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AVAILABILITY AND PHYSICAL PROPERTIES OF RESIDUES FROM MAJOR AGRICULTURAL CROPS FOR ENERGY CONVERSION THROUGH THERMOCHEMICAL PROCESSES

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ABSTRACT

Plant residues from the major agricultural crops (wheat, rice, corn, soybean, sugarcane, coffee and cotton) are abundantly available renewable resources that can be used to supply energy through thermochemical conversion processes. The available amounts of plant residues from these crops and their physical properties (moisture content, particle size, bulk density and porosity) were determined. The annual residues from the wheat, rice, corn, soybean, sugarcane, coffee and cotton were 763.42, 698.10, 1729.92, 416.62, 16.85, 4.01 and 107.13 million tons, respectively. The total amount of plant residues was estimated at 3736.05 million tons with total energy content of 66.92 EJ. These residues can replace 2283.52 million tons of coal, 1551.78 million tons of oil and 1847.63 million m^3 of natural gas. The moisture contents were 7.79, 6.58, 6.40, 7.30, 8.15, 7.86 and 7.45% for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. The corn stalk and sugarcane stalk had a convex particle size distribution, the soybean stalk and cotton stalk had a concave particle size distribution, the wheat straw and rice straw had an increasing trend particle size distribution and the coffee husk had a decreasing trend particle size distribution. The average particle sizes for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk were 0.42, 0.40, 0.49, 0.43, 0.55, 0.67 and 0.38 mm, respectively. The average bulk density was 160.75, 166.29, 127.32, 242.34, 110.86, 349.06 and 230.55 kg m^{-3} for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. The average porosity was 51.25, 83.20, 58.51, 68.03, 77.58, 64.85 and 74.55% for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. The results obtained from this study indicate that different plant residues have different physical properties.

Keywords: Plant residues; Availability; Wheat Straw; Rice Straw; Corn Stalk; Soybean Stalk; Sugarcane Stalk; Coffee husk; Cotton stalk; Physical Property; Moisture Content; Particle Size; Bulk Density; Porosity

1. INTRODUCTION

There are seven important crops that are used by human as sources of food and fiber worldwide. These are: wheat, rice, corn, soybean, sugarcane, coffee and cotton. Wheat, rice, corn and soybean are considered staple foods in many parts of the world, sugar is an important additive in drinks and foods and coffee is used worldwide as a hot drink and forms an important part of the economy of many countries and cotton is used to produce oil and fiber. The world production of wheat, rice, corn, soybean, sugar, coffee and cotton are shown in **Table 1**. The total production of food crops (wheat, rice, corn and soybean) is 2269.45 million metric tons while the production of sugar, coffee and cotton are 168.48, 8.03 and 26.92 million metric tons, respectively.

The processing and consumption of these crops result in significant amount of residues (3736.05 million tons) as shown in **Table 1**.

Table 1. Word production of seven most important crops in 2011 (USDA, 2012)

Crops	Cultivation area (Million ha)	Total production (Million MT)	Total revenue (Billion US $)	Residues (Million MT) [b]
Wheat	222.80	694.02	208.00	763.42
Rice [a]	160.19	465.40	240.00	698.10
Corn	169.29	864.96	199.53	1729.92
Soybean	103.09	245.07	124.32	416.62
Sugar	28.82	168.48	106.14	16.85
Coffee	10.66	8.03	37.16	4.01
Cotton	35.71	26.92	88.08	107.13

