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Phytochemical composition and essential mineral profile, antioxidant and antimicrobial potential of unutilized parts of jackfruit

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Abstract

The processing of jackfruit (*Artocarpus heterophyllus* Lam) yields a considerable amount of bio-waste. Accumulation of this waste is considered a health risk because it is a potential source of air and water pollution. Recycling of the unutilized fruit parts, therefore, reduces the quantity and the impact of the bio-waste released to the environment. The purpose of this study was to determine the phytochemical profile, antioxidant and antimicrobial activities of extracts from three fruit parts (peel, fiber and the core) of jackfruit sampled from the coastal region of Kenya. Different extraction techniques and solvents were tested. The highest phenolic and flavonoid content of the peels, fiber and the core were obtained from methanol extracts following a 48-hour incubation. The values were recorded at 17.07±5.16 mg/g, 23.28±4.73 mg/g, and 15.68±3.74 mg/g for the phenolics and 28.55±12.42 mg/g, 35.4±9.53 mg/g and 36.23±2.54 mg/g for the flavonoids, respectively. The highest tannin content was obtained from distilled water extracts following homogenization recorded at 10.82±2.63 mg/g, 10.39±4.10 mg/g and 10.52±1.05 mg/g for peels, fiber and core, respectively. The fiber extracts gave the highest 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging activity followed by the core at 61.51±29.90% and 51.06±33.39%, respectively. The antioxidant activity was highest for methanol fiber extracts at 61.51±29.90% for DPPH radical scavenging activity and 7.94±4.56 mg/mL for reducing power assay. The best antibacterial activity against *Xanthomonas axonopodis* pv. *manihotis* (*Xam*) was obtained from Ethyl acetate extracts showed. The unutilized jackfruit parts, therefore, are a potential source of natural antioxidants as well as antibacterial, for agriculture and food industry.

1. Introduction

The disposal of unutilized parts of fruits is a key environmental concern because of increased bio-waste accumulation. The waste is considered a potential breeding ground for food-borne and water-borne pathogens (Feumba *et al*., 2016). According to Hoornweg *et al*. (2013), global waste is estimated to be 1.3 billion tons annually and may increase to 2.2 billion tonnes by 2025. The main sources of the bio-waste are factories, such as the fruit juice processing plants in the food industry that leave huge accumulation of unutilized parts of the fruits (Asquieri *et al.* 2008). Therefore, there is a need to recycle unutilized parts of fruits to prevent their bioaccumulation. Phytochemical compounds, essential elements, antioxidant and antimicrobial activities, have been isolated from unutilized parts of fruits found hence making them important to the food, agriculture and pharmaceutical industry (Al-Zoreky, 2009; Dorta *et al*., 2012; Geraci *et al*., 2016). Researches have confirmed that there are appreciable amounts of bioactive compounds in waste fruit parts (peels pomaces, seed and fiber) with potential benefits to human health and can also act as fungicides, bactericides and for disease control in agriculture (Al-Zoreky, 2009; Geraci *et al*., 2016).

The present study utilized a variety of techniques and solvents in the extraction of phytochemicals from the jackfruit parts (the peel, fiber and the core). The extracts from the various solvents were assayed for mineral and various phytochemical compositions. The total phenolic content, flavonoids content, tannins content, DPPH scavenging activity and reducing power were determined using spectrophotometric methods. The mineral analysis was conducted using atomic absorption flame emission spectrometry (AAS). The potential antimicrobial activity of the various solvent extracts was evaluated on *xam*

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pathogen.

Jackfruit (*Artocarpus heterophyllus* Lam) is a large and evergreen tree that can produce about 100 to 200 fruits in a year (Prakash *et al*., 2009). There have been limited studies on unutilized fruit parts of jackfruit. Jackfruit is the largest known edible fruit whose unutilized fruit parts include the peels, fiber and the core are the dominating part of the fruit (accounts for 60% of the entire fruit). It is clear that the edible pulp and seeds of ripe jackfruits are excellent sources of macronutrients and bioactive compounds. There is however lack of reference available on the chemical composition and antioxidant capacity of the peel, fiber and core of ripe Jackfruits. Most studies on the jackfruit phytochemical, antioxidant properties and mineral analysis have focused on the edible regions (pulp and seeds) (Shanmugapriya, 2011; Sreeletha *et al*., 2017; Awuor *et al*., 2018). In addition, lack information on the antibacterial activity of different extracts from peel, fiber and core against bacterial species of agriculture interest. The study of the unutilized parts of the fruit will encourage utilization of the waste parts of the fruits, which will contribute in reducing bio-waste accumulation with the dual aim value addition to jackfruit waste as well as management of pathogenic bacteria in crop plants.

