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ORIGINAL RESEARCH

Characterizing market crop waste as feedstock for composting to reduce environmental pollution in developing countries

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Abstract

Purpose Market crop waste (MCW) contributes significantly to the quantity of municipal solid waste generated in sub-Saharan Africa. These wastes, however, contain high levels of plant nutrients which can be harnessed through composting to improve soil organic matter and nutrient status of impoverished tropical soils.

Method In this work, annual MCWs from two urban markets in Accra, Ghana were characterized by quantifying their seasonal availabilities, primary nutrients, heavy metals concentrations and level of microbial contamination to ascertain their suitability or otherwise for composting.

Results Waste generated in the rainy seasons was higher than in the dry seasons. Primary nutrients sequestered in the MCW collected were 211.1 kg N, 1.84 kg P and 89.66 kg K for both markets. Feedstock quality analysis showed heavy metal levels in the MCW were far below the contaminant levels. Moisture content of vegetable and fruit waste was 74.34 - 90.46% and far above the desired level of aerobic composting. Pathogen levels of 5.92 CFU/g *E. coli* and 5.41 CFU/g *Salmonella* in cocoyam leaves; 6.27 CFU/g total coliform and 4.74 CFU/g *Enterococcus* in cabbage were detected and found to be above the maximum contaminant level as per USEPA standard.

Conclusion Use of cassava, plantain peduncle and corn husk as bulking agents with vegetable and fruit waste as N, P and K sources should serve as feedstock for good quality compost production.

Keywords Market crop waste, Feedstock, Composting, Nutrient flow, Seasonal variation

Introduction

Food distribution and supply in sub-Saharan countries like Ghana is mostly characterized by transportation of crops mainly cereals, vegetables and fruits from farming communities to markets in urban consuming centres. These foodstuffs are largely bulky with minimal processing resulting in the generation of huge quantities of organic wastes. The bad mode of packaging and the poor transportation system promote huge post-harvest losses in transit. Consequently, a chunk of these unwholesome foodstuffs arrives at the markets and increase the volume of organic waste generated in the urban centres (Amoding 2007; Akumah 2018). The contribution of the market organic waste to the municipal solid waste (MSW) has thus become significant in the urban centres of Ghana. However, data on volumes of wastes generated from

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commercial centres and markets in West Africa are inadequate and unreliable.

Uncollected organic wastes are common sights at market places in West African cities hence raising serious environmental concerns. The organic wastes not only serve as breeding sites for houseflies and rodents but also act as substrates for pathogen proliferation (Yoada et al. 2014; Akumah 2018). Delays in organic waste collection from markets is a common phenomenon in West African urban centres. This leads to the decomposition of the organic waste generating foul odour. Apart from some few recycling plants which process the waste, a large proportion of the wastes when collected are dumped at landfill sites and their nutrients lost. These landfill sites which are usually not engineered, are in close proximity to human habitats and pose a lot of environmental challenges. Dumping of organic wastes at the landfill sites breed flies and rodents and the decomposition of the waste thereof culminate in emission of greenhouse gases and contamination of ground and surface water with leachates (Hartmann and Ahring 2006). The continuous use of landfill is not sustainable due to the scarcity of lands (Tumuhairwe et al. 2009). The poor sanitary conditions associated with these dumping sites have resulted in conflicts between city authorities and residents living close to the sites.

In order to protect and maintain environmental health and close the nutrient loop, it is imperative to find sustainable ways of managing the organic fraction of market wastes while making the sequestered nutrients available for increased soil and crop productivity in West Africa. Ironically, West African soils are relatively poor in productivity because of the low organic matter content. Soils in Ghana are, for example, low in organic carbon (< 10 g kg^{-1}).

Total nitrogen and available P are generally below 1 g kg^{-1} and 10 mg kg^{-1}, respectively. The soils also have low cation exchange capacity of below 15 cmolc kg^{-1} (Bationo et al. 2018). Harnessing these organic wastes as amendments, would therefore go a long way in rejuvenating these soils. Composting as a recycling tool is an option that has been accepted and applied globally to manage organic wastes (Kanat et al. 2006; Hansen et al. 2007; Moghadam et al. 2009). However, the commercial production of compost demands a steady and reliable stream of organic waste supply. Crop wastes form the main organic component of wastes found at market places in the major cities of developing countries (Tumuhairwe et al. 2009). The availability of these wastes in large quantities are, however, seasonal and of varied nutrient composition. In Kampala City in East Africa, market crop waste (MCW) was found to contain 50, 10 and 30 metric tonnes of nitrogen, phosphorus and potassium respectively per year (Amoding 2007). Very little information, however, exists on the profile and characteristics of MCWs in West Africa. The information on the type, quantity and the concentration of nutrients in MCWs available across the seasons is vital for decision making. Composting period and compost quality are controlled by several factors, including the type of feedstock, method of preparation, particle size, pH, moisture content, C/N ratio and temperature (Cronjé 2004). Market waste is heterogeneous and there is significant variation in availability. The type and quantity of the organic fraction of market waste vary between the dry and rainy seasons and even within the rainy season in southern Ghana where rainfall is bi-modal. However, there is paucity of data on the type of MCWs generated, their quality and seasonal variation in terms of quantity in Ghana. It has become imperative for these pieces of information to be generated to bridge this gap in knowledge. The quality, types of feedstocks and availability must be ascertained for timeliness of composting operations and for the production of high quality compost at relatively low cost. The quantity and quality of feedstock would help in determining the proportion of the individual crop waste to be used in constituting a compost heap.

The objectives of the study, were to; (1) ascertain the quantity and seasonal variation, (2) determine the chemical characteristics and quality of MCWs and their suitability thereof for composting and (3) estimate the annual nutrients flow from two major markets in Accra, Ghana.