[a] Milled basis
[b] Estimated by the authors

Some of these materials are used for making pulp and paper (Hedjazi *et al*., 2009), as a roughage in animal feeding (Dong *et al*., 2008), producing liquid fuels (Wang *et al*., 2012), as thermal insulation materials (Zhou *et al*., 2010), as an adsorbent (Brandão *et al*., 2010), as microporous materials (Silva *et al*., 1998) and as an fermentation medium (Mazutti *et al*., 2010). However, these materials are renewable and can be used as energy sources to replace fossil fuels in thermochemical conversion processes such as combustion and gasification (Williams *et al*., 2012; Yuan *et al*., 2012; Kumar *et al*., 2008; Sun *et al*., 2010; Zabaniotou *et al*., 2010). The high cost of fossil fuel, limited and uncertain supply and impact on environment make the utilization of biomass as a source of energy very attractive. Biomass materials are CO_2 neutral while CO_2 emissions from coal, Natural Gas (NG) and biomass are 1142, 505-846 and 66-107 t GWh^{-1}, respectively (Hall and Scrase, 1998). In addition, these biomass materials contain low amounts of sulphur and trace metals resulting in lower SO_x and NO_x emissions, acid rain and O_3 smog. Therefore, using biomass material as energy sources can contribute positively to the global environment and human health.

The physical properties (moisture content, particle size, bulk density and porosity) of a given biomass material greatly influence the design and operation of thermochemical conversion systems. High moisture content decreases the heating value of fuel, which in turn reduces the conversion efficiency as a large amount of energy would be used for the initial drying step during the conversion processes (Mansaray and Ghaly, 1997). The particle size distribution affects the flowability, heating, diffusion and rate of reaction (Guo *et al*., 2012; Hernández *et al*., 2010). The bulk density affects the economics of collection, transportation and storage as well as feeding the material into the thermochemical conversion system (Natarajan *et al*., 1998). Porosity affects the interstitial airflow velocity and the heat and mass transfer conditions and ultimately influences reaction parameters such as heat conductivity, burning rate, conversion efficiency and emissions (Igathinathane *et al*., 2010; Hamel and Krumm, 2008). Therefore, full understanding of the physical properties of the plant residues is essential for the design and operation of efficient thermochemical conversion systems such as combustors and gasifiers.

The main objectives of this study were: (a) to determine the availability of residues from the seven most important agricultural crops (wheat, rice, corn, soybean, sugarcane, coffee and cotton) as an alternative source of energy for fossil fuel and (b) to investigate the physical properties (moisture content, particle size distribution, bulk density and porosity) of these residues as related to pre-processing and design of thermochemical conversion systems.

2. MATERIALS AND METHODS

2.1. Sample Collection

Wheat straw, rice straw and cotton stalk were collected from Egypt. Corn stalk was collected from China. Sugarcane stalk was collected from Cuba. Soybean stalk and coffee husk were collected from Guyana.

2.2. Sample Preparation

The plant residues were ground through a coarse sieve (12.7 mm) and a 20-mesh sieve (0.85 mm) on a medium size Wiley Mill (Model X876249, Brook Crompton Parkinson Limited, Toronto, Ontario). The coarse ground samples were then reground through a 40-mesh sieve (0.425 mm) on the Wiley Mill in order to narrow the range of particle size and thus obtain homogeneous samples.

2.3. Moisture Content

Moisture content was determined using the oven-drying method (ASTM 2010). A large aluminum dish was weighed using a digital balance (Model PM 4600, Mettler Instrument AG, Greifensee, Zurich). The ground sample was placed in the dish and the dish and sample were weighed. The dish and sample were then placed in an air-forced drying oven (Heratherm, Thermo Fisher Scientific Inc., Waltham, USA) and kept at 105°C until a constant weight was achieved. The dish containing the dried sample was cooled to the room temperature in a desiccator and then weighed. The moisture content was calculated on a wet basis as follows:

$$MC = \frac{(WW - DW)}{WW} \times 100 \quad (1)$$

where:

MC = The moisture content (%)
WW = The wet weight of the sample and dish (g)
DW = The dry weight of the sample and dish (g)

2.4. Particle Size Distribution

The particle size distribution was determined using seven standard sieves (Canadian Standard Sieve Series, W.S. Tyler Company of Canada Limited, St. Catharines, Ontario) and a bottom pan that collects everything that passed though the seventh sieve. The sieves were mounted on an electrical sieve shaker driven by a 0.25-hp electric motor running at 1725 rpm (Model Rx-86, Hoskin Scientific Limited and Gastonia, North Carolina). The sample was placed in sieve 1, which was then covered with the sieve lid. The shaker was operated at the speed of 350 rpm for 30 min. The particles collected in each sieve were weighed. The sieve number, mesh number and mesh size of the seven sieves are shown in **Table 2**.