This study purposed to determine the phytochemical composition, mineral profiles and *in vitro* radical scavenging activities of phenolic compounds of three jackfruit parts (peels, fiber and core) using different extraction techniques and solvents. The knowledge of the phytochemical composition of these fruit parts will help in providing a cost-effective alternative source of phytochemicals and essential minerals. The potential of the polyphenolic extracts of jackfruit fruit parts against *Xanthomonas axonopodis* pv. *manihotis* (*Xam*) bacteria, the causative agent of Cassava Bacterial Blight (CBB) was also evaluated in search of potential biocontrol agents.

2. Materials and methods

2.1 Plant material and sample preparation

Jackfruits were obtained from farmer's fields in coastal Kenya. Fruits (150 – 180 days old) considered physiologically mature (approximately 10 kg each) were harvested and used for analysis. The peel, fiber and the core were manually separated and chopped into small pieces. The pieces were cleaned using double distilled water, air-dried at 105°C in an oven (Memmert by Vindon Scientific) overnight and ground into fine powder using a grinder (Nutribullet by Homeland Housewares) for subsequent characterization.

2.2 Solvent extraction of phytochemicals

The solvent and extraction method was optimized in order to obtain high antioxidant capacity extracts from the peel, fiber and the core of Jackfruit. Fruit peel, fiber and the core were extracted using two different methods (48-hour extraction and homogenization) and two solvents (methanol and distilled water) were tested. For the 48-hour extraction method, the samples (peel, fiber and the core) were incubated with solvents for 48 hrs at 24°C. A mass of 2.5 g of each sample was placed into separate conical flasks containing 25 mL methanol and distilled water supplemented with 5% acetic acid. The conical flasks containing the samples and the solvents were covered in aluminium foil and incubated at room temperature for 48 hrs as described by Ojwang *et al*. (2017). On the other hand, for the homogenization method, extraction of phytochemicals was performed using a slight modification of Torti *et al*. (1993) protocol with slight modifications. A total of 100 mg of the samples were homogenized for longer time (120 s) at a maximum speed of 3000 rpm instead of 60 s as indicated in Torti *et al*. (1993). The falcon tubes were spanned for 15 mins at 10,000 × *g* at 4°C. The resultant pellet was then re-suspended in 10 mL of the test solvents, centrifuged again at 10,000 × *g* and stored at 4°C for subsequent phytochemical analysis.

2.3 Estimation of phytochemical compounds

Calorimetric assays described by Abu Bakar *et al*. (2015) and As *et al*. (2017) based on the reduction of Folin-Ciocalteu reagent was used to determine the content of phenolic compounds in the various extracts. Absorbance at 725 nm using UV-VIS spectrophotometer (UVmini-1240 by Shimadzu Corporation) was taken and the results expressed as mg of gallic acid equivalents per gram of extracts (mg GAE/g). The equations $y = 0.0057x + 0.4792$ for methanol extracts and $y = 0.009x + 0.3847$ for water extracts were used for further calculations.

Total flavonoid content (TFC) of crude jackfruit extracts was determined by aluminium chloride colorimetric protocol as described by Kumaran and Karunakaran (2006). Absorbance at 510 nm using UV-VIS spectrophotometer (UVmini-1240 by Shimadzu Corporation) was immediately recorded. The similar method was repeated for rutin standard solution and TFC determined using rutin equivalent (RE) (20 to 100 µg/mL) calibration curve. The data was expressed as mg of rutin equivalents RE/g of extract. The equations $y = 0.0004x + 0.0573$ for methanol extracts and $y = 0.0015x - 0.0094$ for water extracts were used to compare the results.

