AEROBIC CO-COMPOSTING OF AGRO-INDUSTRIAL AND MUNICIPAL SOLID WASTE

A Thesis
By

ABDULLAH AL MAMUN
Student No. 1805049

MASTER OF SCIENCE
IN
CROP PHYSIOLOGY AND ECOLOGY

DEPARTMENT OF CROP PHYSIOLOGY AND ECOLOGY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
DINAJPUR-5200, BANGLADESH

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DEDICATED

TO

MY BELOVED PARENTS

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ABSTRACT

A pilot scale experiment was carried out to minimize the problems of municipal waste (such as urban kitchen wastes-KW, tea waste-TW, eggshell-ES) and agro-industrial waste (such as poultry litter-PL, rice husk-RH, and saw dust-SD). Six square shaped bins with dimensions 0.95 m long 0.93 m wide and 0.83 m height (total volume of 0.733 m^3) were used. The study was carried out in the research field of the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology Dinajpur, Bangladesh. To observe the composting process and assess the compost quality, some physicochemical parameters (temperature, moisture content, electrical conductivity, organic matter, volatile solids, total solid, total organic carbon, total nitrogen, total phosphorus, potassium etc.) were measured at different phases of composting. The duration of composting period was 80-85 days. Physicochemical characteristics of the final product were Carbon and Nitrogen ratio:15.37-18.66%, Germination index: 110.89-137.77%, Total Kjeldahl Nitrogen: 1.38-1.43%, Organic Matter: 37.92-44.426%, Total Organic Carbon: 21.99-25.76%, Electrical Conductivity: 2713-3788 ppm and pH: 7.96-9.09). Municipal wastes were used in higher ratios (KW: RH: TW: PL: ES: SD=50:10:10:10:10:10) produce good quality compost. Moisture also played an important role in temperature evolution during composting. Based on experimental results, the problem of agro-industrial and municipal waste could be minimized by aerobic composting and it can be used in crop production. Nevertheless, composting duration and co-composting materials and their ratios are crucial factors that determine the quality of the final product. A full-scale compost unit could be designed based on the experimental results. Therefore, an urban area consisting of 500-600 families requires about 10-12 m^2 area to compost the entire annual kitchen wastes production.

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CHAPTER-1

INTRODUCTION

The increasing number of population, industrialization and trend of urbanization cause the problem of various types of anthropogenic wastes generation are gradually increasing day by day in developing countries. There are different types of wastes like solid (kitchen waste, municipal waste), liquid (industrial waste water, sewerage) and gas (brick kiln, sugar industry), which are needed to be controlled immediately. Among them agro-industrial and municipal wastes are important one to manage properly. Bits of food that are left over from cooking, eating such as vegetables and fruit peeling, meal leftovers, coffee grounds, tea bags, stale bread, grains, and general refrigerator spoilage are called municipal waste. The agro-industrial and municipal wastes are rich in carbohydrate, protein, fat and other nutrients which mainly come from grain, meat, bone, eggs and other animal. Municipal waste such as kitchen waste contains about 90% organic compositions (dry mass) and it could be recycled by feed, fermentation and composting process (Hall *et al*., 2009). But the complicated compositions of kitchen waste cause a lot of problems in the collection, transportation, segregation and disposal process (Domingo *et al*. 2009; Schapper and Chan, 2010; Regassa *et al*. 2011). In Bangladesh rural and urban population is also increasing day by day resulting increase agro-industrial and municipal waste. Dhaka, the capital of Bangladesh, is one of the fastest growing megacities in the world. The city generates about 3,500 tons of solid waste (kitchen waste municipal waste) per day (Sinha and Enayetullah, 2000).

Generally, a family generates kitchen 0.35 kg/day. Kitchen wastes are thrown in front of houses, roadsides drains etc. These create several problems such as bad odor, drainage sestagnation, increase COD (Chemical Oxygen Demand) and environmental problem. But this waste has also high amount of organic matter. Several ways the problem created by agro-industrial and municipal waste could be managed such as by burning, dumping of throwing into flowing water or aerobic decomposition (composting). Earlier three is not a good solution due to environmental and land scarcity problems. By decomposing it, we can contribute towards cleaner environment and also its benefit to plants (Federici *et al.*, 2011). The main products of the aerobic microbiological transformation of putrescent, bulky organic waste are CO_2, and humus-like material which is comprised primarily of stable, lignocellulose compounds. The residual compost has been described as the sanitized and humus-like material rich in organic matter and free from offensive odors resulting from the composting process of separately collected bio waste. The definition of composting may also be broadened to include cooler aerobic breakdown of bulky wastes in small scale composters, as is the case with small pile composting in the domestic context, and by 'slow-stack' treatment methods, where temperatures are in the psychrophilic (0-20 °C) to mesophillic (20-45 °C) ranges. Under suitable condition, composting has three consecutive phases a) the initial activation phase, b) a thermophillic phase recognized by a sudden temperature increase and c) a mesophillic phase where theorganic materials cool down to the surrounding temperature (Ryckeboer *et al.* 2003a). The organic matter conversion is caused by the enzymatic activities of microbial populations (Tuomela *et al*. 2000). Compost as an alternative fertilizer has a series of advantages according to Cooperband (2002), since it a) improves soil water capacity and aggregate stability; b) enhances action exchanges, c) increases microbial activity and d) enhances the degradation pesticides and other synthetic organic compounds. Composting of kitchen wastes is an imperative activity as far as composting at urban area is concerned. Today, the use of composition to turn kitchen organic wastes into a valuable resource is expanding rapidly in many countries as landfill space become scarce and expensive and as people become more aware of the impact they have on the environment. Most of the soils of Bangladesh have low organic matter content, usually less than 2%. About 45% of net cultivable area of the country has less than 1% organic matter content (BARC 1999). Side by side, intensive use of chemical fertilizer leads to soil fertility loss, soil erosion, water contamination, soil compaction & reduction of organic matter content thereby, reduces crop productivity. At this tilting situation, composting of kitchen waste may play an important role on waste management of the country as well as impart our soils new juvenility (Bari and Koenign, 2002). Organic wastes can be used as compost through recycling of various organic wastes such kitchen and drainage wastes for the maintenance of soil fertility which is a prerequisite for long term sustainable agriculture. So kitchen waste as compost in the soil can play a vital role in sustaining soil fertility and crop production than the use of chemical fertilizers (Islam *et al* 2009).Waste management receives concern both nationally and internationally due to the waste of identified urban environmental problems. Proper waste management can save citizens from different diseases, improve environmental conditions, promote urban economic development and generate employment (Huda 2002). Fortification of compost with suitable amount of chemical fertilizer could enhance fertilizer efficiency and return back organic matter into soil, restoring soil health and improving crop yield on suitable basis (Ahmad *et al.*, 2008)

However, sufficient research have not yet been carried out in Bangladesh regarding the available nutrients as agro-industrial and municipal waste by composting process. Keeping the above facts in view, the present study was undertaken in achieving the following objectives:

i) To minimize the problem of agro-industrial and municipal waste by acrobic decomposition;

ii) To measure the physicochemical attributes during composting and

iii) To evaluate the compost by phytotoxicity test (germination index) using lentil seeds.

CHAPTER-2

REVIEW OF LITERATURE

Composting is the process of the bio-chemical aerobic degradation of organic waste materials. Under suitable conditions, composting has three consecutive phases: a) the initial activation phase, b) a thermophillic phase recognized by a sudden temperature increase and c) a mesophillic phase where the organic materials cool down to the surrounding temperature (Ryckeboer, *et al*. 2003a) (Figure 2.1).