2.5. Bulk Density

An empty container (150 mL) was weighed using a digital balance (Model PM 4600, Mettler Instrument AG, Greifensee, Zurich) to the nearest 0.0001g. The container was filled with the sample and the material was slightly compacted to ensure absence of large void spaces. The container and the sample were then weighed. Three replicates were carried out. The wet bulk density of the sample was calculated from the following equation:

$$\rho_b = \frac{(W_2 - W_1)}{V} \quad (2)$$

where:

ρ_b = The bulk density of the sample (g cm^{-3})
W_2 = The weight of the container and sample (g)
W_1 = The weight of the container (g)
V = The volume of the container (cm^3)

2.6. Porosity

The porosity of biomass was determined using the water pycnometer method. A sample of approximately 33 mL was placed in a 100 mL graduated cylinder. A wire mesh screen was placed on the top of the sample to prevent material from floating once submerged in water.

Table 2. Sieve number, mesh number and mesh size

Sieve number	Mesh number	Mesh size (mm)
1	20	0.850
2	25	0.710
3	35	0.500
4	40	0.425
5	45	0.355
6	50	0.300
7	70	0.212
Pan	-	0.000

Distilled water was slowly poured over the sample until the water level was above the top of the sample. The cylinder was gently rocked from side to side ten times to free trapped air bubbles before recording the final water level. The amount of added water and the water level were recorded to the nearest 1 mL. The cylinder was emptied and cleaned thoroughly after each test. Three replicates were carried out. The porosity of biomass was calculated from the following:

$$P(\%) = \frac{V_i - V_f}{V_s} \times 100 \quad (3)$$

where:

P = The porosity of the sample (%)
V_i = The combined volume of the sample plus added water (mL)
V_f = The final total volume of the sample and added water (mL)
V_s = The volume of the sample (ml)

3. RESULTS AND DISCUSSION

3.1. Availability of Plant Residues

The world productions of the seven most important agricultural crops are shown in **Table 1**. The annual production of wheat, milled rice, corn, soybean, sugar, coffee and cotton were 694.02, 465.40, 864.96, 245.07, 168.48, 8.03 and 26.92 million metric tons, respectively. **Figure 1-7** show the production of wheat, rice, corn, soybean, sugar, coffee and cotton by the top 10 countries. The top 10 countries produce 65.95% of wheat, 85.62% of rice, 79.26% of corn, 64.21% of soybean, 67.96% of sugar, 84.09% of coffee and 89.71% of cotton.

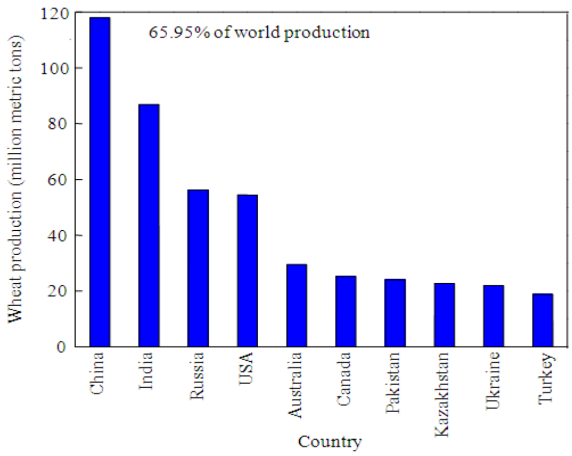

Fig. 1. Top 10 wheat producing countries (USDA, 2012).