The amount of tannin in the sample was estimated

using Folin-Ciocalteu method. A total of 100 µL of extracts was added to 0.25 mL Folin-Ciocalteu reagent, incubated for 5 mins before the addition of 1.25 mL of the sodium carbonate solution, mixed well and the absorbance read against a blank at 725 nm after 40 mins. The total tannin content was calculated as GAE with reference to a standard curve prepared based on standards of Gallic acid concentration (0 to 100 µg/mL). The equations y = 0.0089x + 0.1312 for methanol extracts and y = 0.0086x + 0.136 for water extracts were used to calculate the values.

2.4 Determination of DPPH radical scavenging activity

The protocol was based on 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity by Adjimani and Asare (2015) with some modifications was used to determine the antioxidant activity of the extracts. A standard (ascorbic acid) and a blank containing all the test reagents except the test extract were used. Calculations were based on the following equation:

$$\text{Scavenging activity}(\%) = \frac{\text{Absorbance of Control} - \text{Absorbance of Sample}}{\text{Absorbance of Control}} \times 100$$

2.5 Reducing power of the extracts

The method described by Sylvie *et al*. (2014) was used to estimate the reducing power of the extracts. One mL of extract was added to a mixture containing 2.5 mL, of 0.2 mol/L phosphate buffer (pH 6.6) and 2.5 mL, (1%) potassium ferricyanide. The mixture was kept in an oven for 20 mins at 50°C before the addition of 2.5 mL of 10% Trichloroacetic acid (TCA) and then centrifuged at 3 000 rpm for 10 mins. The upper phase (2.5 mL) of the solution was mixed with an equal volume of distilled water and 0.5 mL, 0.1% ferric chloride ($FeCl_3$). The absorbance of the mixture was read at 700 nm against a blank containing all the test reagents except the extract.

2.6 Mineral analysis

These were analyzed by atomic absorption flame emission spectrometry (AAS) according to Osarumwense *et al*. (2013) but using Varian SpectrAA-10 machine instead of a bulk Scientific VGP 210 model of AAS. A wet digestion technique was used to convert solids to liquids. One g each of the finely powdered sample was treated with 60% HNO_3 in a beaker for digestion and placed in a hot plate in a fume cupboard. The mixture was allowed to boil for 30 mins where brown fumes were released with a resultant clear liquid. The mineralized samples were transferred into 50 mL volumetric flasks and de-ionized distilled water used to adjust volumes to the mark.

For AAS, an atomic absorption flame emission spectrophotometer (Varian SpectrAA-10) with an air-acetylene flame was used. The wavelengths were set to 422.7 nm for calcium (Ca), 279.5 nm for manganese (Mn), 248.3 nm for iron (Fe), 213.9 nm for zinc (Zn), 589.0 nm for Sodium (Na), 766.8 nm for potassium (K), 324.8 nm for copper (Cu) and 285.2 nm for Magnesium (Mg) determination were used. Stock solutions (1000 ppm) of Ca, Mn, Fe, Cu, Na, K, Mg and Zn were used to prepare working standard solutions with at least 3 concentrations (1 ppm, 5 ppm and10 ppm) within the analytical range.

2.7 Determination of antimicrobial activities

Xanthomonas axonopodis pv. *manihotis* (*Xam*) is a pathogenic bacterium that causes bacterial blight disease in cassava. A few infected leaf samples from plants of cassava cultivar TME14 were collected from western Kenya. The protocol by Chege *et al*. (2017) was used in the isolation of the pathogen. A total of 5 mL of yeast peptone glucose (YPG) media was sterilized, after which cephalexin and cycloheximide antibiotics at 150 mg/L and 50 mg/L respectively were added. Small pieces of leaf tissues were cut into sterile 15 mL falcon tubes containing the selective media and incubated at 28°C for 48 hrs. The resultant bacterial suspension was serially diluted to 10^3 and 50 µL of each dilution plated on YPGA medium supplemented with cephalexin and cycloheximide antibiotics and incubated for 48 hours at 28°C. Single colonies were picked, purified and used for antimicrobial test.