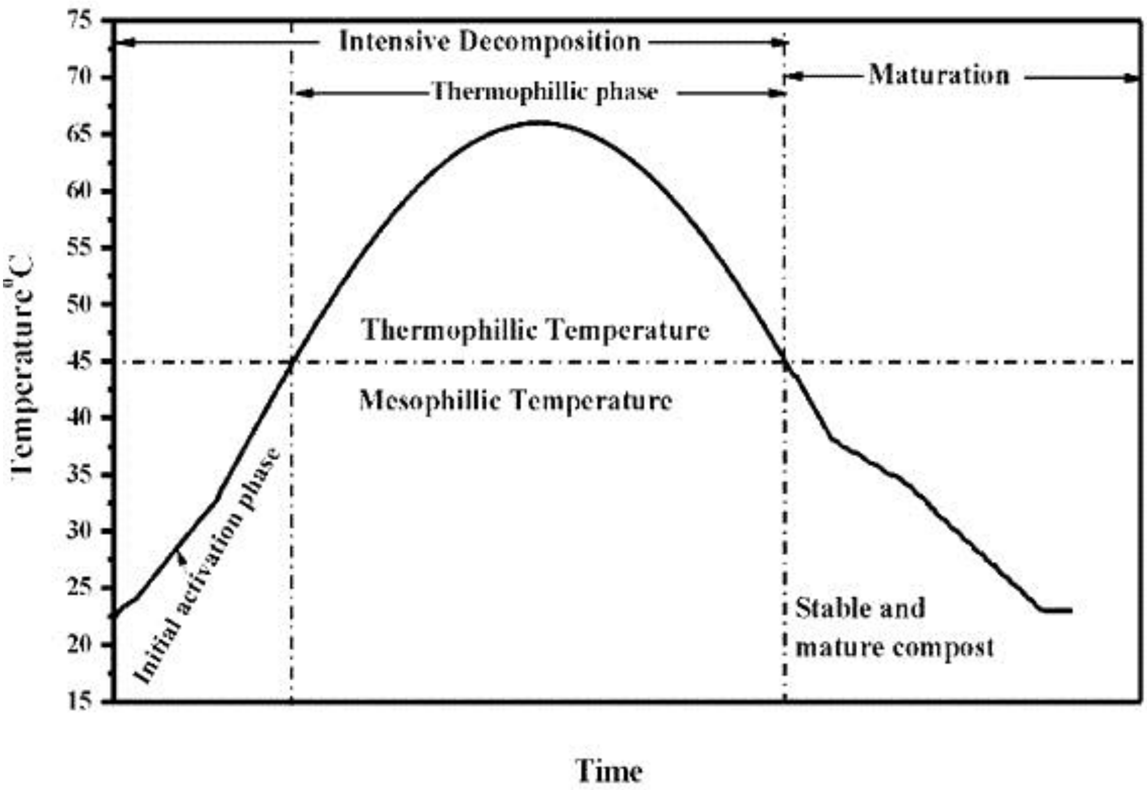


Figure 2.1: The different phases of the composting process

2.1. Factors affecting the composting process

Organic by-product are mostly used for composting. Poultry, cattle and pig manures, food processing waste, sewage sludge, leaves, plant and grass clippings, sawdust and other by-products of wood processing industries etc. are commonly used materials for composting. Feedstock quality and compost management was indicated the quality of the finished compost.

Several factors should-be regulated to overcome operational problems during composting, including odors, dust and ensuring good quality of the final product. The desirable conditions are fundamental requirement to achieve an aerobic composting procedure and to have, anaerobic fermentation. Over recent decades, research has focused on the complex interaction between physical, chemical and biological factors during composting. Controlling factors such as temperature, pH, moisture, bulk density, porosity, particle size, nutrient content, C/N ratio and oxygen supply, have been proved to be key elements for composting since they lead the proper conditions for microbial growth, development and organic matter decomposition (Agnew and Leonard, 2003; Richard *et al.* 2002; Chowdhury and Bari, 2014).

The factors influencing composting can be classified into two groups: those depending on the composting mixture's preparation such as pH, particle size, porosity, volume, initial moisture and nutritional balance and which depending on the process management, such as moisture content, temperature and aeration mainly. The nutritional balance in compost defines by C/N ratio. The ideal C/N ratio for composting ranges from 25-35, since it is thought that microbes require 30 parts of C per unit of N (Bishop and Godfrey, 1983), High C/N ratios delay the process as there is a surplus of degradable substrate for the microbes. While with a low C/N ratio, there is an excess amount of N per decomposable C and therefore excess inorganic N can be lost by ammonia volatilization or by leaching from the composting mass. Thus, low C/N ratios can be corrected by the addition of a bulking agent to provide degradable organic- C (Rynk *et al.*, 1992 and Alfano *et al.* 2008).

2.1.1. pH

The pH is a parameter that greatly affects the composting process. The range of pH values suitable for bacterial development is 6.0-7.5, while fungi prefer an environment in the range of pH 5.5-8.0 (Kapetanois *et al*. 1993; Zorpas *et al*. 2003). When pH values exceed 7.5, gaseous losses of ammonia are more likely to occur during composting. Some specific materials such as dairy manure, paper processing wastes, olive mill wastes (Cooperband, 2002; Tortosa *et al*., 2012) and cement kiln dust can increase pH, while food processing wastes or pine needles can reduce pH (Cooperband, 2002)

2.1.2. C/N ratio

The relative proportion of carbon and nitrogen is a major controlling factor in the composting process. Carbon serves primarily as an energy source for the microorganisms, while a small fraction of the carbon is incorporated to the microbial cells. Nitrogen is critical for microbial population growth, as it is a constituent of protein that forms over 50% of dry bacterial cell mass. If nitrogen is limiting, microbial populations will remain small and it will take longer to decompose the available carbon. Excess nitrogen, beyond the microbial requirements, is often lost from the system as ammonia gas. Nitrogen mineralization generally occurs in two phases, a rapid exponential immobilization or mineralization phase, followed by a slow linear mineralization phase. The C/N ratio of the substrate determines whether immobilization or mineralization will dominate in the early stages of composting. The rate of inorganic N release to the soil from composted manure depends on the rate of decomposition of the organic matter and on subsequent turnover of the decomposed C and N in soil. Release of plant available N from manure in the oil is controlled by the balance of N immobilization and mineralization, which in turn is controlled, to a large extent, by the C/N ratio of the decomposing organic material Cambardella *et al*. 2003). According to Golueke (1992), rapid and entire humification of a substrate essentially depends on it initially having a C/N ratio between 25 and 35.

2.1.3. Microorganisms

Various groups of microbial populations can decompose organic material (Ryckeboer *et al*. 2003a). Depending on the temperature of the composting mass, different groups of microbes are involved in the composting process and these clearly indicate the different steps of the process (Keener *et al*. 2000). Bacteria prevails early stage of composting, fungi are present during the entire process but can highly active when moisture levels fall below 35% and are inactive at temperatures greater than 60ºC. During the maturation phase *Actinomycetes predominate* and together with fungi are capable of degrading highly resistant polymers. The particle size of the feedstock affects microbial activities. Smaller particles have more surface area per unit volume and therefore, microbes have more surfaces to work. However, if particles are too small porosity will decrease and airflow within the compost pile will be restricted or lowered (Bernal *et al*. 2009).

2.1.4. Volume of compost pile

The ideal volume of the compost pile depends on the porosity and moisture content of the raw materials and the composting method. For example, a dry light pile can be mounded higher than a wet dense pile, without the risk of leading to anaerobic conditions. Smaller piles are capable of maintaining higher internal oxygen concentrations than larger piles, but larger piles can maintain higher temperatures better than smaller ones (Cooperband., 2002).

2.1.5. Aeration

Aerobic composting has many key factors, aeration is one of them. An aerobic composting pile should contain at least 5% oxygen during the bio-oxidative phase of composting (optimally closer to 10%). Composts must be aerated either passively or actively as aeration is a key element to successful composting. As microbial activity increases with time in the composting pile, more oxygen will be consumed with time. If this oxygen demand is not supplied decomposition can become anaerobic, slowing down, the composting process and producing foul odors (Cooperband, 2002).

2.1.6. Porosity

Substrates porosity plays a vital role on composting performance since a suitable physical environment for aeration must be maintained during the composting process. If porosity exceeds 50% then the pile may remain at a low temperature due to energy loss. Low porosity leads to anaerobic conditions and hence bad odors. Ideally, the air-filled pore space of the compost pile should be 35-50% (Bernal *et al*. 2009)

2.1.7. Moisture

Moisture is one of the composting variables that affect microbial activities, as it provides a medium for the transport of dissolved nutrients required for the metabolic and activities of microorganisms. It is essential for the decomposition process, as most of the decomposition occurs in the thin liquid films on the surfaces of particles Excess moisture will fill many of the pores between particles with water, thereby limiting oxygen transport. This in turn would create anaerobic conditions and brings about putrefaction, resulting in disagreeable odor and undesirable products. On the other hand, if the composting substrate is supplied with insufficient water, the growth and proliferation of microorganisms as well as the rate of decomposition of the organic material would be slowed down or even stopped. Moisture contents of between 45-60% by weight are ideal for composting processes (Gajalakshmi and Abbasi 2008). Low moisture contents slow down the process. Moisture also governs temperature.