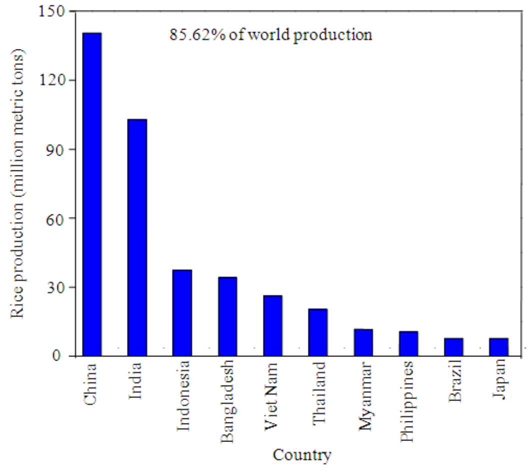

Fig. 2. Top 10 rice producing countries (USDA, 2012).

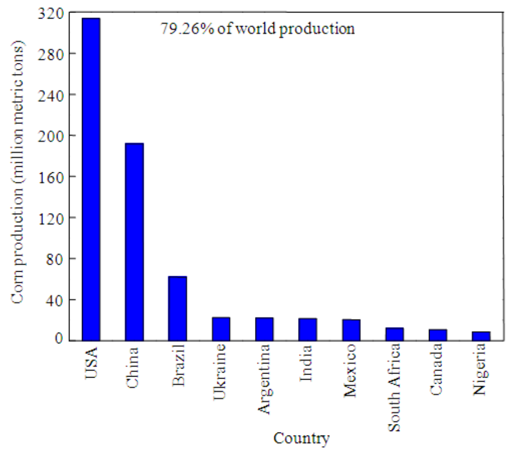

Fig. 3. Top 10 corn producing countries (USDA, 2012).

The processing and consumption of these crops result in significant amounts of residues (**Table 1**). The total amount of these residues was estimated at 3736.05 million tons; 763.42 million tons of wheat straw (20.43%) on an annual basis, 698.10 million tons of rice straw (18.69%), 1729.92 million tons of corn stalks (46.30%), 416.62 million tons of soybean stalks (11.15%), 16.85 million tons of sugarcane stalks (0.45%), 4.01 million tons of coffee husks (0.11%) and 107.13 million tons of cotton stalks (2.87%). These residues can supply a total energy of 66.92 EJ. **Table 3** shows the estimated energy equivalent for coal, oil and Natural Gas (NG) from these residues. The annual amounts of coal, oil and Natural Gas (NG) that can be replaced with biomass are 2283.52 million tons, 1551.78 million tons and 1847.63 million m^3, respectively.

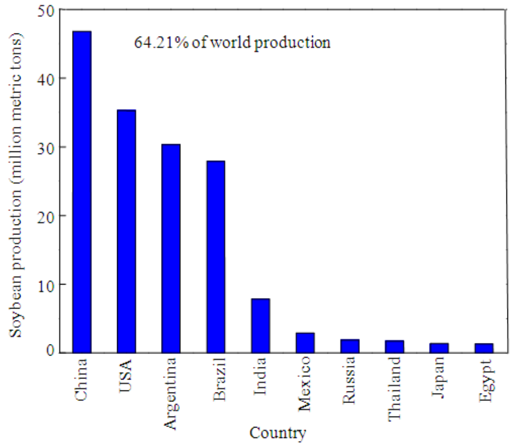

Fig. 4. Top 10 soybean producing countries (USDA, 2012).

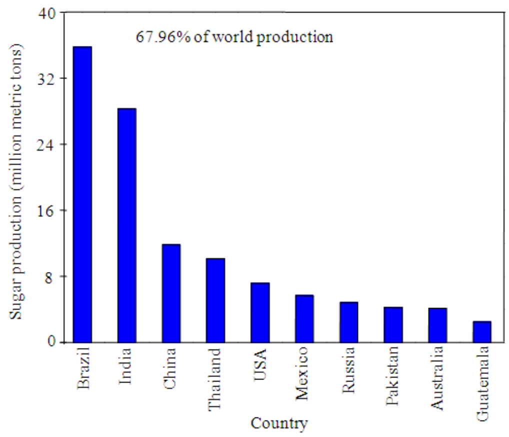

Fig. 5. Top 10 sugar producing countries (USDA, 2012).