Antibacterial sensitivity assay was done using the disc diffusion method highlighted in As *et al*. (2017). Extracts obtained from the various powdered jackfruit wastes using different solvents were tested on *Xam* pathogen. The *Xam* bacteria were cultured for 48 hrs and then evenly spread on Mueller Hinton agar plates. Sterile discs of Whatman paper (6 mm in diameter) were dipped in extract solution and placed in the inoculated agar plate before incubating at 28°C for 48 hrs and eventually measuring the zones of inhibition. Three replicates were used and the experiment was repeated twice.

2.8 Statistical analysis

The mean values of the data obtained were determined and analyzed using one-way ANOVA at $P<0.05$. The data was analyzed using Microsoft Excel 2011 data analysis tool and StatPlus statistical software. The relationship between phenolic, flavonoid, tannins, DPPH and antioxidant activity were determined using a correlation matrix.

3. Results and discussion

3.1 Effect of solvent and extraction technique on the content of phytochemicals

The total phenolic content of peels, fiber and the core were determined spectrophotometrically after extraction with methanol and with distilled water. In general, the highest phenolic content was found in the fiber followed by peels and then the core at 23.28 mg/g, 17.07 - 6.38 mg/g and 15.68-8.37 mg/g, respectively (Table 1). The differences in total phenolic content extracted using different solvents with 100% methanolic extract (48 hrs) having the highest composition, followed by the 70% methanolic extract was significant ($P<0.05$). The lowest phenolic content was recorded from the distilled water extract for both 48 hrs incubation and homogenization methods. Previously used organic solvents for extraction of phenolic compounds from plants include methanol, ethanol acetone and ethyl acetate (Lafka *et al*., 2007; Alothman *et al*., 2009). It has been shown that phenolic content differs with solvent polarities; pure methanol and acetone were found to be better solvents than water (Addai *et al*., 2013).

The flavonoid contents of peel, fiber and the core were as shown in Table 1. Fibers had the highest flavonoid content in samples that were incubated with a solvent for 48 hours, while peels showed the highest flavonoid content in the samples that were homogenized and centrifuged. There was a significant variation ($P<0.05$) in flavonoid compounds extracted using different solvents. The methanolic extract (48 hours incubation) gave the highest composition in all parts. The fiber had the highest flavonoid content in the 48 hours extraction in both methanol and distilled water, while the peels had the highest composition in homogenized extracts. The highest levels of flavonoids in peripheral tissues are consistent with other studies. Banana peels were found to have higher flavonoid content than the pulp (Fatemeh *et al*., 2012)

The tannin content from unutilized parts of jackfruit was depended on the extraction method used (Table 1). Homogenization method was the best method for extraction of tannins for all samples while the best extraction solvent for tannins was distilled water. The fiber consistently gave high values in all extraction methods and solvents. There was a significant variation ($P<0.05$) in the extraction solvents used with distilled water and 70% methanol recording high values compared to the methanol. This could be attributed to the fact that tannin compounds are soluble in water (Mena *et al*., 2015)

The variation in the phytochemical composition of samples extracted with methanol and distilled water with 48 hours incubation as well as with the homogenization method was significant ($P<0.05$). Flavonoids had the highest composition in the methanol extraction, followed

Table 1. Concentration of phytochemical compounds extracted from fruit peels, fiber and core extracts of Jackfruit using different solvents and extraction methods