2.1.8. Bulking agent

Bulking agents are used to increase porosity, decrease phytotoxic materials and maintain optimum level of C/N ratio. During composting different type of bulking materials are used such as poultry manure, sheep manure, olive tree pruning, cereal straw, waste wool, olive leaves, sheep litter, wheat straw, bean straw, grape stalks, cow manure, horse manure, turkey manure, pre-composting materials, wood chips, agricultural by-product and grass from municipal pruning, rice by-products, straw trimming, sesame bark, sewage sludge, cotton gin waste, fresh cow bedding, yard trimmings, maize wastes etc. Some authors also utilized different types of chemical additives such as urea, P, Fe and S to reduce the pH and electrical conductivity and biological agents like fungi and earth worms (Marin *et al*. 2005; Tortosa *et al*. 2012; Sanchez-Monedero *et al*. 1999)

2.1.9. Temperature

Ambient air temperatures influence microbial activity in the compost pile, and hence the raw materials decompose. In temperate climates composting is quickest in spring summer and autumn and is almost ceases in winter (Cooperband 2002).He also added that, compost pile temperature is a key factor for the composting process since it controls organic material biodegradation and is affected by a series of operational parameters such as pile volume, acration strategy, compost porosity and moisture. Usually, in an aerobic system, the temperatures rises to 50-60^{0} C in just a few days and can even go up to 70^{0} C in some cases. If done correctly, a compost pile will heat to high temperatures within 24 to 48 hours, If it doesn't, the pile is too wet or too dry or there is not enough green material (or nitrogen) present. The high temperature rise in the compost heap destroys weeds, pathogenic microorganisms, maggots, and worms, and prevents fly breeding. This happening and the generation of antibiotics during composting drastically reduce pathogens in the final compost. A temperature in the range of 55 to 65^{0} C ensures destruction of pathogenic organisms (Finstein *et al.*, 1987). A temperature of 65°C for at least 30 minutes is considered a critical threshold for plant pathogens (Lopez-Real and Foster 1985: Bollen *et al.,* 1989). Human pathogens are also inactivated at high temperatures (Burge, 1983). The temperature and the time interval required to destroy most common types of pathogenic microorgani heat resistance of human pathogens increases markedly under dry conditions (Cooper and Golueke 1977). Therefore, wet conditions must prevail in the compost pile. Standards have been proposed by the U.S. Environmental Protection Agency (EPA) to judge pathogen destruction. The U.S. EPA recommends a five days period at 55°C (U.S. EPA 1999), whereas Bertoldi *et al*. (1988) suggest that a three day period at 65'C and moist conditions is required. According to Vinneras *et al.* (2003), to achieve inactivation of pathogens, the reactor has to be sufficiently insulated so that the materials at the walls also attain high temperature. When low-temperature areas are present, turning of the material will increase the inactivation of pathogens. Therefore, it is important to have adequate insulation of the contents, even in areas with high temperature climates. With sufficient insulation, it is possible to reach temperatures over 60°c. The maximum temperature of the composting process. The maximum temperature of the composting process reaches 60-70^{0}C, the tempature level where many microorganisms become less active (Epstein 1997). At the top of the pile, the temperature is slightly lower due to conductive heat loss from the top to the surroundings. Over time, the temperature gradually drops off as the degradation rate of organic matter becomes less. This course in composting will result in adequate stabilization of organic matter, drying of the compost, and killing of pathogens and weeds. According to Rynk *et al*. (1992) and Fernandes *et al*. (1994), low temperature typically indicates low aerobic activity in the composting pile.

2.1.10. Electrical conductivity (EC)

Generally, it is found that EC increases during composting as volatile solids (VS) are degraded and the amount of water-soluble salts increases on a total solids (TS) basis. At lower pH values, negatively charged surface sites of organic matter are occupied by protons, which thus lowers CEC (Bolt and Bruggenwert, 1988). A decrease in CEC results in a lower adsorption of cations to organic matter and thus an increase in EC.

2.2. Agro-industrial and Municipal waste

2.2.1. Kitchen waste

As a result of the normal everyday processes of the urban kitchen waste a huge amount of kitchen wastes occurs. It is well-know from the literature that food materials (meat, vegetables, fruits etc.) are basically made up of water, fats, proteins and carbohydrates. These building blocks can be broken down into clemental components like carbon hydrogen and oxygen, which combine into the hydrogen and carbon monoxide fractions of the process gas. The KW is rich in sugar, carbohydrate, protein, fat and other nutrients which mainly come from grain, meat ,bone, eggs, and other animal tissue .KW contains more then 90% organic composition (dry mass) and it could be recycled by feed, fermentation and composting process. Kitchen waste as compost can increase soil fertility, keep soil health as a result increases in crop yield and quality of crop production.

Table 2.1: Chemical constituent of kitchen wastes (Islam *et al*. 2009)

Parameters	Quantity
pH	7.8
Organic carbon (%)	36.53
Organic matter (%)	62.83
Nitrogen (%)	2.70
Phosphorous (%)	0.43
Potassium (%)	0.92
Sulphur (%)	0.2
Calcium (%)	1.50

A summary of the properties of kitchen waste is shown in Table 2.1 and 2.2. Many environmental and physiological factors may impact on kitchen waste composition .Nitrogen, Phosphorus, potassium, Carbon, Hydrogen, Oxygen, ash and other some nutrient are different on various types of kitchen wastes.

Table 2.2: Elemental composition and ash content of kitchen wastes and dry food waste samples (Nagy *et al*. 2014)

Samples	Elemental composition of kitchen waste dried samples,%m/m					Ash content % m/m
	Nitrogen	Carbon	Hydrogen	Sulphur	Oxygen	
Potato chips	.56	43.97	7.58	0.08	44.80	3.01
Boiled potatoes	2.01	36.67	6.53	1.66	49.81	3.33
Rice(steamed)	1.13	41.13	6.90	1.58	48.10	1.16
Rice(cooked)	.70	42.08	7.02	1.98	47.04	1.19
Mixed vegetable side dish	2.10	40.44	8.66	2.13	42.43	4.24
Baked beans	3.18	43.26	6.76	2.01	40.46	4.33
Green pea stew	2.30	44.16	7.38	1.84	41.30	3.02
Beef stew	13.53	46.22	9.18	2.72	24.02	4.33
Breaded chicken breast	6.18	49.50	7.75	2.83	30.56	3.18
Fried chicken breast	13.30	48.48	9.59	2.68	20.77	5.18
Fried fish	12.91	49.69	9.50	3.12	19.33	5.45
White bread	1.90	44.02	7.07	2.8	42.65	1.56
Withered cabbage	3.85	42.0	5.48	1.23	38.16	9.28
Dry garlic	2.28	42.20	5.90	0.76	42.69	6.17
Clementines peel	1.27	41.94	6.51	<100ppm	47.39	2.89
Withered potato skins	2.32	42.09	6.23	0.42	44.55	4.39
Onion skins	1.68	25.28	4.92	0.70	60.93	6.49
Withered apple	0.34	39.3	6.69	<100ppm	52.42	1.22
Withered carrot	1.41	40.32	4.84	0.29	47.30	5.84
Orange peels	0.91	44.0	6.15	<100ppm	46.95	1.99
Banana peels	0.87	40.60	5.36	<100ppm	43.75	9.42
Kohlrabi peels	1.89	39.96	4.68	3.51	45.45	7.51
Capsicum leftovers	2.67	41.60	5.14	0.40	41.93	8.26
Withered lettuce	3.58	56.64	5.75	0.21	24.95	8.87
Cumcumber peels	3.32	52.40	6.23	0.12	29.29	8.64

Table 2.3: The main characteristics of kitchen waste compost

Reference	Composting materials	Aeration strategy	Composting pile type	Moisture (%)	Max temp (^{0}C)	Thermophillic phase duration	Composting duration (days)
Albasa *et al*. 2015	Kitchen waste and cow dung	Na	Vermicomposting	Na	Na	Na	60
Islam *et al*. 2009	Kitchen waste, dairy and drainage waste	Na	Quick compost	26%	Na	Na	90
Castaldi *et al*. 2005	MSW+ vegetable waste	Na	Na	40-50%	Na	8-12 weeks	Na
Haydar and masood, 2011	Kitchen waste, sewage and animal manure	Na	Windrow composting	26%	Na	Na	2-4 months
Tanksali *et al*. 2014	Kitchen waste, vegetable waste and saw dust	Na	Mega-bacillus Culture	60-70%	60%	Na	16
Kwon and Lee, 2004	Food waste	Na	Na	58.1%	58%	Na	Na
Smars *et al*. 2002	Organic household waste	Na	Na	65%	Above 40^{0}C	Na	Na
Raviv *et al*. 2005	Orange peels + cow manure	Na	Na	initially 50-60%, finally 40-50%	55^{0}C	Na	Na