Materials and methods

Study sites

MCWs were collected from the Madina and Dome Markets, which are located in two different districts in Accra, Ghana as shown in Fig. 1. Madina market lies between Latitude 5º 40' 44.294'' and longitude 0º 10' 8.778'' while Dome market is located within Latitude 5º 38' 36.871'' and Longitude 0º 14' 11. The Dome and Madina markets are two highly patronized markets in the eastern part of Accra. These two markets are in close proximity to the University of Ghana and serve over two hundred thousand people (GSS 2012). These two markets operate daily and generate tonnes of organic wastes; quantity and quality which have not been estimated. These two markets were, therefore, used as case studies to estimate the annual variation in quantity and quality of crop waste in urban markets of southern Ghana where rainfall is bimodal. Information on the seasonal variation in quantity and quality of MCWs in these two markets could be used to estimate the nutrient flow from markets in Accra, the capital of Ghana.

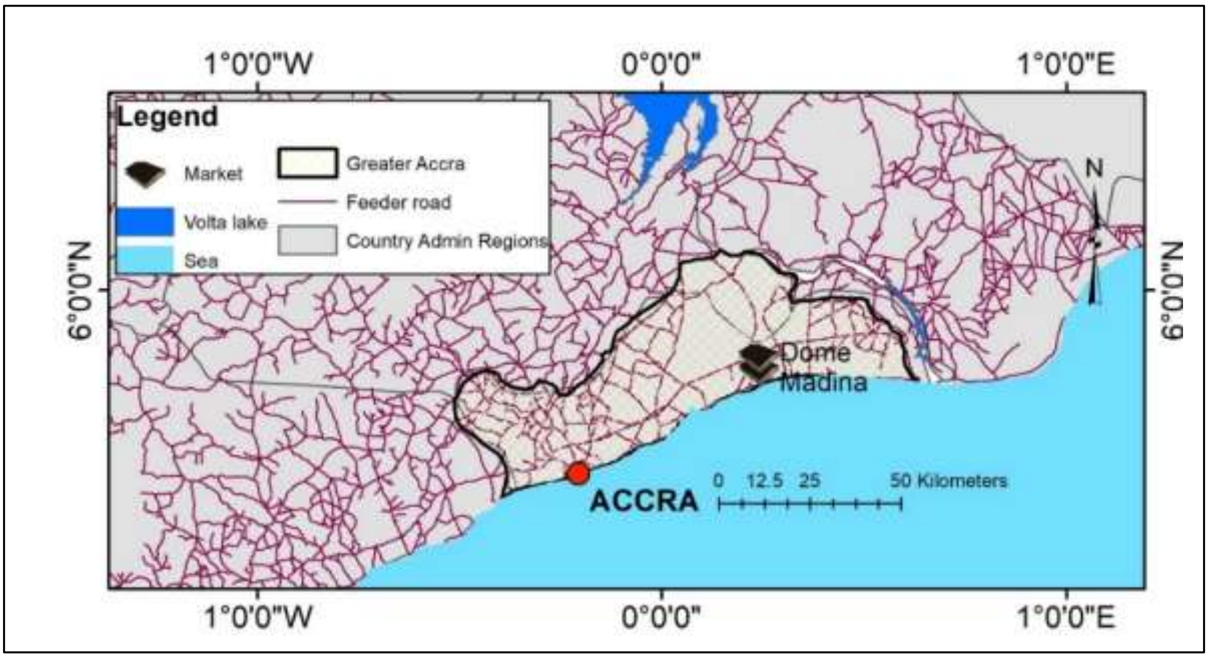

Fig. 1 Map of Southern Ghana showing the location of the two markets in the Greater Accra Region

Waste collection and profiling

The collection of MCW was done three days in a week, including the official market days for each of the two markets for each month, from January to December, 2016. There was source separation in the two markets. At the close of each collection day, the MCW was separated from other market wastes and grouped into four main classes. The classifications were vegetable waste (VW) viz. cabbage, carrot, lettuce and cocoyam leaf (kontomire); fruit waste (FW), i.e., orange, pineapple and watermelon; fresh food waste (FFW), i.e., plantain, cassava and yam and others, i.e., plantain peduncle and corn husk. There were thus in total twelve different types of crop wastes. Each crop waste type was then packed into jute sacks and transported to a composting platform for further processing. Fresh crop wastes collected from the markets were weighed to determine the quantity coming from each market. The wastes were then manually chopped using stainless steel machetes and or knives and then air-dried at ambient temperatures of between 28 and 32 °C on a drying platform to reduce their respective moisture contents.

Sample moisture content determination

Samples of the individual air-dried MCWs were then oven-dried at 70 °C until constant weights were attained. The moisture content of each waste type was then determined as:

$$\%\ Moisture = \frac{Fresh\ mass - Dry\ mass}{Dry\ mass} \times 100$$

The fresh and dry masses of each of the segregated waste collected over the three-day period in a week for the month were aggregated and extrapolated as an estimation of amount of MCW generated for each month.

Sample preparation for chemical laboratory analysis

Each of the monthly segregated air-dried MCW was homogenized and subsampled for chemical characterisation. The air-dried samples of the various MCW types were milled using stainless steel milling machine and stored in desiccators for chemical analyses.

Chemical analysis

The pH of the milled samples was measured electrometrically using a sample to de-ionised water ratio of 1:10 (w/v) on a digital pH meter (Metrohm 691). Electrical conductivity (EC) was also determined with an EC meter using the same de-ionised-sample extract used for the pH determination. The total carbon and nitrogen contents of the samples were determined using a Carbon Nitrogen Sulphur Analyzer (Leco Trumac version 1.3). The milled samples were digested using a mixture of concentrated HNO_3 and 60% $HClO_4$ in the ratio of 1:1.5. Total phosphorus in the digest was determined according to the method of Murphy and Riley (1962). The concentrations of sodium and potassium in the digests were read using a Perkin Elmer AAnalyst 800 Atomic Absorption Spectrophotometer. Heavy metals (Fe, Cu, Zn, Pb and Cd) concentrations in the samples were determined according to the standard procedures of Chapman and Pratt (1961).