Method of Extraction	Tissue	Solvent	Phytochemicals		
			Phenolics	Flavonoids	Tannins
48 hrs Extraction	Peels	Meth	17.07±5.16	28.55±12.42	5.83±2.83
		dH_20	10.19±2.32	3.11±0.79	4.9±0.14
	P-values		0.638273	0.000727	0.308509
	Fiber	Meth	23.28±4.73	35.4±9.53	8.73±3.58
		dH_2O	15.15±4.47	3.67±3.18	7.76±4.20
	P-values		0.798075	0.014103	0.162447
	Core	Meth	15.68±3.74	24.15±20.99	4.61±2.64
		dH_2O	14.12±5.41	2.66±1.62	5.37±2.01
	P-values		0.114262	0.014047	0.661028
Homogenization	Peels	Meth	6.38±2.80	22.17±26.08	5.96±2.07
		dH_2O	7.7±3.73	25.25±4.55	10.82±2.63
	P-values		0.015424	0.006625	0.011504
	Fiber	Meth	13.91±12.66	14.72±9.81	12.27±5.55
		dH_2O	11.92±4.24	13.59±1.15	10.39±4.10
	P-values		0.655119	0.529461	0.922842
	Core	Meth	13.91±1.25	12.27±19.91	9.69±6.94
		dH_2O	8.37±2.81	17.16±2.95	10.52±1.05
	P-values		0.057748	0.065747	0.656972

Values are means ± standard deviation of triplicate analysis. P-values on the table indicate difference in solvent extraction efficiency of the various phytochemicals.

by phenolics and lastly tannins (Table 1). Among the fruit parts, fibers showed the highest phytochemical composition, followed by peels and then the core (Table 1). The extraction with distilled water gave the highest composition for the phenolic compounds and the least for the flavonoids. The highest levels of tannins were extracted in distilled water for 48 hours and there was no variation in the level of tannins between the different parts (Table 1).

3.2 Effect of solvent and extraction methods on the antioxidant activities

There was a significant variation ($P<0.05$) in DPPH scavenging activity of the extracts. The highest DPPH scavenging activity was 50.78±3.81% for peels using H_2O and centrifugation, followed by 61.51±29.90% for fiber using H_2O for 48hrs incubation and 51.06±33.39% for core using H_2O and centrifugation method. Water extracted the highest antioxidants from all the parts but the levels varied with respect to the extraction method used (Table 2).

Table 2. Iron reducing power of extracts from Jackfruit peels, fiber and the core

Extraction technique and solvent used	Ferric reducing power (mg/mL)		
	Peels	Fiber	Core
48 hrs extraction, distilled H_2O	3.59±0.15^{a}	6.12±2.80^{e}	5.09±0.14^{i}
Homogenization, distilled H_2O	2.49±0.34^{b}	2.89±0.91^{f}	2.63±1.17^{b}
48 hrs extraction, methanol	6.69±4.07^{c}	7.94±4.56^{g}	5.20±1.33^{j}
Homogenization, 70% methanol	2.11±0.36^{d}	2.46±0.96^{h}	2.10±0.49^{d}

Values are means ± standard deviation of triplicate analysis. Values in the same column with different superscript letters are significantly different ($P<0.05$).

The variation in the ferric reducing antioxidant power of the extracts from different unutilized parts of jackfruit (Table 2) was significant ($P<0.05$). The extracts from the fiber consistently gave the highest iron reducing power in all the extracting solvents and extraction techniques used (Table 2). The variation in Iron concentration from one tissue to the other is an indication of the difference in its utilization by tissues. These results confirm that the presence of high levels of flavonoids does not always correspond to high antioxidant properties in plants (Teixeira *et al*., 2017).

3.3 Correlating phytochemical contents to total antioxidant capacity

There was a positive correlation between DPPH scavenging activity and the phenolic and tannin composition (Table 3) of the jackfruit parts studied. This was also the case between polyphenol levels and reducing power activity. However, there was a negative correlation in the flavonoids extracted from the same jackfruit parts studied (Table 3).

3.3.1 Mineral profile

Mineral analysis of Jackfruit peels, fiber and the core showed the presence of high levels of essential elements within the waste parts of the fruit. There was a significant variation ($P<0.05$) in K, Na and Ca levels present in the parts studied. Potassium accounted for the major element followed by Ca while Na levels were the least (Table 4). This is consistent with other studies where the peels of watermelon, mango, pomegranate, banana, apple and pineapple were found to be rich in essential minerals such as calcium, zinc, iron and manganese (Romelle *et al*., 2017).