NA =Not available

Table 2.4: Physicochemical properties of kitchen waste

Reference	pH		Ec (ds/m)		OM (%)		TOC (%)		TN (%)		TP (%)		C/N		GI (%)	
	initial	final	initial	final	initial	final	initial	final	initial	final	initial	final	initial	final	Initial	Final
Albasa *et al.* 2015	7.9	7.1	Na	Na	Na	Na	Na	Na	0.14	0.35	0.76	1.21	30.8	5.54	Na	Na
Islam *et al.* 2009	Na	5.57	Na	Na	Na	Na	Na	1.61	Na	1.174	Na	21.74	Na	Na	Na	Na
Castaldi *et al.* 2005	7.6	8.9	Na	Na	Na	2.78	Na	Na	Nana	Na	Na		51.1	28.3	Na	Na
Haydar and masood, 2011	6	8.4	Na	Na	90.7	16.7	Na	Na	Na	1.80	Na	Na	24.35	10.67	Na	Na
Tanksali *et al.* 2014	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na	18.5	8.5	Na	Na
Kwon and Lee, 2004	7.94		Na	Na	Na	Na	Na	Na	Na	Na	Na	Na	16.4	12.37	Na	Na
Raviv *et al.* 2005	6.7	7.1	Na	Na	Na	Na	Na	Na	Na	Na	Na	Na	30	11.9	Na	Na

NA =Not available; Ec: Electrical conductivity; TOC: Total organic carbon; TN: Total nitrogen; C/N: Carbon to nitrogen ratio; TP: Total phosphorous; OM: organic matter; GI: Germination index

2.2.2. Saw dust

Saw dust is the by- products of wood processing and furniture industries. It has high surface area, porosity and high water retention capacity. The chemical composition varies with the nature of trees (Banegas *et al*. 2007) found that saw dust is a good compost bulking agent. It is also an available by product in our country. Saw dust has a variety of other practical uses, including serving as mulch, as an alternative to clay cat litter, or as a fuel. Until the advent of refrigeration, it was often used in icehouses to keep ice frozen during the summer.

Table 2.5: Characteristics of saw dust (Banegas *et al*. 2007)

Properties	Values
pH	5.08
EC (%)	0.2
OM (%)	99.4
TOC (%)	51-53
TKN (%)	1.8
C/N ratio	90-103

2.2.3. Tea waste

Tea waste means tea sweepings, tea fluff, tea fiber or tea stalk or any article purporting to be tea which does not confirm to the specification for tea laid down under the prevention of Food Adulteration Act, 1954 (37 of 1954) .

Table 2.6: Properties of tea waste

Physical properties	**values**
BET surface area m^2/g	22.658
Total pore volume m^3/g	0.0255
Monolayer volume cm^3/g	4.387
Chemical properties	**values**
Moisture (wt%)	8.01
Volatile matter	5.09
Ash content	12.45
Fixed carbon	74.45

2.2.4. Rice husk

Rice husk a major by-product of the rice milling industry, is one of the most commonly available lingo cellulosic materials that can be converted to different types of fuels and chemical feed stocks through a variety of thermochemical conversion processes. Proper understanding of the physical and thermochemical properties of rice husk is necessary for the design of thermochemical conversion systems. This study provides information on moisture content, bulk density, particle size, heating values, proximate analysis, ultimate analysis, ash composition, and ash fusibility characteristics for six rice husk varieties. The moisture content ranged from 8·68 to 10·44%, and the bulk density ranged from 86 to 114 kg./ m^3. The results showed excessive volatile release of over 60%, high ash content ranging from 15·30 to 24·60% (dry weight basis), and high silica content of the ash ranging from 90 to 97%. The lower heating values ranged from 13·24 to 16·20 MJ / kg (dry weight basis). The ash fusion temperatures of all the varieties were found to be over 1600°C. The differences in varietal characteristics have significant effects on the chemical properties of rice husk. Physical and Thermochemical Properties of Rice Husk.

2.2.5. Poultry litter

In Bangladesh near about 1,50,000 commercial poultry farms (broiler and layer farms) and about 130 Parent stock farms are present (ICDDRB, 2008). The weight of fresh poultry manure is estimated as 15% of the total dry matter intake. It contains about 28-30% crude protein in which 36-50% is true protein (Bhattacharya and Taylor, 1975). About 3079 metric tons poultry manures are produced daily from a total of 42 million chickens in Bangladesh (Waste concern, 2005) The large quantities of poultry waste production causes serious socio- economic problems, the most prominent of which is the pollution of our environment and our environmental resources particularly polluting the surface water, groundwater and air environment at high level (Alabadan *et al.*, 2009; FAO, 2008; Dahal, 1993). Poultry litter also contains pathogens which may potentially affect soil and water resources and can remain viable in the environment for long periods of time (Bowman *et al.*, 2000) and continuous dumping can lead to serious health concerns (Akinbile, 2012).

Table 2.7: Chemical and physiochemical characterization of poultry manure (Guerra-Rodriguez *et al*., 2001)

Parameters	Values
Organic matter content,% dry matter	85.38
pH	8.8
Moisture, % wet weight	48.69
Total nitrogen,% dry weight	3.58
Inorganic nitrogen, % dry weight	1.74
Ammonium nitrogen,% dry weight	1.76
OCC/nitrogen ratio	10.89
TCC/nitrogen ratio	12.24
P_2O_5,% dry weight	0.71
K_2O_5, %dry weight	3.79

CHAPTER-3

MATERIALS AND METHODS

3.1. Composting materials and process

To evaluate agro-industrial and municipal waste composting an experiment was conducted using various materials such as: poultry litter (PL), rice husk (RH), saw dust (SD), Kitchen waste (KW) Tea waste (TW) and eggshell (ES). The kitchen waste (KW) was collected from nearby urban area (Dinajpur); rice husk was obtained from the local rice husking mill and saw dust was obtained from a local wood processing industry. Tea waste was collected from the local tea stalls. Poultry litter was collected from local poultry farm. Six square-shaped composting bins were made with 0.83 m height, 0.95m length and 0.93 m width and a total volume of 0.733 m^3. Bin 1 was filled with kitchen waste, saw dust, tea waste and eggshell, bin 2 with kitchen waste, rice husk, tea waste and eggshell, bin 3 with kitchen waste, saw dust, and eggshell, bin 4 with kitchen waste, saw dust, and tea waste, bin 5 kitchen waste, rice husk, and tea waste and bin 6 with kitchen waste, rice husk, saw dust, tea waste, eggshell and poultry litter. The experiment was carried out at the facilities of the Department of Crop physiology and Ecology, Hajee Mohammad Danesh Science and Technology University research field area. Tables 3.1 present the experimental set-up for this composting experiment. Different composting materials were used in the experiment to determine optimal mixing ratios.

Table 3.1: Description of experimental setup

Bin No.	Composting materials ratio (%)						Moistening agent	Initial Mass (kg)	Initial Volume (L)	Final Mass (kg)	Final Volume (L)
	Kitchen waste	Saw dust	Tea waste	Poultry litter	Eggshell	Rice husk					
1	60	20	10	_	10	_	water	255.32	412.65	145.32	180.7
2	70	_	10	_	10	10		261.49	467.3	163.52	185.12
3	50	40	_	_	10	_		301.52	491.5	180.32	213.6
4	60	30	10	_	_	_		292.79	432.2	173.2	193.8
5	50	_	25	_	_	25		310.32	511.5	198.25	236.2
6	50	10	10	10	10	10		298.69	545.5	188.32	221.9

Figure 3.1: Pilot-scale compost bin used during composting period

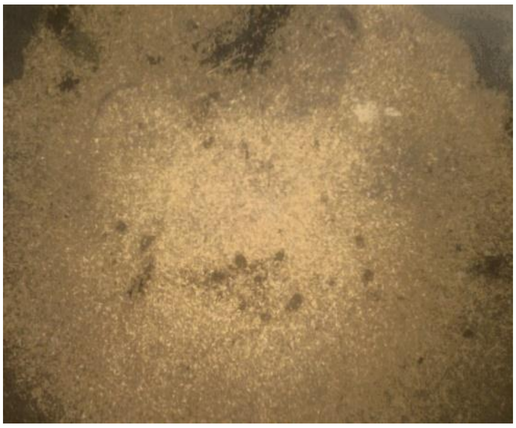


Figure 3.2: Rice husk

Figure 3.3: Kitchen waste

Figure 3.4: Tea waste

Figure 3.5: Saw dust

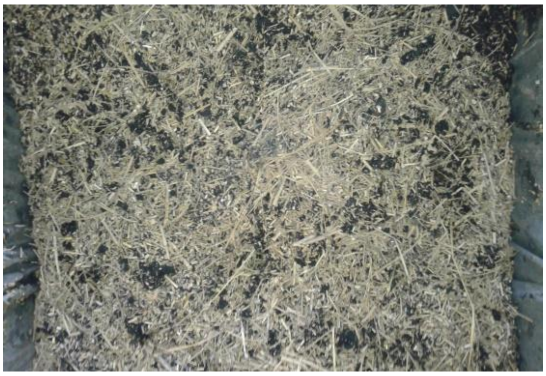
Figure 3.6: Raw poultry litter

Bin 1

Bin 2

Bin 3

Bin 4



Bin 5

Bin 6

Figure 3.7: Mature composts

3.2. Physicochemical Analysis

In this experiment, aeration was achieved by mechanical turning, which took place daily for the first three days, once every four days during thermophillic phase. Samples of about 1 kg were collected from the top to the bottom of each bin with a sampling auger and homogenized by mixing after each 7 days interval. One portion was analyzed immediately for moisture content, pH, electrical conductivity (EC), oxygen consumption, and volatile solids. Moisture content was measured from the weight loss after sample drying 105°C for 24 h. The organic matter and ashes contents were determined by loss-on-ignition, at 600°C for 4 h. Electrical conductivity (EC) and pH measurements were performed by electrometric determination in aqueous extracts ratio of the samples. The Kjeldahl digestion method was followed to evaluate the total nitrogern content while the phosphorus content was determined by the vanado-molybdate method and potassium was nitric perchloric digestion method. The details procedure of physicochemical analysis is given below-

Pre-treatment of sample

For measuring certain parameters, samples needed to be pre-treated. Pre-treatment included drying the sample at 65 °C for 24 hours to remove moisture and then grinding and sieving (0.5 mm). Samples were kept in aluminum foil bags. Pre-treatment was required before measuring nitrogen, phosphorus, total carbon, and organic matter. The remaining parameters did not need pretreatment.