Microbial analysis

The method of Raj et al. (2014) was adopted in the microbial analysis of each of the segregated MCW. An equivalent of 1 g of dry matter of each of the samples on fresh weight basis was weighed into 10 mL Falcon tube and 9 mL of sterile Phosphate Buffer Salt solution was added. The mixture was allowed to stand for about 30 min, after which the supernatant was taken into another 10 mL Falcon tube and serially diluted. An aliquot of 1 mL of the serial diluent was used for membrane filtration for the determination of *Salmonella* species, *Enterococcus* species, total coliform and *E. coli* bacteria using Bismuth Sulphite Agar, Slanetz and Bartley and HiCrome™ Coliform Agar media, respectively.

Analytical quality control (AQC) and analytical quality assurance (AQA)

Data collection, processing and analyses were scientifically executed to prevent huge errors.

Analytical grade chemicals were used in all the chemical analyses undertaken. All instruments used in the analyses were in good condition and were duly calibrated before use. Standards of known concentrations were prepared and read to crosscheck the reading of the samples after every 5 readings were taken. Readings were replicated three times to ensure that true measurement value was taken. Chemical analyses were done in a standard lab and all lay down procedures were duly followed.

Statistical analysis

Data on pathogen counts were logarithmically transformed before statistical analysis. Shapiro-Wilk test was used to test for normality of data before subjecting it to one-way ANOVA test at significance level of 5%. The differences among the mean values were separated using Tukey test. All analysis was done using GenStat 12 edition software.

Results and discussion

Seasonal variation of market crop waste from Dome and Madina markets

The quantity of crop waste collected from Dome market in the 12 months ranged between 1289 to 3154 kg, whiles that of Madina market ranged between 1517 and 3395 kg (Fig. 2a-b). The higher tonnage from Madina market could be attributed to the bigger size of the market, which makes it accommodate more traders and consequently generate more waste. Significant variation in market crop waste was observed across the 12-month study period as evident in Fig. 2a-b. This variation seems to be a reflection of the weather pattern in southern Ghana. It is noteworthy that at the two markets, the lowest quantity of crop waste, i.e., 1289 and 1517 kg were collected in January and were less than half the quantities collected in July and August. The rainy season in southern Ghana starts from the middle of March when grasses start springing up, reducing the competition for waste by ruminant and rabbit farmers. The peak waste collection in August coincided with harvest in southern Ghana. Thus, there was abundance of food waste from the two markets. Crop waste from the two markets was the lowest and generally did not vary much within the first four months of the year.

The total quantities of waste collected from the two markets were between 2806 kg in January and 3576 kg in April.

From May thereafter, total quantities of waste collected from the two markets started increasing sharply till it peaked in August with about 6549 kg. It then decreased steadily to 4651 kg in December.

The total mass of MCW collected for the major rainy season (March – July) from the two markets was 24462 kg, accounting for almost 43% of the total mass of waste collected for the whole year.

Mass of MCW from the two markets collected during the dry season, which was from November to February, was 15290 kg accounting for almost 27% of the annual total crop waste.

In the short minor season from September to October, 10656 kg of MCW was collected, and this formed 18.7% of waste over the one-year period.

It is worthy of note that the one-month dry spell of August between the major and minor rainy seasons yielded 6.55 Mg of MCW, which formed 11.5% of total waste collected from both markets in a year.

The month of August which is the harvest period in southern Ghana, produced the largest mass of crop waste which was similar to the 6477 kg of waste collected in July.

Estimated annual total waste collected was 27109 and 29848 kg for Dome and Madina markets, respectively. The two markets thus generated approximately 56957 kg fresh weight waste per year.

Composting these wastes in January, February, March and April would be neither ideal nor economical because of low volumes of waste generated within these periods.

Composters should plan their activities such that collection and composting of market waste would be from June to December when waste is abundant.

