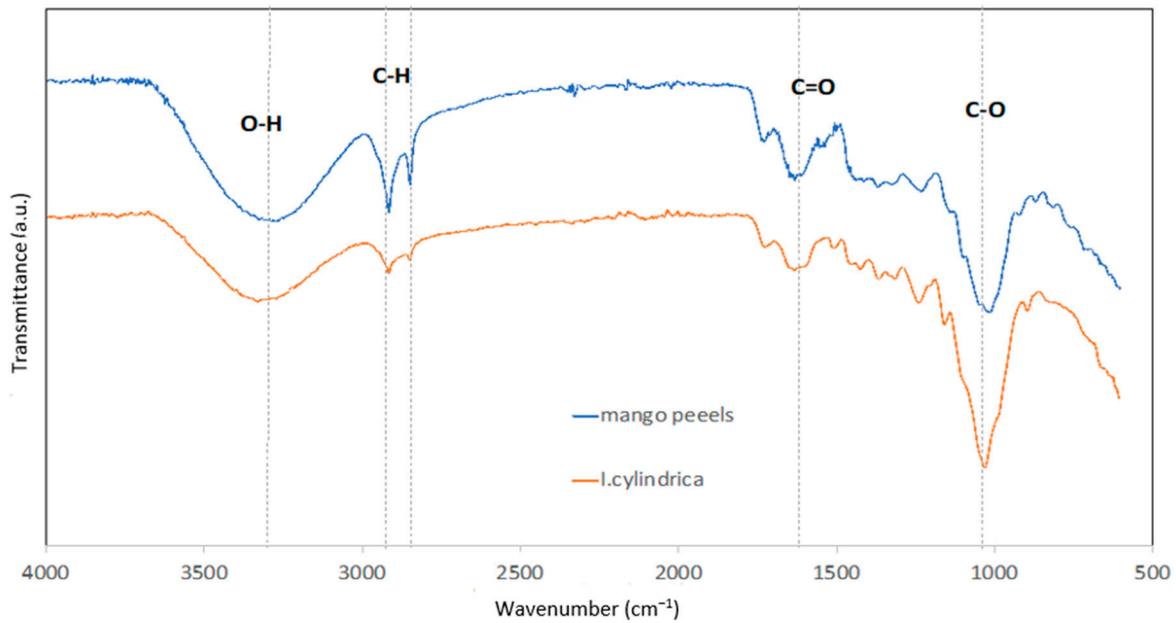


Figure 1. FTIR spectra for *Imperata cylindrica* vs. mango peel.

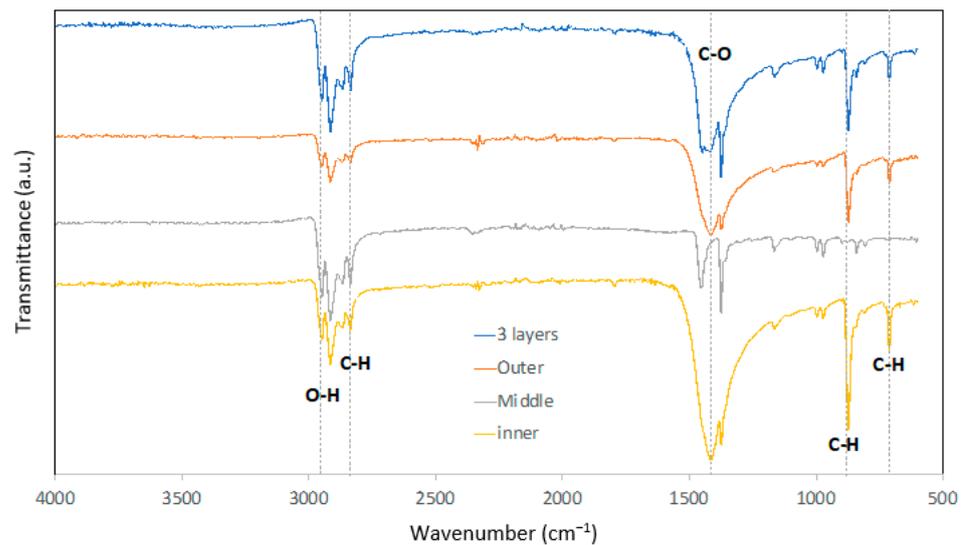


Figure 2. FTIR spectra for face mask waste (three layers, outer layer, middle layer, and inner layer).

The data presented in Table 5 show the functional groups of all three materials analyzed, where both agricultural wastes were in the oxygen type group while the face mask waste (PP) was in the methyl type group. *Imperata cylindrica* and mango peel both have the functional group C–O–H and the functional group for the face mask waste was CH₃. Zhang et al. [54] stated that the three layers of surgical face masks (of various different types and colors) contain are in the methyl type (CH₃) group, indicating that all three layers of face masks, regardless of brand, have similar functional groups.

Table 5. The functional groups of *Imperata cylindrica*, mango peel and face mask waste.

Material	Group	Compound	Functional Group
<i>Imperata cylindrica</i>	Oxygen	Alcohol	C–O–H
Mango peel	Oxygen	Alcohol	C–O–H
Face mask waste	Methyl	Alkene	CH ₃

This study investigated the potential of each raw material to be used for briquettes based on their physical and chemical properties. Based on the study conducted on the raw materials, the best candidates for further processing into briquettes based on the proximate analysis and ultimate analysis conducted were face mask waste and mango peel. Both face mask waste and mango peel had low moisture contents, high carbon and volatile matter contents, and relatively low ash contents. The volatile matter for *Imperata cylindrica* was too high, which resulted in a faster burning time. Face mask waste could be the potential binder for the briquette as it contains cellulose (O–H) stretching [5].

4. Conclusions

This study was conducted to determine the characteristics of raw plastic (face mask) and agricultural wastes (*Imperata cylindrica* and mango peel) as potential materials for briquette production. FTIR analysis determined that both agricultural wastes are from the same functional group (C–O–H), while the face mask waste was from the CH₃ group. Based on the results from the proximate analysis, the face mask waste, mango peel, and *Imperata cylindrica* all have low moisture content but a high volatile content. A high volatile content means that the briquette starts to burn easily but also indicates that the briquette will have a faster burning time. *Imperata cylindrica* has the lowest fixed carbon amount compared to mango peel and face mask waste. The ultimate analysis (CHNS) results showed that the face mask waste contained the highest carbon and hydrogen values. High carbon affects the calorific values and briquette performance. With this investigation, the physical and chemical properties of potential materials (*Imperata cylindrica*, face mask waste, and mango peel) for solid fuel briquette production were determined. This study helps to provide more information regarding briquette production in terms of raw material compatibility. With the optimum ratio and technique, briquettes made from the combination of plastic waste and lignocellulosic biomass can be converted into a high value potential alternative energy source that can be commercialized, allowing for the successful translation into an economically viable commercial product.

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