3.2. Moisture Content

The moisture content results of the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk are shown in **Table 4**. The moisture content was 7.79, 6.58, 6.40, 7.30, 8.15, 7.86 and 7.45% for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. The moisture content of the wheat straw is within the range of 4.3-9.5% reported by Adapa *et al*. (2010). The moisture content of the rice straw is within the range of 2-10% reported by Chang *et al*. (2011). The moisture content of the corn stalk is similar to the value of 6.44% reported by Ioannidou *et al*. (2009). The moisture content of the sugarcane stalk is similar to the value of 8.1% reported by Brandão *et al*. (2010).

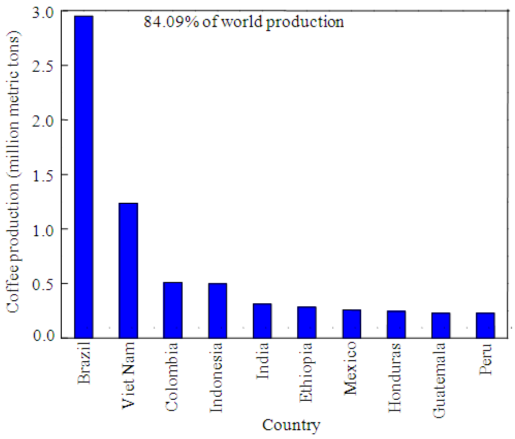

Fig. 6. Top 10 coffee producing countries (USDA, 2012).

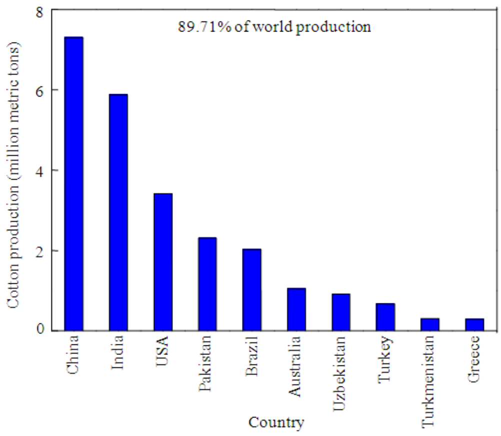

Fig. 7. Top 10 cotton producing countries (USDA, 2012).

Table 3. Available energy from important plant residues

Residues	Energy content (MJ kg^{-1})	Estimated energy (10^9 MJ y^{-1})	Coal (Million MT y^{-1})	Oil (Million MT y^{-1})	NG Million y^{-1})
Wheat	17.98[a]	13726.29	468.38	318.29	378.97
Rice	17.12-18.68[b]	12495.99	426.40	289.76	345.00
Corn	15.40-18.25[c]	29105.90	993.17	674.92	803.59
Soybean	21.81-23.01[d]	9336.45	318.59	216.50	257.77
Sugar	15.90-18.73[a]	291.76	9.96	6.77	8.06
Coffee	24.91[e]	99.89	3.41	2.32	2.76
Cotton	17.40[a]	1864.06	63.61	43.22	51.46

[a] Munir *et al*. (2009)
[b] Deng *et al*. (2009)
[c] Ioannidou *et al*. (2009)
[d] Zabaniotou *et al*. (2010)
[e] Silva *et al*. (1998)

The moisture content of the coffee husk is within the range of 5.8-8.5% reported by Devi *et al*. (2008). The moisture content of the cotton stalk is within the range of 3.42-7.73% reported by Deng *et al*. (2011).

Table 4. Moisture content, average particle size, bulk density and porosity of plant residues.