Sample Maintenance: Samples were analyzed immediately or were refrigerated at 4 ^{0}C.

3.2.1. Compost, Temperature (ºC)

To measure the temperature of the compost a special thermometer probe was used .The probe was positioned at 30 cm and 50 cm depths in the composting bins.

3.2.2. Air Temperature (^{0}C)

Air temperature was measured with a standard thermometer.

3.2.3. pH

The pH of a solution is simply the measurement of its acidity or alkalinity. It is a decisive attribute of aqueous solutions and thus an important parameter verifying water, as well as liquid and solid waste. An electronic pH meter, was used to measure pH .

Apparatus required

1. Analytical balance
2. Glass beaker (I.0 L)
3. Magnetic shaker

Procedure

1. 50.00 gm of each compost sample was weighed in the beaker.
2. 500 mL of deionized water was added and the solution was stirred for 2 h on a magnetic shaker.

3. The solution was allowed to calm for 30 min during which most of the solid in suspension was separated from the liquid. The pH probe was inserted into the solution to measure pH.

Calculation: The result was characterized as compost pH in water.

3.2.4. Electrical Conductivity of Compost (EC, µS/cm)

The ability of an aqueous solution to conduct electricity is the mathematical expression of electrical conductivity. This ability depends on the presence of ions, their vigor, mobility and their concentration and temperature, viscosity of the solution and the size of the potential difference at which the measurement is made. The solutions of most inorganic acids and bases and all salts are relatively good conductors of current, unlike the molecules of organic compounds, which do not dissociate when dissolved in water and conduct little or no electricity. The conductivity measurement was performed using a multi parameter analyzer.

Apparatus required

1. Analytical balance
2. Glass beaker (1.0 L)
3. Magnetic shaker

Procedure

1. 50 g of each compost samples was weighed in the glass beaker.
2. 500 ml of deionized water was added and the solution was stirred for 2 h on a magnetic shaker.

3. The solution was allowed to settle for 30 min during which the most of the solids in suspension from the solution .The EC probe was inserted into the solution to measure EC.

Calculation: The result was characterized as compost electrical conductivity in water.

3.2.5. Moisture percentages

Apparatus required

1. Aluminum foil box
2. Analytical balance
3. Electric oven
4. Desiccator with desiccant and humidity indicator dye concentration

Procedure

1. An empty aluminum foil box was weighed.
2. 50 g compost sample was weighed at in the aluminum foil box.
3. The measured sample then placed into the oven and dried at 105 °C for 24h.
4. After 24 h, the sample was removed and placed in the desiccator for 20 min to reach environmental temperature and stabilize the humidity.
5. The dry sample was weighed together with the aluminum foil.
6. Compost moisture was calculated using the following formula.

Calculation

The compost moisture was calculated from the following equation:

Moisture content, %= (A-(B-C)) * 100

Where: A: Fresh sample weight (g)

B: Oven-dried sample weight (g)

C: Weight of empty aluminum foil box (g)

3.2.6. Measuring volatile suspended solids (VSS, %)

Volatile suspended solids are the fraction of total suspended solids which evaporates at 550 °C. To determine the crucible in which they have retained total suspended solids fired to constant weight in an oven at 550 °C. Reducing the weight of the filter corresponds to volatile suspended solids.

Apparatus required

1. Small aluminum crucible
2. Analytical balance
3. Electric furnace
4. Desiccator with desiccant and humidity indicator dye concentration

Procedure

1. The empty aluminum crucible was weighed.
2. 3 g of compost was weighed at in the crucible (from the previously dried sample).

3. The crucible with compost was then placed in the furnace at 600 °c for 4 h.
4. After 4 h the sample was removed from the furnace and placed in the desiccator for 15 min to reach environmental temperature and stabilize the humidity.
5. The dry sample in the aluminum crucible was then weighed.
6. Volatile suspended solids were calculated by the following equation.

Calculation

Volatile Suspended Solids, % = (A-(B-C)) × 100

Where: A: Fresh sample weight (g)

B: Oven-dried sample weight (8)

C: Weight of empty aluminum foil box (g)

3.2.7. Determination of nitrogen (N, %)

Sample Preparation

The sample was pre-treated it was dried at 65 °C for 24 h and was Sieved through a 0.5 mm sieve.

Apparatus required

1. Analytical balance
2. Digester
3. Distiller
4. Pipette
5. Flasks, Erlenmeyer Flasks

Reagents

1. H_2SO_4 + salicylic acid: 25 g of salicylic acid powder (kept in the atmosphere) was added to IL H_2SO_4 (concentration 95-97 %).
2. Indicator of Total Nitrogen:
   a. 0.35 g bromcresol green was weighed in a volumetric flask of 250 ml containing 10 ml absolute ethanol.
   b. 10 ml 0.IN NaOH (1 g in 250 ml 0.1 N) was added.
   c. Approximately 150 ml of water was added.
   d. 22 ml 1% aqueous ponceaw 4R (0.22 gm ponceaw in 22 ml water) was added.
   e. 0.75 g nitro phenol diluted in 5 ml absolute ethanol was added.
   f. Finally distilled water was added up to the mark of 250 ml.
3. Sodium Thiosulfate Penta Hydrate
1. 4 Kjeldahl Tablet (selenium tablets)
4. NaOH 10.5 N
5. Boric acid, H_3BO_3 (2%)
6. Hydrogen chloride, HCI (0. 05 N)

Procedure

1. 0.50 g samples were weighed and each was placed in of the cylinder of Kjeldahl.
2. 20 ml reagent (H_2SO_4* + salicylic acid*) was added in each tube (Table 1)

Table 1 H_2S0_4 and Salicylic acid preparation

H_2SO_4 (mL)	Salicylic Acid (g)
50	1.25
120	3
150	3.75
260	6.5
300	7.5

The tubes were stirred gently and left to stand for 30 minute.

Digestion process

1. Two catalysts were added to the samples to accelerate the digestion process. 1g Sodium Thiosulfate Penta Hydrate was added to each tube. When the smoke began to evolve a tablet of Kjeldahl (selenium tablets) was added to the tube
2. Digestion took place at 430 °C for 1 h (program 6 of the digester).
3. After 1 h the samples were removed from the digester and left to cool.

Distillation process

1. The Kjeldahl device I was adjusted for the following parameters: 30 ml H_2O. 100 ml NaOH 10.5N (420 g/until 1L H_2O) Distillation Time 3 min.
2. 100 ml of boric acid was added to each Erlenmeyer flask with 250 ml, H_3BO_3, 2% (20 g/1000 ml).
3. Nitrogen indicators 10-12* * (blue) drops were added to the conical flask after each distillation.

4. Titration was performed with HCI 0.05 N until the contents of the conical flask became orange.
5. The amount of HCI needed to complete the titration was recorded

Calculation

Kjeldahl Nitrogen was calculated by the following formula.

Kjeldahl N % = (ml sample-0.2) x 0.05 x 14 x 100 (Weight of sample x 1000)

Where, ml sample: ml sample used in titration and Sample weight: sample used for digestion.

3.2.8. Determination of Total Organic Carbon (TOC, %) and Organic Matter (OM)

Sample Preparation: The sample was pre-treated. The sample was initially dried at 65°C for 24 h. Then ground and sieved through a 0.5 mm sieve.