3.3.2 Antimicrobial activity

Acetone and ethyl acetate extracts had antibacterial activity against *Xam* pathogen (Table 5). For the acetone extracts, the peels gave the highest inhibition followed by the fiber while the core gave the least. On the other hand, ethyl acetate extracts from jackfruit fiber and the core gave the highest and least antibacterial activities respectively. In general, Ethyl acetate was a better solvent than the aqueous (50%) acetone. These findings differ from those on *Pisang Abu* where 90% and 70% acetone gave the highest levels of phenolic compounds compared to other solvents (Toh *et al*., 2016).

4. Discussion

The unutilised parts of the fruits have been found to have phytochemical compounds, essential elements, antioxidant and antimicrobial activities, which makes

Table 3. Correlation matrix of phytochemical composition and antioxidant activity of extracts of Jackfruit bio-waste

	Phenolics	Flavonoids	Tannins	DPPH	Reducing power
Phenolics	1	0.145	0.99	0.996	0.999
Flavonoids	-0.145	1	0.281	0.053	0.095
Tannins	0.99	-0.281	1	0.973	0.982
DPPH	0.996	-0.053	0.973	1	0.999
Reducing power	0.999	-0.095	0.982	0.999	1

Linear regression analysis between estimated antioxidant activities, free radical scavenging activities and iron reducing power with total phenolic, flavonoid and condensed tannins.

Table 4. Mineral composition of extracts from jackfruit peels, fiber and the core

Parameters	Mineral content (mg/g DW)		
	Peels (mg/g)	Fiber (mg/g)	Core (mg/g)
Potassium (K)	22.8±9.400	31.07±17.502	24.15±8.105
Sodium (Na)	0.47±0.087	0.48±0.091	0.43±0.079
Calcium (Ca)	4.9±1.929	7.32±4.099	6.94±2.074
Magnesium (Mg)	1.456±1.291	1.24±0.421	1.322±0.752
Zinc (Zn)	1.44±1.038	0.98±0.044	1.9±0.408
Copper (Cu)	0.018±0.017	0.005±0.005	0.009±0.011
Manganese (Mn)	0.015±0.0072	0.01±0.0025	0.011±0.004
Ferrous (Fe)	0.112±0.060*	0.088±0.133	0.051±0.023*

Values are means ± standard deviation of triplicate analysis. The difference between values with an asterisk (*) is significant ($P < 0.05$).

Table 5. Antibacterial activity of extracts from the peel, fiber and core of the jackfruit against *Xanthomonas axonopodis* pv. *manihotis* (*Xam*)

Solvent used	Inhibition zone diameter (mm)		
	Peels	Fiber	Core
Acetone	4.39±1.35	3.56±2.17	3.08±2.28
Ethyl acetate	6.50±1.62	7.10±2.13*	5.06±2.64*
P values	0.0428925	0.000522	0.093637

Values are means ± standard deviation of triplicate analysis. The difference between values with an asterisk (*) is significant ($P<0.05$) while the P-values on the table indicate the difference in activity of extracts from the two solvents used in each tissue.

them important to the food and pharmaceutical industry (Al-Zoreky 2009; Dorta *et al*., 2012; Geraci *et al*., 2017). In the present study, considerable amounts of phytochemical compounds with remarkable antioxidant and antimicrobial activities were obtained from peel, fiber and the core of Jackfruit. In addition, the study confirmed that the extracting solvent and extraction method are critical factors in the extraction of phytochemicals from bio-waste. This agrees with the study by Do *et al*. (2014) who also found out that the extraction of phytochemicals varies with the type of solvent used and extraction technique applied.

The chemical composition of unutilized fruit parts of jackfruit is essential in order to establish a potential relationship and understanding of their role in different valuable biological activities. There was no significant variation in total phenolic contents (TPC) from the different unutilized parts of the fruit. This could be attributed to the fact that all the studied sections are parts of the entire fruit. Metabolites are known to diffuse from one part of the fruit to another, which makes the TPC levels almost the same (Etxeberria *et al*., 2012). The solubility of polyphenolic compounds in the extracting solvent and the extraction method used determines the ease of their recovery from plant materials. The polarity of the solvent will also play a crucial role in raising the solubility of phenolic acids (Do *et al*., 2014). In the present study, methanolic extracts had the highest composition of phenolic compounds in comparison to distilled water extracts and this could be attributed to the amphiphilic nature of methanol. Another explanation for the polyphenols in water extracts could be due to the degradation of polyphenols in aqueous extracts (observed as brown color the extracts) by the enzyme polyphenol oxidase. This enzyme is inactive in methanol as reported by Gonźalez-Montelongo *et al*. (2010). Phenolic compounds have varying degrees of polarity and some may not dissolve in a 100% polar solvent like water (Boeing *et al*., 2014). Studies have also shown that there are quantifiable water-soluble polyphenols present in plants (Kawakami *et al*., 2010).