Residues[a]	Moisture content (%)	Average particle size (mm)	Bulk density (kg m^{-3})	Porosity (%)
Wheat straw	7.79	0.42	160.75	51.25
Rice straw	6.58	0.40	166.29	83.20
Corn stalk	6.40	0.49	127.32	58.51
Soybean stalk	7.30	0.43	242.34	68.03
Sugarcane stalk	8.15	0.55	110.86	77.58
Coffee husk	7.86	0.67	349.06	64.85
Cotton stalk	7.45	0.38	230.55	74.55

[a]Average of three replicates

Variations in procedures used to collect and store plant residues and in techniques used to determine the moisture content can result in differences in the moisture content. Moisture in the solid fuels provides a medium for the transport of dissolved nutrients which are required for the metabolic and physiological activities of microorganisms (Liang *et al*., 2003). An increase in moisture content will increase the biodegradation rate of organic material, resulting in the loss of potential fuels (Pommier *et al*., 2008). High moisture content of plant residues will substantially decrease their heating values and reduce the conversion efficiency and performance of the system, because some of energy generated would be used for vaporization of the fuel moisture during the conversion processes (Chen *et al*., 2009; Ghaly and Al-Taweel, 1990). Therefore, low moisture content is preferred for the storage and thermochemical conversion of these plant residues.

3.3. Particle Size Distribution

Table 5 shows the particle size distribution results of the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk. Most of the particles of the wheat straw (82.41%), rice straw (86.56%), corn stalk (80.86%), soybean stalk (76.74%) and cotton stalk (80.28%) were less than 0.710 mm, while most of the particles of the sugarcane stalk (81.69%) and coffee husk (86.97%) were larger than 0.355 mm.

Figure 8 shows the particle size distribution for the seven plant residues. The particle size distribution of the corn stalk and sugarcane stalk had a convex distribution, while the particle size distribution of the soybean stalk and cotton stalk had a concave distribution. The particle sizes of the wheat straw and rice straw had an increasing trend distribution (the larger the particle size the higher the weight percentage), while the particle size of the coffee husk had a decreasing trend distribution (the smaller the particle size the higher the weight percentage).

Table 5. Particle size distribution of plant residues.

	Weight percentage (%)[a]						
Size range (mm)	Wheat straw	Rice straw	Corn stalk	Soybean stalk	Sugarcane stalk	Coffee husk	Cotton stalk
0~0.212	17.66	18.42	8.490	23.90	5.610	3.610	32.22
0.212~0.300	16.65	17.58	8.700	15.09	6.290	4.630	15.99
0.300~0.355	14.17	13.99	10.67	11.15	6.410	4.790	9.760
0.355~0.425	12.05	13.54	12.60	9.790	10.97	7.230	7.770
0.425~0.500	11.28	13.17	16.93	7.290	16.06	10.77	7.700
0.500~0.710	10.60	9.860	23.47	9.520	28.21	14.61	6.840
0.710~0.850	9.080	8.020	12.45	10.51	15.53	19.82	8.440
>0.850	8.510	5.420	6.690	12.75	10.92	34.54	11.28

[a]Average of three replicates

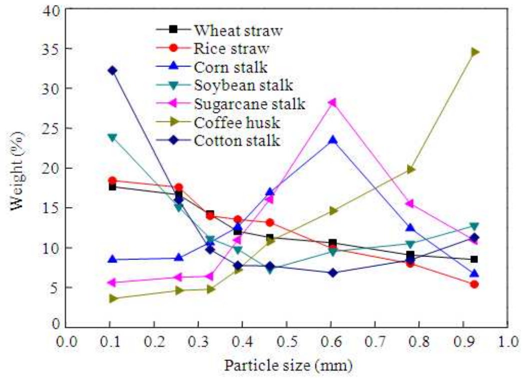

Fig. 8. Particle size distribution of plant residues.