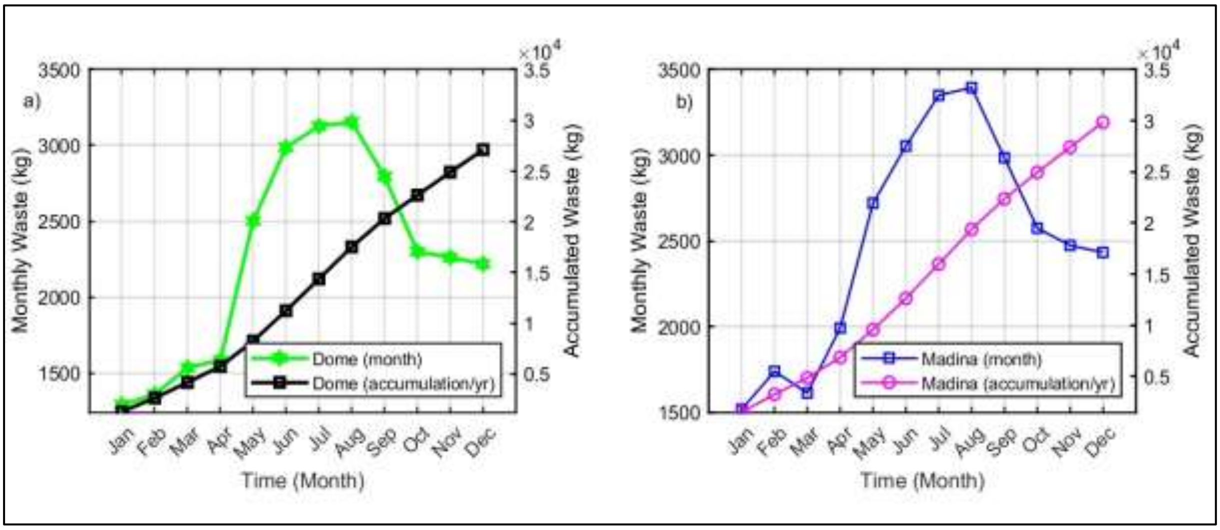

Fig. 2 Quantity of waste collected from Dome and Madina Market

Percentage market crop waste types generated in each month

The proportion of each of the twelve crop waste types in the total monthly waste generated and collected from the two markets is presented in Table 1. The variation in the composition of individual wastes was due to their production patterns which was controlled by weather, mainly rainfall. Corn husk recorded the lowest waste collected and constituted between 2.79 and 5.46% of the total waste collected for the period of study. This waste is a by-product from maize de-husking and is used primarily in the preparation of kenkey, a delicacy of the natives of Accra. Many foodstuff traders are not usually involved in the distribution and selling of corn husk, and that may explain its lowest availability as a waste during the year of study. Percentage of plantain waste generated from the two markets were also low throughout the year ranging between 2.91 and 8.7%. Yam waste in terms of quantity was the third lowest after corn husk and plantain waste ranging from 4.63% in June to the highest of 10.76% in December. Cassava, which is the main foodstuff in the preparation of fufu, a local delicacy in southern Ghana had its waste ranging from 5.37% in March to 11.5% in August. Plantain peduncle formed 3.81% of the total waste in February, increased to 13.65% in December.

Apart from July, November and December, cabbage waste seemed to be the most abundant waste in the two markets contributing between 10 and almost 19% of the waste generated. Cabbage waste seemed to be available throughout the year with the least contribution of 8.45% generated in November. The largest contributor to the total waste generated in the two markets during the major and minor seasons was the leafy vegetable, kontomire (cocoyam leaves). This leafy vegetable contributed between 11 and 12% to the total crop waste generated during the period. It is noteworthy that whilst the least contribution to total waste generated from corn husk and plantain was in February, that month recorded the highest generation of cabbage (18.97%) as waste. Vegetables are always in high demand, and thus there is all year-round production, especially in cities where small farm holdings are sited by drains (Amoah et al. 2005). The short maturation period of leafy vegetables and carrot and the fact that these vegetables are produced all year round by market gardeners in Accra, and its environs make these produce readily available all year in the two markets. The vegetables had higher moisture contents between 78 and 86% (Table 2) and lower C/N ratios between 12.9 and 21 (Table 3). They are, therefore, more susceptible to decomposition and hence spoilage accounting for their higher volumes as waste.

Table 1 Total percentage of individual waste collected from the two markets

Market crop waste	**Percentage (%) collection of specific waste per month**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cabbage (VW)	14.04a	18.97a	14.81a	10.53ab	11.45ab	11.89a	9.89cd	10.33abc	10.69ab	9.94a	8.45bc	10.19bc
Lettuce (VW)	8.90d	11.53b	9.44bc	8.50bcd	10.13bc	10.29ab	11.05bc	11.88a	11.32a	11.39a	9.38b	8.43cd
Carrot (VW)	5.53fg	6.09de	7.17cd	8.16bcd	6.96ef	6.32de	5.59fg	5.76de	5.26d	5.96d	5.91d	4.33f
Kontomire* (VW)	10.12bc	9.91b	10.64b	12.06a	11.32abc	12.55a	12.85a	12.26a	11.31a	10.97a	9.36b	8.16cd
Pineapple (FW)	10.83b	10.95b	10.67b	8.39bcd	7.36de	5.55de	7.32e	6.81de	8.87bc	7.46bc	9.78b	9.38bcd
Orange (FW)	9.50cd	7.15cd	7.48cd	9.37abc	9.34bcd	11.77a	9.73cd	10.74ab	8.82bc	7.64bc	7.18cd	7.40de
Watermelon (FW)	10.84b	11.01b	10.99b	10.76ab	13.45a	11.99a	11.40b	7.77bcd	10.35abc	8.26b	8.34bc	8.57cd
Plantain (FFW)	5.59fg	2.91f	2.92e	5.28de	4.63g	4.73de	5.48fg	4.83de	5.29d	6.13cd	7.06cd	8.70cd
Cassava (FFW)	6.30ef	9.04bc	5.37de	6.08cde	6.81ef	8.80bc	8.88d	11.50a	8.58c	9.96a	6.72cd	5.77ef
Yam (FFW)	7.31e	5.83de	5.12de	4.70e	5.09fg	4.63e	5.59fg	6.01de	5.67d	6.18cd	9.10b	10.76b
Plantain Peduncle (Other)	6.20f	3.81ef	11.01b	11.43ab	9.16cd	6.94cd	6.83ef	7.59cde	8.54c	11.13a	13.27a	13.65a
Corn Husk (Other)	4.93g	2.79f	4.39e	4.75e	4.29g	4.53e	5.37g	4.53e	5.32d	5.25d	5.46d	4.68f

* Kontomire = cocoyam leaves

Letters a-g, are assigned to means from highest to lowest in a column. Means sharing similar letter(s) in a column do not differ significantly at $P < 0.05$ by the Tukey test.

The contribution of orange to the total waste generated was generally uniform throughout the year and between 7.15% and 11.77%. It is worthy of note that the highest contribution of pineapple as a waste which was approximately 11% monthly was in the dry season between January and March. Watermelon waste generated was on the average between 10.76% and 13.45% from January to July with the waste generally declining thereafter. The relatively higher availability of pineapple waste in the first quarter of the year which coincides with the peak of the dry season in southern Ghana is as a result of glut of the fruit in southern Ghana. Watermelon and oranges are also readily available all year round, making them suitable materials for composting throughout the year. Composting of these organic waste bans will be achieved if their moisture contents can be brought down to acceptable level to facilitate aerobic decomposition. Watermelon and orange waste types have been identified to be suitable for the rearing of the Black soldier fly larvae (Ewusie et al. 2018). Thus, the availability of the fruit waste all year round could be exploited for the commercial cultivation of black soldier fly larvae as feed for fish (Teye-gaga 2017) and compost preparation (Akumah et al. 2021).