There was a significant variation in the levels of flavonoids extracted using different solvents. Methanol extraction gave the highest total flavonoid content (TFC) in all fruit parts and in all techniques compared to water. This is because the concentration of extracted flavonoid compounds extracted from plant material is influenced by the polarity of solvents used (Tambe and Bhambar, 2014). Naturally occurring flavonoids such as rutin, have low solubility in water (Lipkovska *et al*., 2014). Homogenization with water and methanol solvents was found to be the best technique for extraction of flavonoid compounds. This is because homogenization results in the grinding of the plant material to a fine powder with resultant disruption of cell walls hence increased extraction surface area (Das *et al*., 2010).

There was no significant variation in total tannin content (TTC) ($P > 0.05$) in the different parts as there is an exchange and free movement of tannins between the three interconnected parts of the fruit when the need arises (Shitan, 2016). There was however a significant variation ($P<0.05$) in TTC extracted using different solvents. Distilled water extracts had the highest composition of phenolic compounds compared to methanolic extracts. Previous research by Mena *et al*.

(2015) showed that most tannin compounds are soluble in water. However, our results contradict reports by Baldosano *et al*. (2015) who indicated that water proved to be an ineffective solvent for the extraction of tannins due to the formation of insoluble complexes with proteins. Results from the current study could be as a result of low protein content in the parts studied as was shown in other previous studies which reported lower content of proteins in Jackfruit (Swami *et al*., 2012; Madruga *et al*., 2014).

The findings of the present study are consistent with those of Boeing *et al*. (2014), that showed methanol as a better solvent in the extraction of phenolic compounds in berries. Total phenolic content differs with solvent polarities (Addai *et al*., 2013). A similar scenario was also observed in the current study. Pure methanol and acetone were found to be better solvents than water (Addai *et al*., 2013). A study by Alothman *et al*. (2009), revealed that the type of solvent used had an effect on the quantity of phenolic compounds extracted from plants (Alothman *et al*., 2009). The current results were also consistent with those of Iloki-Assanga *et al*. (2015), that indicated that the levels of phytochemicals in *Bucida buceras L*. and *Phoradendron californicum* was affected by the extraction solvent used.

The assay on DPPH scavenging activity is based on the donation of hydrogen by antioxidant groups like phenolics, flavonoids and tannins (Rohman *et al*., 2010). The fiber samples had an average of 58% scavenging activity, 10% higher than the peels and the core, which were equal at about 48%. The results also showed that antioxidant activity is not very sensitive to extraction solvents as the values were mostly above 50% but higher radical scavenging compounds were from distilled water extracts. There variation in reducing power depending on the technique and solvent used was significant ($P<0.05$). Incubation of sample with solvent for 48 hours was a better technique as compared to homogenization for the extraction of compounds with reducing power, while methanol was a better solvent as compared to water. Fiber samples consistently had the greatest iron reducing power in all the solvents and techniques.

The correlation between DPPH scavenging activity and the composition of phenolic and tannin in the Jackfruit parts studied were positive. This was also the case in a study by Almeida *et al*. (2011), which focused on free radical scavenging activity of fruit samples. There was however no correlation between flavonoid and radical scavenging activity just like it was in the study by Bilušić *et al.* (2007). The results generally indicate the presence of high antioxidant activity in the extracts of the peels, fiber and the core of jackfruit. Hence, the fruit is a potential source of natural antioxidants. Polyphenol levels positively correlated with reducing power activity while flavonoids extracted from the peels, fiber and core parts of the Jackfruits studied negatively correlated. These results contrast with other studies which showed a positive correlation between flavonoids extracted and their DPPH scavenging activity as well as iron reducing power (Rohman *et al*., 2010; Abu Bakar *et al*., 2015; Ojwang *et al*., 2017). These results show that the presence of high levels of flavonoids does not always correspond to high antioxidant properties in plants as these metabolites have a wide variety of activities (Teixeira *et al*., 2017).