Apparatus required

1. Analytical balance
2. Electric oven
3. Aluminum crucible

Procedure

1. A 5gm sample was weighed and placed in a crucible for incineration.
2. The sample was allowed to dry in the oven at 105 °C for 24
3. Then the sample was burnt at 600^0 C for about 4
4. The sample was then removed from the oven and placed in a desiccator

5. The deference of the sample weights was then calculated (initial weight- final sample weight).

Calculation

The percentage of organic matter is given by

Organic matter= (initial sample weight- final sample weight) X 100/ initial weight

Organic Matter={[(W1- wt of aluminum foil) - (W2- wt of aluminum foil)]*

100/W1- wt of aluminum foil)}

Total carbon (%) was calculated as a percentage of organic matter in accordance with the following formula: Total Organic Carbon=Organic matter x 0.58

3.2.9. Determining Phosphorus (%)

Sample Preparation: The compost sample was initially dried at 65 °C for 24 h. It was then ground and sieved through a 500 microns sieve.

Apparatus required

1. Colorimeter
2. Cuvettes
3. Vanadate-molybdate reagent,
4. 1 mL variable micropipette

Colorimeter set-up

1. A double beam spectro-photometer with wave length 660 nm was used.
2. A phosphate standard data file was prepared.
3. Before measuring samples, the colorimeter was calibrated against water or compost sample developed with vanadate-molybdate reagent.

Procedure

1. 1 mL of compost sample was transferred into a clean cuvette.
2. 025 mL of vanadate-molybdate reagent was added and mixed by pipetting up and down several times.
3. At least 10 minutes waited for color to develop
4. The cuvette with sample was placed into the colorimeter and measure was clicked The program was returned the phosphate concentration in ppm.

3.2.10. Measurement of Potassium (%)

Sample Preparation

The sample was initially dried at 65 "C for specify 24 h. It was then ground and sieved through a 500 microns sieve.

Apparatus required

1. Analytical balance
2. Oven drying
3. Pipettes

4. Flasks, Erlenmeyer Flasks
5. Capsule
6. Crucible
7. Bottles

Reagents

I, Nitric acid, HNO_3, 65%

Procedure:

1. 0.50 g of the compost sample was placed in small aluminum foil box and burnt at 500^0 C for 3.5 h. it was then allowed to cool.
2. Conical flasks of 100 ml were prepared with funnels and filters. The burned samples were poured into 5 ml of nitric acid (65%).
3. Each sample was filtered. The volume of the filtered solution was made up to the 100 ml mark by adding distilled water.
4. The sample was then divided into two bottles with lids and with lids and refrigerated for future measurement.
5. K was measured using atomic absorption spectrophotometer.

Calculation

The values of K and Na were given by the formula: K= Indication atomic absorption spectrophotometer × Volume (L) /weight % K.

3.3. Phytotoxicity

Tomato seeds were used for the phytotoxicity test. Phytotoxicity was estimated using the germination index (GI) as described by Zucconi *et al.* (1981). Phytotoxicity was determined by comparing the root development of each seed that sprouted in the compost and in deionized water (the control sample). For this test, 10 g of powdered compost were mixed with 100 ml of deionized water and the solution was then stirred for 2 h. After stirring, the solution was allowed to rest for half an hour and was then diluted with distilled water to two different concentrations (50% and 100%) with clear supernatant. The control concentration (0%) comprised only deionized water. Five ml of each compost solution was added to a petridish containing five pieces of blotting paper onto which 25 Capsicum seeds were placed. All the concentrations of each compost sample, including the control, were replicated three times. Ptridishes were incubated for 96 hours at 25 °C. After the incubation period, root length was measured in each sprouted seed and GI was estimated.

3.3.1. Estimation of Phytotoxicity (Germination Index, GI %)

Sample Preparation: The was initially dried at 65 °C for at least 24 h. It was then ground and sieved in a 500 micron sieve.

Apparatus required

1. Analytical balance
2. Oven drying
3. Pipettes
4. Bottles

5. Petridishes
6. Filter paper

Procedure

1. 1.10 g of powdered sample was weighed.
2. 100 ml distilled water was added.
3. The solution was stirred for 2 hours and left to settle for half an hour.
4. The different concentrations (50% and 100%) were made with supernatant.
5. Five filter papers were placed in each petridish and were moistened with 5ml of the dilutions (control dish was moistened with distilled water).
6. 25 tomato seeds were evenly placed onto each petri dish.
7. The petridishes were placed in a room with $25^{O}C$ controlled temperature and constant light for 48 hours.

Calculation

After 96 hours, the seeds germinated and the radicle length of each sprouted seedling was measured

Germination percentage % = Number of seeds germinated/total number of seeds (25)

Phytotoxicity expressed by the Gl values which contain the length of the roots and the germination percentage expressed as a percentage of the control.

G.I. (%) = {Y x D / Xo x C} x 100

Where:

Y: the average number of germinated seeds in the test sample,

D: The average root length of the germinated seeds in the test sample

Xo: the average number of seeds germinated in the control dishes (the set of reference samples is 3)

C: The average root length of the germinated seeds in the controls.

3.4. Statistical analysis

The collected data were analyzed by computer package program Small Stata 12.0 and significance of mean differences was adjusted by "Tukey test"

CHAPTER-4

RESULTS AND DISCUSSION

4.1. Physical Properties of compost during the Composting Process

4.1.1. Temperature (^{0}C)

Figure 4.1 presents the time series charts of compost and ambient temperature during the composting period. The ambient temperature was around 21-32°C. The thermophillic phase (over 45 ^{0}C) established at day 6 in bin 6, at day 7 in bin 3, at day 8 in bin 1, bin 4, bin 5 and at day 9 in bin 2 respectively. Maximum temperature in bin 1 (79^{0}C) was observed at day 26, while in bin 2 (79^{0}C), bin 3 (79^{0}C), bin 4 (67^{0}C), bin 5 (67^{0}C) and bin 6 (61^{0}C) found at days of 19, 15, 13, 15 and 17 respectively. The similar pattern was also observed by Tanksali *et al*. (2014), Kwon and Lee (2004), Chowdhury *et al*. (2013). Bins 1,3,4,5 had longer thermophillic phases (almost 51 days), bin 2 (38 days) and bin 6(44 days). Thermophillic temperature lingered over 50°C for 32 days in Bins 1, 3, 4 and 5. This might be due to higher initial moisture of bins 1, 3, 4 and 5. The U.S. EPA recommended a five days period at 55°C (U.S. EPA 1999) to kill the pathogens, whereas Bertoldi *et al*. (1988) suggested that a three day period at 55'C and moist conditions is require. According to Vinneras *et al*. (2003), to achieve inactivation of pathogens, the reactor has to be sufficiently insulated so that the materials at the walls also attain high temperature.