The proportion of vegetable waste (VW), i.e., lettuce, kontomire, cabbage and carrot to the total waste generated every month in the two markets was highest accounting for approximately 40% of the total throughout the study period (Fig. 3). The monthly contribution of fruit waste (FW) to total MCW generated was between 20 and 30%. The components of fresh food waste (cassava, yam and plantain) are usually processed in homes and restaurants and not in the markets. Consequently, their proportion to the MCW generated was between a paltry 5 and 15%. The lowest contribution to MCW were from the plantain peduncle and corn husk.

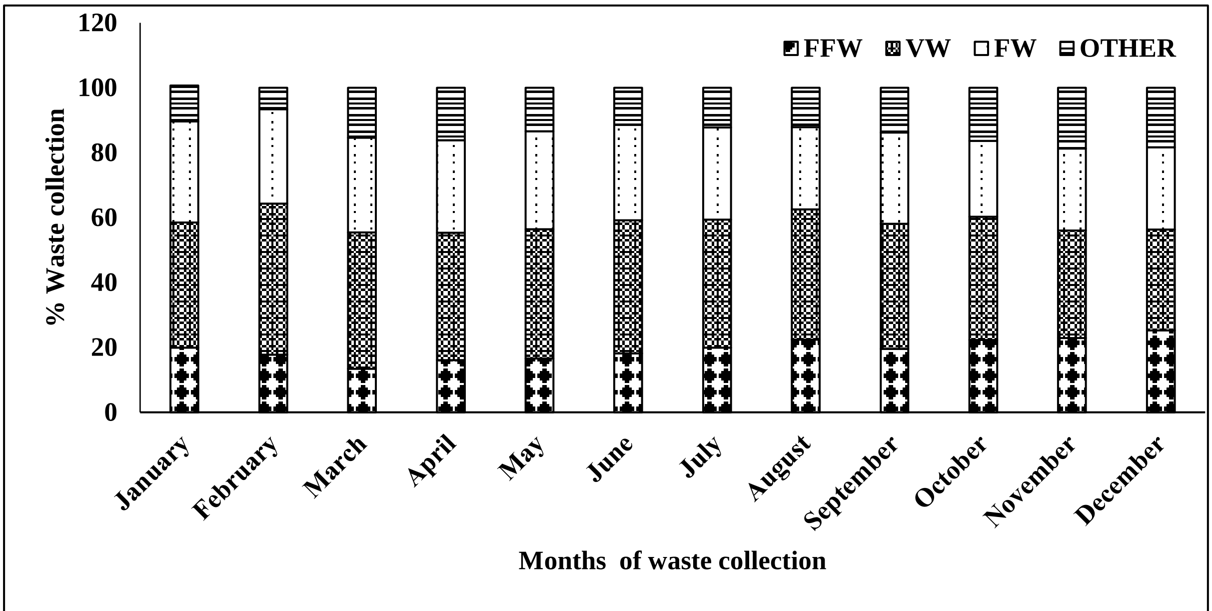

Fig. 3 Percentage contribution of various classes of market crop waste collected from the two markets

Moisture content of market crop waste

Watermelon expectedly recorded the highest moisture content of 90.46%, whilst the lowest of 45.32% was observed in the corn husk (Table 2). The other fruit wastes, i.e., oranges and pineapples, also had high moisture contents of 78.75 and 74.34%, respectively. The leafy vegetables, i.e., lettuce, cabbage and kontomire all had very high moisture contents of between approximately 82 and 86%.

The other vegetable, carrot had a slightly lower moisture content of 78.61%. Fresh food waste, i.e., yam, plantain and cassava had relatively lower moisture contents of 61.45, 58.73 and 56.82%, respectively. The suitable moisture content of feedstock for composting should be between 65 – 75% (Guo et al. 2012). Feedstock with high moisture contents decreases the yield of compost and delays the maturation of products during aerobic composting. The high moisture in vegetable and fruit wastes makes them unsuitable for use as composting feedstock in their fresh state. However, considering their relatively uniform availability throughout the year and their relatively high N and P concentrations (Table 1 and Table 3), these materials could be collected and air dried to reduce their moisture content to an acceptable level for composting. Leachates from the FW and VW during air drying which would contain high level of nutrients could be used to fortify compost nutritionally whilst serving as moisture sources during aerobic composting. Fresh food waste including plantain peduncle and corn husk has lower moisture content (Table 2), but higher C content (Table 3). They could serve as bulking agents to formulate compost mixtures with both VW and FW. The high C/N (85 to 248) ratio of FFW (Table 3) will contribute to higher yield of compost.

Chemical characteristics of market crop waste

Some chemical characteristics, including primary plant nutrients (N, P and K), Na, pH and EC of the MCWs, are presented in Table 3. The pH of the fruit waste ranged from extremely acidic of 3.5 in orange through strongly acidic of 5.0 in pineapple to near neutral of 6.5 in watermelon. The pH of the leafy vegetables was strongly acidic in cabbage and kontomire, and alkaline pH of 8.0 in lettuce. Carrot, which is a root vegetable, had its waste being alkaline with pH of 8.6. Fresh food waste, yam was strongly acidic (pH 5.4), with its cassava and plantain counterparts being neutral (pH 6.9). The highest alkaline pH of 9.9 was recorded in the plantain peduncle. The general acidic nature of the FW could be due to the presence of acetic and citric acids in these materials. Feedstocks with pH within the acidic medium such as orange, kontomire, corn husk, cabbage and yam could produce short-chain organic acids during composting which comprise mainly lactic and acetic acid (Beck-Friis et al. 2001). The concentrations of these acids increase during the initial stages of composting (Beck-Friis et al. 2003). This inhibits the activities of bacteria, the major decomposers responsible for the degradation of organic matter during the most active stage of composting (Sundberg 2005). As a result, the process is slowed, and the maturity is prolonged. In the choice of feedstock for composting; the proportion of the acidic feedstock should not be too much as that may delay the composting process. Should they be the main feedstock, then they would have to be co-composted with some alkaline feedstock such as rice husk and saw dust biochar (Akumah et al. 2021; Sulemana et al. 2021). These biochar types are generally alkaline (Eduah et al. 2019) and coupled with their hydrophilic nature, may absorb moisture. They neutralise the acidic content of the compost which would culminate in an increased bacterial activity to hasten maturity (Akumah et al. 2021). They in addition, increase the P content of compost (Sulemana et al. 2021).