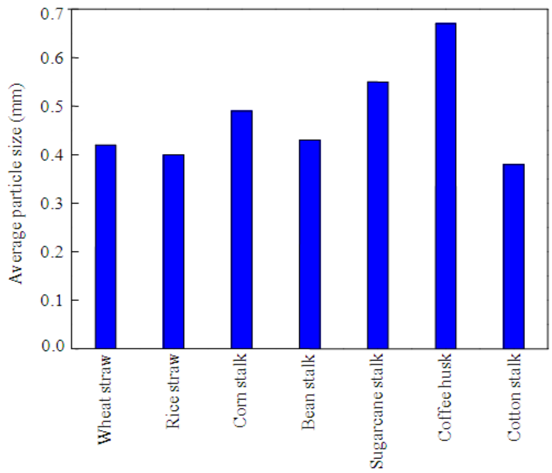

Fig. 9. Average particle size of plant residues.

The average particle sizes for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk were 0.42, 0.40, 0.49, 0.43, 0.55, 0.67 and 0.38 mm, respectively (**Fig. 9**). The average particle size of the wheat straw is within the range of 0.309-0.568 mm reported by Adapa *et al*. (2011). The average particle size of the rice straw is within the range of 0.25-0.45 mm reported by Chou *et al*. (2009). The average particle size of the corn stalk is within the range of 0.25-4.42 mm reported by Ileleji and Zhou (2008). The average particle size of the soybean stalk is within the range of 0-1 mm reported by Zabaniotou *et al*. (2010). The average particle size of the sugarcane stalk is within the range of 0.5-1 mm reported by Inyang *et al*. (2010). The average particle size of the coffee husk is within the range of 0.583-0.880 mm reported by Silva *et al*. (1998). The average particle size of the cotton stalk is within the range of 0.20-0.42 mm reported by Zheng *et al*. (2008).

There were significant differences in both particle size distribution and average particle size among the plant residues. Large particles are thermally thick thereby having slow devolatilization rate and more distributed heat transfer to nearby particles (Ryu *et al*., 2006). On the other hand, small particles may enhance the reaction area and result in high burning rates (Kwong *et al*., 2007), increase the bulk density of biofuels and eventually increase the energy density and reduce the costs of transport and storage (Sangnark and Noomhorm, 2004; Chiueh *et al*., 2012; Deng *et al*., 2009). Thus, size reduction appears to be beneficial and important for pretreatment of biofuels before the utilization (Zhang and Zhang, 1999).

3.4. Bulk Density

The bulk density results of the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk are shown in **Table 4**. The average bulk density was 160.75, 166.29, 127.32, 242.34, 110.86, 349.06 and 230.55 kg m^{-3} for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively.

The average bulk density of the wheat straw is within the range of 150-250 kg m^{-3} reported by Zhou *et al*. (2004). The average bulk density of the rice straw is similar to the value of 177.6 kg m^{-3} reported by Yuan *et al*. (2012). The bulk density of the corn stalk is similar to the value of 127.5 kg m^{-3} reported by Sciban *et al*. (2008). The bulk density of the sugarcane stalk is within the range of 60-150 kg m^{-3} reported by Duarte *et al*. (2012). The bulk density of the cotton stalk is within the range of 150-450 kg m^{-3} reported by Zhou *et al*. (2010).

There were significant differences in the bulk density among plant residues. The bulk density of plant residues can be significantly affected by the particle size distribution (**Fig. 9**) and the chemical composition (**Table 6**) of these materials. The bulk density of fuel affects its residence time in the reactor. Lower bulk density may result in lower conversion efficiency, as it gives rise to poor mixing characteristics and a nonuniform temperature distribution, both of which may create unfavorable operating conditions in the thermochemical conversion systems (Rozainee *et al*., 2008). On the other hand, higher bulk density may result in lower transportation and storage costs and lower emissions during combustion (Sokhansanj *et al*., 2010; Ryu *et al*., 2006; Mani *et al*., 2006; Khan *et al*., 2009). Therefore, densification of plant residues may be required. Studies showed that densification can increase the density of wheat straw to 813-931 kg m^{-3} (Adapa *et al*., 2009), the density of rice straw to about 730 kg m^{-3} (Okasha, 2007) and the density of corn stover to more than 1100 kg m^{-3} (Kaliyan and Morey, 2009). Also, pulverization of cotton stalk can increase its density to 1080 kg m^{-3} (Luo *et al*., 2011) and pelletizing of sugarcane bagasse can increase its density to 1030-1260 kg m^{-3} (Erlich *et al*., 2005). However, the high investment on equipment and the energy input are the major constrains of the densification processes (Adapa *et al*., 2009).