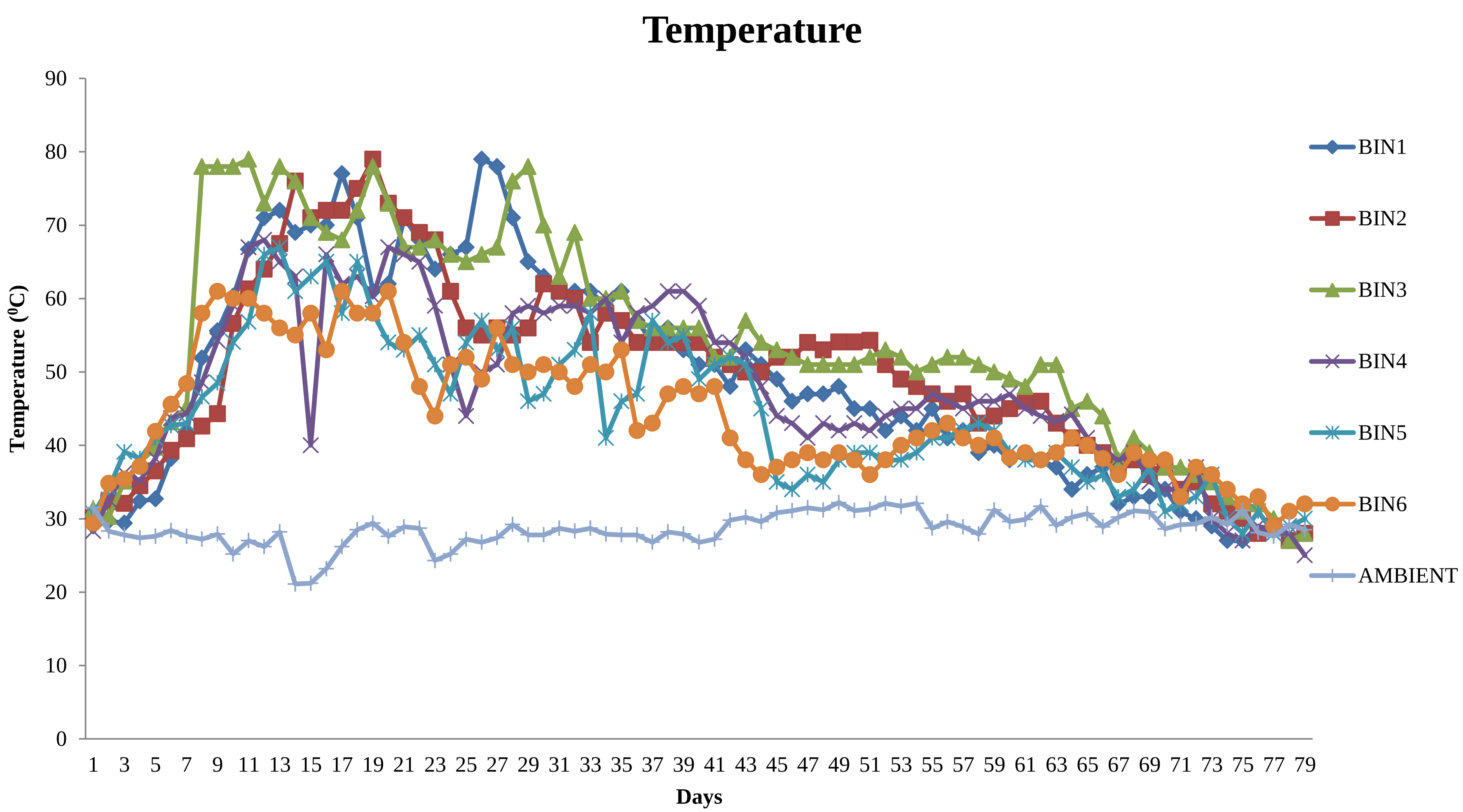


Figure 4.1: Compost temperature during the composting period

4.1.2. Moisture (%)

Table 4.1 presents the moisture contents at the initial day, at the end of the thermophillic phase and at the end of the maturation phase. Initial moisture content was 71.86%, 72.7%, 68.20%, 67.34%, 68.4% and 61.23% in bin 1, 2 , 3, 4, 5 and 6 respectively. At the end of thermophilic phase the moisture contents were 51.30%, 54.1%, 56.3%, 57.1%, 52.9% and 49.8% and at the end of the maturation phase were 45.5%, 47.7%,44.3%,48.4%,39.2% and 41.1% in bins 1, 2, 3, 4,5 and 6 respectively. In this experiment, moisture contents maintained around 50%-60%. Gajalakshmi and Abbasi, 2008 reported that moisture contents of between 45-60% by weight are ideal for composting processes.

4.1.3. Bulk density

Bulk density is defined as the dry weight of sample per unit volume of sample. Bulk density is an indicator of soil compaction and soil health. It affects infiltration, rooting depth/restrictions, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity, which influence key soil processes and productivity. The bulk density of end composting product was 0.365 , 0.462 , 0.464 , 0.455 , 0.575 and 0.519 for bins 1, 2, 3, 4, 5 and 6 respectively. The highest bulk density were recorded in bin 5 followed by bins 1, 2, 3, 4 and 6. This might be due to the use of different composting materials and different mixing ratios.

4.2. Chemical Properties during the Composting Process

4.2.1. pH

Changes in pH for all the bins during the composting process are shown in Figure 4.2. In the experiment, the change in pH for all the bins followed a similar pattern. The initial pH content were 8.45, 8.04, 7.65, 8.29, 7.95, 8.63 in bins 1, 2, 3, 4, 5 and 6 respectively. At the end of thermophilic phase pH value were 8.81, 9.04, 8.92, 8.52, 8.25, and 8.12 and at the end of maturation phase were 8.91, 9.09, 8.97, 7.95, 7.96, and 8.02 in bins 1, 2, 3, 4, 5 and 6 respectively. The variation of the initial pH values observed in all bins were due to the use of different materials and ratios (kitchen waste, tea waste, rice husk, saw dust and poultry litter). Rynk *et al.* (1992) suggested that a pH ranging between 6.0 and 7.5 is preferred by bacterial decomposers while a pH ranging from 5.5 to 8.0 is a good working environment for fungal decomposers. Similar results were also observed by other research groups (Albasha *et al*. 2015; Islam *et al*. 2009, Tanksali *et al*. 2014). Since aerobic conditions can be provided to the composting mixture by mechanical turning or forced aeration, an increased pH indicates degradation of organic acids or oxidation of phenolic compounds (Gigliotti *et al*. 2012). The composting process releases ammonium or volatile ammonia during the mineralization of proteins, amino acids and peptides are also contribute to an increase in pH. The optimum pH levels for compost microorganisms range from 5.5 - 8.5 (Islam *et al*. 2009). The variation of pH values among the bin might be happened for different composting materials and different mixing ratio. By the end of the composting process, the pH fell to nearly neutral values (-7.0), which is an indication of stabilized organic matter (Martin 1992). The pH values of this research work (matured composts) range from 8.02 to 8.54 ensure compatibility with most cultivated crops. All the values of pH were differed at 5% level of significance (Appendix 1).

Table 4.1: Physicochemical parameters of compost during the composting process

BIN	MC(%)	pH	EC(ppm)	TS(%)	VS(%)	OM(%)	TOC(%)	TKN(%)	C/N	P(%)	K(%)	GI(%)	
												50	100
Initial													
1	71.86	8.45	2600	28.14	48.02	67.42	39.1	1.67	23.41	1.069	0.461	68.10	61.05
2	72.07	8.04	2663	27.93	39.08	65.62	38.05	1.64	23.2	0.938	0.431	65.80	60.50
3	68.20	7.65	2643	31.38	55.07	67.12	38.92	1.69	23.02	0.912	0.490	67.64	62.10
4	67.34	7.45	2685	32.66	45.03	63.42	36.78	1.65	22.29	0.753	0.473	69.28	56.36
5	68.4	7.95	2675	31.6	51.08	62.08	36.006	1.62	22.23	0.981	0.385	62.10	57.72
6	61.23	8.63	2770	38.77	55.05	67.39	39.08	1.70	22.98	1.1	0.498	71.62	65.42
End of the thermophilic phase													
1	51.30	8.81	2771	48.7	37.98	55.109	31.96	1.53	20.88	1.044	0.451	86.30	79.25
2	54.1	9.04	2786	45.9	29.02	49.1	28.42	1.50	18.98	0.921	0.422	88.39	89.20
3	56.3	8.92	2686	43.7	40.93	54.82	31.49	1.57	20.24	0.901	0.478	95.60	54.50
4	57.1	8.52	2745	42.9	36.97	47.13	27.33	1.54	17.74	0.738	0.477	98.40	71.45
5	52.9	8.25	2730	47.1	40.92	45.48	26.3	1.49	17.67	0.969	0.372	89.60	74.30
6	49.8	8.12	2752	50.2	45.02	57.61	33.41	1.56	21.14	1	0.453	105.65	92.5
End of maturation phase													
1	45.5	8.91	2776	54.5	29.01	44.426	25.76	1.38	18.66	1.036	0.442	134.20	119.18
2	47.7	9.09	2788	52.3	25.04	42.08	24.4	1.41	17.3	0.914	0.415	137.77	130.59
3	44.3	8.97	2713	55.7	33.03	41.09	23.83	1.41	16.9	0.872	0.471	127.40	121.33
4	48.4	8.29	2754	51.6	30.92	43.11	25.003	1.48	16.83	0.729	0.457	127.72	110.89
5	39.2	7.96	2746	60.8	37.01	37.92	21.99	1.43	15.37	0.947	0.364	126.02	129.11
6	41.1	8.02	2782	58.9	38.10	41.7	24.186	1.43	16.91	0.987	0.482	127.53	134.89

MC: Moisture Content, EC=Electrical conductivity, VS= volatile solid, TS= Total solid, TOC=Total organic carbon, TKN=Total Kjeldahl nitrogen, C/N=Carbon Nitrogen ratio, P= Phosphorous, K= Potassium, GI= Germination Index