Table 2 Moisture content of the crop waste

Market crop waste	Moisture content (%)
Cabbage (VW)	84.41
Lettuce (VW)	86.32
Carrot (VW)	78.61
Kontomire* (VW)	81.54
Pineapple (FW)	74.34
Orange (FW)	78.75
Watermelon (FW)	90.46
Plantain (FFW)	58.73
Cassava (FFW)	56.82
Yam (FFW)	61.45
Plantain Peduncle (Other)	45.64
Corn Husk (Other)	45.32

* Kontomire = cocoyam leaves

The other feedstocks like carrot, lettuce and plantain peduncle which are alkaline could be selected to blend with the acidic feedstocks so as to reduce the negative effect on bacterial activity during the initial stages of composting.

Table 3 Chemical characteristics of the market crop waste types

Treatment	**pH (H_2O)**	**EC (μScm^{-1})**	**C ($g\ kg^{-1}$)**	**N ($g\ kg^{-1}$)**	**C/N**	**P ($mg\ kg^{-1}$)**	**K ($g\ kg^{-1}$)**	**Na ($g\ kg^{-1}$)**
Cabbage (VW)	5.2	11.83_c	656.4_c	36.00_b	18.25_g	104.3_f	4.40_g	11.03_{ab}
Lettuce (VW)	8.0	10.31_d	545.4_d	24.87_c	21.99_{fg}	195.7_b	8.50_d	10.00_{cd}
Carrot (VW)	8.6	7.34_g	666.5_c	12.93_f	51.67_e	196.3_b	9.07_c	9.07_{de}
Kontomire* (VW)	5.3	12.83_a	519.0_d	40.47_a	12.86_g	145.7_c	7.53_e	12.00_a
Pineapple (FW)	5.0	7.83_f	748.6_b	21.47_d	34.89_f	96.7_g	3.13_h	8.03_g
Orange (FW)	3.5	8.13_e	769.9_b	15.43_e	49.89_e	95.3_g	2.10_j	9.03_{def}
Watermelon (FW)	6.5	5.34_h	669.7_c	20.67_d	32.44_f	205.0_a	9.73_b	8.07_{fg}
Plantain (FFW)	7.0	4.20_j	744.5_b	8.77_g	85.17_d	108.7_e	6.77_f	8.10_{efg}
Cassava (FFW)	6.9	3.92_k	840.4_a	3.40_i	247.83_a	86.0_i	2.03_{jk}	6.97_h
Yam (FFW)	5.4	4.64_i	770.9_b	3.63_{hi}	212.65_b	90.3_h	2.67_i	8.00_g
Plantain Peduncle (Other)	9.9	12.88_a	845.8_a	5.27_h	160.93_c	117.0_d	11.53_a	10.97_{bc}
Corn Husk (Other)	5.1	12.62_b	767.3_b	3.53_{hi}	217.93_b	105.0_f	1.83_k	11.03_{ab}

*Kontomire = cocoyam leaves
Letters a-k, are assigned to means from highest to lowest in a column. Means sharing similar letter(s) in a column do not differ significantly at $P < 0.05$ by the Tukey test.

In the selection of plantain peduncle as a feedstock, however, care must be taken not to add it in high proportion as it may slow down the decomposition process due to its high C/N ratio of 160.9. The acidic feedstock, especially orange, could come in handy to neutralize the concentration of hydroxyl ion that would be produced during the ammonification process as evident in equation below, to minimise ammonia volatilization.

$$R\text{-}NH_2 + 2H_2O \longrightarrow OH^- + R\text{-}OH + NH_4^+$$

The EC contents of the feedstocks are below 5 dS/m, the threshold in compost for greenhouse crop production (Cai and Gao 2011) and could, therefore, be used for composting. The plantain peduncle and corn husk could thus be used as bulking agents without fear of salt injury to crops. The highest accumulation of approximately 840.4 g kg^{-1} carbon was found in cassava and plantain peduncle, 9% significantly higher than the contents in yam and corn husk, orange and pineapple. Cassava, plantain and yam are crops cultivated for their energy or carbohydrate content. It is, therefore, not surprising that their waste accumulated the highest level of C. The high level of carbon in FW could be due to their high sugar content. The third highest accumulation of carbon in the range of 656.4 and 669 g kg^{-1} was observed in watermelon, carrot and the leafy vegetable cabbage. Notably, the other two leafy vegetables, lettuce and kontomire, had the lowest carbon concentrations, about 38% lower than that found in cassava. Total N (TN) was comparatively and significantly the highest in the leafy vegetables ranging between (24.87 and 40.47 g kg^{-1}). The N accumulation in the leafy vegetables was in the order of kontomire > cabbage > lettuce. Nitrogen is the main component of chlorophyll (Marschner 2011) and with their high green pigmentation as a result of high chlorophyll content, it stands to reason that the leafy vegetables, especially kontomire, had the highest TN concentration. The TN concentration in the carrot was almost half than that in the lettuce and a third of the content in the cabbage. The watermelon and pineapple had statistically similar TN concentrations of approximately 21 g kg^{-1}, almost half the concentration in the kontomire. The other FW (orange), though lower in