In the current study, mineral analysis of jackfruit peels, fiber and core showed that there are high levels of essential elements present within the waste parts of the fruit. In general, most fruits contain high levels of potassium (Julian-Loaeza *et al*., 2011). The Jackfruit biowaste contained high levels of potassium followed by calcium and then sodium. Similar finding was reported by Akinmutimi, (2006) and Swami *et al*. (2012). Consumption of food with high potassium/calcium to sodium levels have been shown to mitigate the risk of hypertension (Perez and Chang, 2014). The elements Sodium and potassium in combination, maintain optimal acid-base balance and nerve impulses transmission in the body (Adumanya *et al*., 2015). The study also showed the presence of trace elements namely zinc and magnesium in high quantities. These elements are important in plants for their normal growth and development. It is important to note that the mineral Zinc, is essential in the functioning of enzymes involved in carbohydrate, lipid and protein metabolism of zinc is also an essential mineral for (Julian-Loaeza *et al*., 2011; Osarumwense *et al*., 2013). There were also low amounts of iron, copper and manganese, which are essential for proper plant daily functions. Jackfruit peels, fiber and core are a, therefore, a potential source of essential minerals and their use in biofortification of food could lead to improved health.

The antibacterial properties of different extracts of peel, fiber and core were assayed against *Xam* and measured inhibition zones exerted by each extract towards the bacteria. Both acetone and ethyl acetate extracts showed efficacy in antibacterial activity against *Xam.* The activity was highest in the peels and lowest in the core. This could be attributed to the fact that the peels form the protective outer layer of the fruit and it is more exposed to microbial pathogens compared to the inner parts of the fruit and hence the antimicrobial compounds are more likely to be in the peels. Furthermore, antimicrobial activity of polyphenol and flavonoids have demonstrated by a number of studies (Swami *et al*.,

2012; Sylvie *et al*., 2014) and therefore the same can be inferred for the antimicrobial activity of extracts from jackfruit unutilized parts. The broad-spectrum antibacterial activities of phenolic compounds are attributed to the configuration of their structure. The hydroxyl group content and degree of polymerization contribute to their antimicrobial activities (Daglia, 2012). Ethyl acetate extracts were the most significantly effective solvent than aqueous acetone against *Xam* bacteria. These results agree with those by As *et al*. (2017) and Swami *et al*. (2012) which showed that the edible parts of Jackfruit have antimicrobial activity.

The high potential revealed by peel, fiber and core extracts of jackfruit to inhibit a cassava bacterial pathogen, highlights the promising potential application for this bio-waste. The high content of polyphenols in the studied parts of the fruit may be attributed to their strong antibacterial activity against the bacteria tested. These data suggest that peels, fiber and core of Jackfruits contain potential inhibitors of plant pathogenic bacteria and would be a good candidate for the future development of a bio-bactericide for agricultural application.

5. Conclusion

The unutilized parts (peels, fire and the core) of jackfruit are all good natural sources of phytochemicals such as phenolics, flavonoids and tannins. That the solvent used and the extraction technique affects the levels of phytochemicals extracted and hence their functional properties (antioxidant and antimicrobial) to various magnitudes. Phenolic and flavonoid contents were highest in methanol extracts and 48 hours incubation, whereas the highest content of tannins was obtained with distilled water and homogenization. The peels, fiber and the core are all good sources of essential minerals such as Fe, Ca, K, Na and Mg amongst others. The extracts of unutilized parts of jackfruit have potential antioxidant and antimicrobial properties that vary depending on the extraction solvent used. These results have therefore established that peels, fiber and the core of jackfruits exhibited high antioxidant and antibacterial activities *in vitro*.

Conflict of Interest

The authors declare no conflict of interest.

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