3.5. Porosity

The porosity results of the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk are shown in **Table 4**. The average porosity was 51.25, 83.20, 58.51, 68.03, 77.58, 64.85 and 74.55% for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. The porosity of the wheat straw is within the range of 25.06-62.75% presented by Chevanan *et al*. (2010). The porosity of the corn stalk is within the range of 33-68% (computed from the true density and particle density) presented by Tsai *et al*. (2001). The porosity of the sugarcane stalk is within the range of 65-78% presented by Membrillo *et al*. (2011). The porosity of the coffee husk is similar to the value of 63% presented by Silva *et al*. (1998). The porosity of the cotton stalk is within the range of 71.74-78.28% presented by Sun *et al*. (2010).

The porosity of biomass samples depends on a number of factors including particle size distribution, particle shape, shaking and pressing (Igathinathane *et al*., 2010). A decrease in the porosity will increase the interstitial airflow velocity and bring changes in heat and mass transfer conditions and ultimately influence the combustion parameters such as heat conductivity, burning rate, conversion efficiency and emissions (Igathinathane *et al*., 2010; Hamel and Krumm, 2008). Pelletizing or compacting can decrease the porosity of biomass samples. However, these dense materials may deteriorate the flow characteristics in the gasifier or combustor, thereby causing post-processing problems (Chen *et al*., 2009).

Table 6. Chemical composition of the plant residues.

Crop residues	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)
Wheat straw[a]	46.2-49.2	31.4-32.7	10.0-10.8
Rice straw[b]	33.4-41.8	16.2-23.6	8.8-8.9
Corn stalk[c]	40.4	71.3	18.3
Bagasse[d]	40.6-45.7	18.9-26.9	21.5-25.4
Coffee pulp[a]	23.0-24.5	15.1-17.1	25.0-26.0
Cotton stalk[c]	50.2	75.1	22.0[a]

Salmones *et al*. (2005)
[b] Ma *et al*. (2009)
[c] Luo *et al*. (2011)
[d] Rocha *et al*. (2012)

4. CONCLUSION

The availability of plant residues from major agricultural crops (wheat, rice, corn, soybean, sugarcane, coffee and cotton) was estimated and the physical properties (moisture content, particle size distribution, bulk density and porosity) of these residues were also determined. The annual residues from the wheat, rice, corn, soybean, sugarcane, coffee and cotton crops were 763.42, 698.10, 1729.92, 416.62, 16.85, 4.01 and 107.13 million tons, respectively. The amount of plant residues available for energy conversion was estimated at 3736.05 million tons which can supply a total energy of 66.92 EJ. Therefore, these residues can replace 2283.52 million tons of coal, 1551.78 million tons of oil and 1847.63 million m^3 of natural gas. The moisture contents were 7.79, 6.58, 6.40, 7.30, 8.15, 7.86 and 7.45% for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. The corn stalk and sugarcane stalk had a convex particle size distribution, the soybean stalk and cotton stalk had a concave particle size distribution, the wheat straw and rice straw had an increasing trend particle size distribution and the coffee husk had a decreasing trend particle size distribution. The average particle sizes for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk were 0.42, 0.40, 0.49, 0.43, 0.55, 0.67 and 0.38 mm, respectively. The average bulk density was 160.75, 166.29, 127.32, 242.34, 110.86, 349.06 and 230.55 kg m^{-3} for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. The average porosity was 51.25, 83.20, 58.51, 68.03, 77.58, 64.85 and 74.55% for the wheat straw, rice straw, corn stalk, soybean stalk, sugarcane stalk, coffee husk and cotton stalk, respectively. The results obtained from this study indicate that different plant residues have different physical properties.

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