TN concentration (15.43 g kg^{-1}) was almost twice higher in the nutrient than plantain (8.77 g kg^{-1}). The lowest TN accumulations were observed in the more carbonaceous plantain, cassava, yam and corn husk wastes with values less than 3.7 g kg^{-1}. Nitrogen is a limiting nutrient in most tropical soils. Therefore, in producing compost, it is important to consider a finished product which contains high N. The VW (kontomire, cabbage and lettuce) could serve as suitable feedstock in producing high N composts. The C/N of kontomire and cabbage which are below 20 (Table 3) and the FW being 32 and 50 despite their high moisture content could upon drying be mixed to produce compost with high N. The C/N ratio of cassava waste at 247.83 was the highest and significantly different from corn husk and yam wastes, which were 217.93 and 212.65, respectively. The lowest C/N ratio of between 12 and 22 was in the leafy vegetables. It is worthy of note that kontomire and cabbage had C/N ratio below the 20 threshold for net mineralization in soil. The highest total P concentration of 205 mg kg^{-1} was recorded in watermelon. The level of the primary nutrient in the other two FW was 52% lower than in watermelon. The major nutrient P accumulation in the vegetables was in the order of lettuce = carrot > kontomire > cabbage. Cassava waste recorded the lowest P concentration of 86.0 mg kg^{-1}. The low P contents of all the crop waste attest to the fact that Ghanaian soils on which the crops were grown are low in P. Compost prepared from these wastes would have to be supplemented with P sources such as those from biochar (Eduah et al. 2019) or these wastes should be co-composted with biochar to boost their P levels (Sulemana et al. 2021). Plantain peduncle recorded the highest K concentration of 11.53 g kg^{-1} with the lowest K of 1.83 g kg^{-1} found in corn husk. Total K concentration determined in the MCWs showed that all the wastes differed significantly ($P < 0.05$) in their concentrations except cassava and corn husk, orange and cassava which had similar values of between 1.8 to 2.1 g kg^{-1}. The Na concentration of the market wastes ranged between 7 g to 12 g kg^{-1} with the lowest concentration of 7 g kg^{-1} in the cassava and the highest of between 11.03 and 12 g kg^{-1} in kontomire, corn husk and cabbage.

Estimated nutrient flow from the two markets

On the dry matter basis, a total of 15.4 Mg of waste was generated in 2016 from the two markets which had accumulated 211.1 kg of N, 1.84 kg P and 89.66 kg K (Table 4). The VW had contributed almost 54, 32 and 30%, respectively, of the total N, P and K in the waste. The contribution of FW to the total primary nutrient pool was 26, 18 and 13, respectively,s for N, P and K. The FFW contributed 10.6% of N, 24% P and 18% K. The other crop waste which included corn husk and plantain peduncle had a paltry proportion of 9.5% of the total N with 24% P and 39% K bound up in their tissues.

Heavy metals concentrations in market crop waste

The concentrations of heavy metals in the feedstock used in composting determines the quality of the product (Chimuka and Manungufala 2009). The heavy metals concentrations in the MCWs were far below the acceptable limit (Pb – 150, Cu – 100, Zn – 400, Cd – 2 mg kg^{-1}) (Hogg et al. 2002). These waste types are therefore suitable for composting. The concentration of Pb was below detection in the yam waste. However, the lead concentration in the rest of the waste ranged from 5.00 to 20.67 µg kg^{-1} (Table 5). The concentration of Zn, which is a plant nutrient in the waste, ranged from 26.00 to 273 µg kg^{-1}. Zinc concentration was the highest in the leafy vegetable waste (lettuce, cabbage and kontomire) and differed significantly from the rest of the waste. Copper had statistically similar concentration among the waste types ranging between 5.00 and 15.00 µg kg^{-1}. The concentration of Fe in the waste was the highest among the heavy metals analysed, ranging from 282.30 to 868.30 µg kg^{-1}.

Table 4 Primary nutrients concentration from the two markets

Treatment	Dry matter (kg)	N (g kg^{-1})	P (mg kg^{-1})	K (g kg^{-1})	N kg	P kg	K kg
Cabbage (VW)	1044.62	36.00	104.3	4.40	37.6	0.11	4.60
Lettuce (VW)	793.73	24.87	195.7	8.50	19.7	0.16	6.75
Carrot (VW)	738.67	12.93	196.3	9.07	9.6	0.15	6.70
Kontomire* (VW)	1152.06	40.47	145.7	7.53	46.6	0.17	8.68
Pineapple (FW)	1258.97	21.47	96.7	3.13	27.0	0.12	3.94
Orange (FW)	1070.24	15.43	95.3	2.10	16.5	0.10	2.25
Watermelon (FW)	560.24	20.67	205.0	9.73	11.6	0.11	5.45
Plantain (FFW)	1244.94	8.77108.7	6.77	10.9	0.14	8.43	
Cassava (FFW)	1922.54	3.4086.0	2.03	6.5	0.17	3.90	
Yam (FFW)	1390.42	3.6390.3	2.67	5.0	0.13	3.71	
Plantain Peduncle (Other)	2825.61	5.27117.0	11.53	14.9	0.33	32.58	
Corn Husk (Other)	1460.57	3.53105.0	1.83	5.2	0.15	2.67	
Total	**15462.61**				**211.1**	**1.84**	**89.66**

*Kontomire = cocoyam leaves

Table 5 Heavy metals concentrations in market crop waste

Treatment	**Pb**	**Zn**	**Cu**	**Fe**	Cd
		……………… ……………………..	µg kg^{-1}	…………………………….	
Cabbage (VW)	15.00_{ab}	263.30_{a}	15.00_{ab}	868.30_{a}	73.33_{a}
Lettuce (VW)	20.67_{a}	273.30_{a}	14.67_{ab}	773.30_{a}	45.33_{abc}
Carrot (VW)	8.33_{bc}	71.70_{bcd}	6.67_{ab}	460.00_{bc}	11.67_{d}
Kontomire* (VW)	11.67_{bc}	235.00_{a}	18.33_{a}	805.00_{a}	41.67_{abcd}
Pineapple (FW)	8.33_{bc}	103.30_{bc}	15.00_{ab}	768.30_{a}	10.00_{d}
Orange (FW)	5.00_{c}	78.30_{bcd}	8.33_{ab}	435.00_{bc}	16.67_{cd}
Watermelon (FW)	11.67_{bc}	65.00_{bcd}	11.67_{ab}	553.30_{b}	25.00_{bcd}
Plantain (FFW)	5.00_{c}	126.70_{b}	10.00_{ab}	283.30_{c}	11.67_{d}
Cassava (FFW)	5.00_{c}	133.30_{b}	8.33_{ab}	403.30_{bc}	50.00_{ab}
Yam (FFW)	ND**	136.70_{b}	5.00_{b}	288.30_{c}	30.00_{bcd}
Plantain Peduncle (Other)	5.67_{c}	44.00_{cd}	10.33_{a}	282.30_{c}	26.00_{bcd}
Corn Husk (Other)	11.00_{bc}	26.00_{d}	7.00_{ab}	373.30_{bc}	63.33_{a}

*Kontomire = cocoyam leaves; ** ND = not detected; Letters a-d, are assigned to means from highest to lowest in a column. Means sharing similar letter(s) in a column do not differ significantly at $P < 0.05$ by the Tukey test.

Cadmium concentration in the waste was between 10 and 73.33 µg kg^{-1}. Major sources of heavy metals contamination are through crop uptake, pesticide sprays, automobile and industrial exhaust (Banerjee et al. 2010) or contamination in the market when the crop waste types come into contact with old paint containers, newsprint, machine oils etc. (Richard and Woodbury 1992). Majority of these waste types were source sorted early in the market to avoid mixing with non-organics. These source separations avoided other routes of contamination other than crop uptake and possibly receptacles used in transportation to the markets. These source separations must have imparted in the low level of heavy metal contamination of the MCWs. The low level of the heavy metals could also be attributed to the low levels of the metals in Ghanaian soils with the exception of Fe.

Levels of faecal indicators and pathogenic bacteria in market waste

Pathogenic contamination levels in the various MCWs are presented in Table 6. *Escherichia. coli* was present in the leafy vegetables (kontomire, cabbage, lettuce) and watermelon waste types only. Contamination of kontomire waste with *E. coli* was high (5.92 log CFU/g) and differed significantly from cabbage, lettuce and watermelon. In fact, the waste that was contaminated with the bacteria were in the order kontomire > watermelon = lettuce > cabbage. The rest of the wastes were free from *E coli*.

Table 6 Levels of faecal indicators and pathogenic bacteria in market crop waste

Treatment	*E. coli*	Total coliform	*Salmonella spp*	*Enterococcus spp*
	………………	…….. (log CFU/g)	………………	
Cabbage (VW)	3.32_{c}	6.27_{a}	5.31_{ab}	4.74_{a}
Lettuce (VW)	4.58_{b}	6.21_{a}	5.16_{b}	4.64_{a}
Carrot (VW)	0.00_{e}	4.29_{c}	0.00_{d}	2.58_{b}
Kontomire* (VW)	5.92_{a}	6.24_{a}	5.41_{a}	2.39_{c}
Pineapple (FW)	0.00_{e}	6.23_{a}	0.00_{d}	2.45_{bc}
Orange (FW)	0.00_{e}	2.70_{e}	0.00_{d}	0.00_{d}
watermelon (FW)	4.60_{b}	4.79_{b}	3.78_{c}	4.61_{a}
Plantain (FFW)	0.00_{e}	2.67_{e}	0.00_{d}	0.00_{d}
Cassava (FFW)	0.00_{e}	2.47_{e}	0.00_{d}	0.00_{d}
Yam (FFW)	0.00_{e}	2.49_{e}	0.00_{d}	0.00_{d}
Plantain Peduncle (Other)	0.00_{e}	2.44_{e}	0.00_{d}	0.00_{d}
Corn Husk (Other)	0.00_{e}	3.86_{d}	0.00_{d}	0.00_{d}

*Kontomire = cocoyam leaves
Letters a-d, are assigned to means from highest to lowest in a column. Means sharing similar letter(s) in a column do not differ significantly at $P < 0.05$ by the Tukey test.

All the wastes had total coliform with the highest contamination in the leafy vegetables and pineapple. The high contamination of particularly leafy vegetables where faecal indicators and pathogenic bacteria manifested, could have come from the cultivation and handling processes. In the cities, most vegetables especially cabbage and lettuce, are grown by drains where wastewater is used to irrigate them. This source of irrigation has been implicated in vegetable coliform and *Salmonella* contamination in Accra (Amoah et al. 2005). In addition, the large surface of these vegetables with their high moisture and N contents make them prone to microbial infection. It is therefore, not surprising that *Salmonella spp.* contamination followed the pattern of *E. coli* with the highest contamination recorded in kontomire and cabbage. No *Salmonella spp.* was present in the other eight waste types. *Enterococcus spp*. contamination was present in VW (kontomire, cabbage, carrot, lettuce), watermelon and pineapple. The highest contamination of *Enterococcus spp.* was recorded in the leafy vegetable waste. Composting aerobically generates thermophilic temperatures which could denature pathogens making the product safe for agricultural application (Paul and Geesing 2009). The air drying to drain off moisture before composting might also help reduce the microbial load.

Conclusion

MCWs generated from the Madina and Dome markets in Accra, Ghana is dominated by leafy vegetables with very high moisture content and *E coli* but very low heavy metal content. Adequate drying of the MCW should make them suitable feedstock for composting. Quantity of waste generated was highest in the rainy season warranting composting within that period. The dry season should be for stockpiling and air-drying pineapple and orange waste which abound for composting in the rainy season. Annual dry matter MCW of 15,462.61 kg which had sequestered 211.1 kg N, 1.84 kg P and 89.66 kg K was generated from the two markets. Quality of the MCW shows that, vegetable waste (VW) and fruit waste (FW) will contribute more to N, P, K availability with the more carbonaceous cassava, plantain, plantain peduncle and corn husk being used as bulking agents to improve aeration and increase compost yield. The acid orange waste should be more suitable for use as an acidulant to minimise NH_3 volatilisation during the compost ammonification process.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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