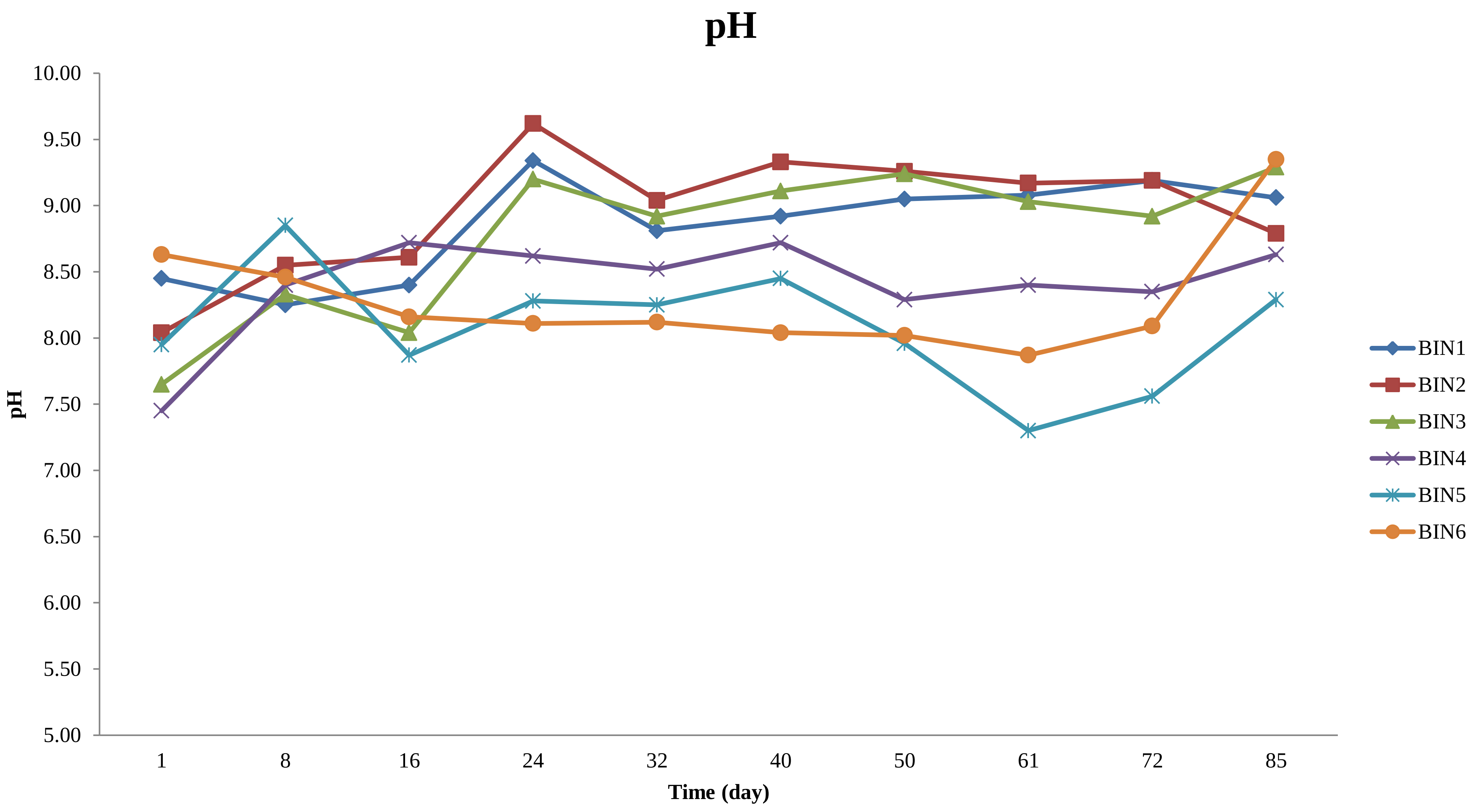


Figure 4.2: Compost pH evolution during the composting period

4.2.2. Electrical Conductivity

Time series chart of EC for the experiment is presented in Figure 4.3. In this experiment, the alteration of EC in all the bins almost followed a similar pattern. EC values of the various phases are also presented in Table 4.1. The initial EC content was 2600 µS/cm, 2663 µS/cm, 2643 µS/cm, 2685 µS/cm, 2675 µS/cm and 2770 µS/cm in bins 1, 2, 3, 4, 5 and 6 respectively. At the end of thermophilic phase EC value were 2771 µS/cm, 2663 µS/cm, 2686 µS/cm, 2745 µS/cm, 2730 µS/cm and 2752 µS/cm and at the end of maturation phase were 2776 µS/cm, 2788 µS/cm, 2713 µS/cm, 2754 µS/cm, 2746 µS/cm and 2782 µS/cm in bins 1, 2, 3, 4, 5 and 6 respectively.

Normally, the highest EC alues are recorded at the end of the process, due to evaporation and condensation as total compost mass decreases (Gigliotti *et al*. 2012). The difference of initial EC values between the bins could be attributed to the different material's ratio and different initial moisture content. All values of EC for all bins were differed at 5% level of significance (Appendix II).

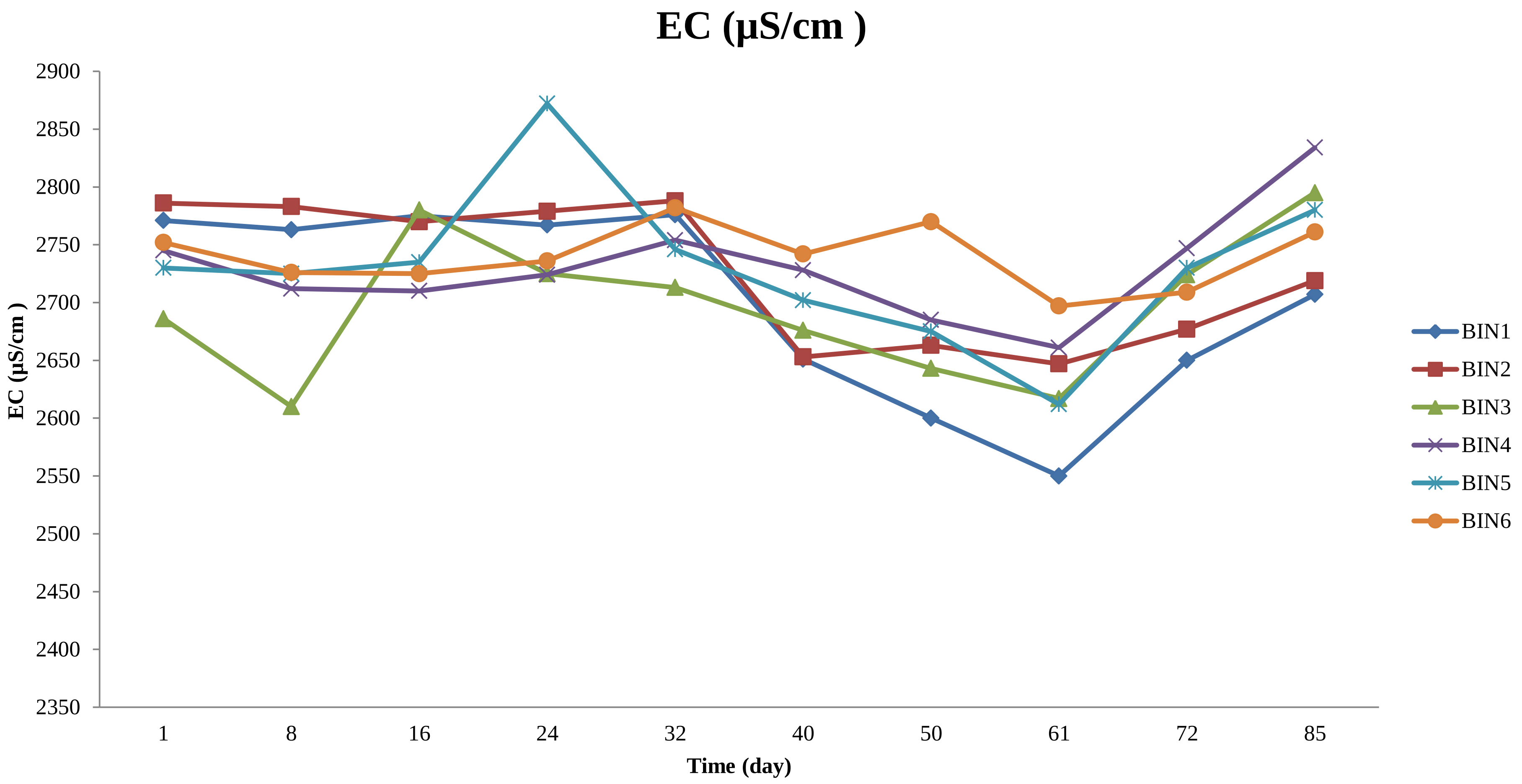


Figure 4.3: Electrical conductivity of composts during composting period

4.2.3. Volatile Solids

Volatile Solids-(VS%) concentrations in all the bins throughout the composting process is presented in figure 4.4. The initial VS content was 48.02%, 39.08%, 55.07%, 45.03%, 51.08% and 55.05% in bins 1, 2, 3, 4, 5 and 6 respectively. At the end of thermophilic phase VS value were 37.98%, 29.02%, 40.93%, 36.97%, 40.92% and 45.02% and at the end of maturation phase were 29.01%, 25.04%, 33.03%, 30.92%, 37.01%, and 38.10% in bins 1, 2, 3, 4, 5 and 6 respectively. The values of volatile solids in this experiment for all bins were decreased, this was happened due to the heterogeneous compost materials and their different mixing ratios were responsible for the differences in initial volatile solids concentrations values to end of thermophillic phase and maturation phase between the bins. The values of VS were varied at 5% level of significance (Appendix III).

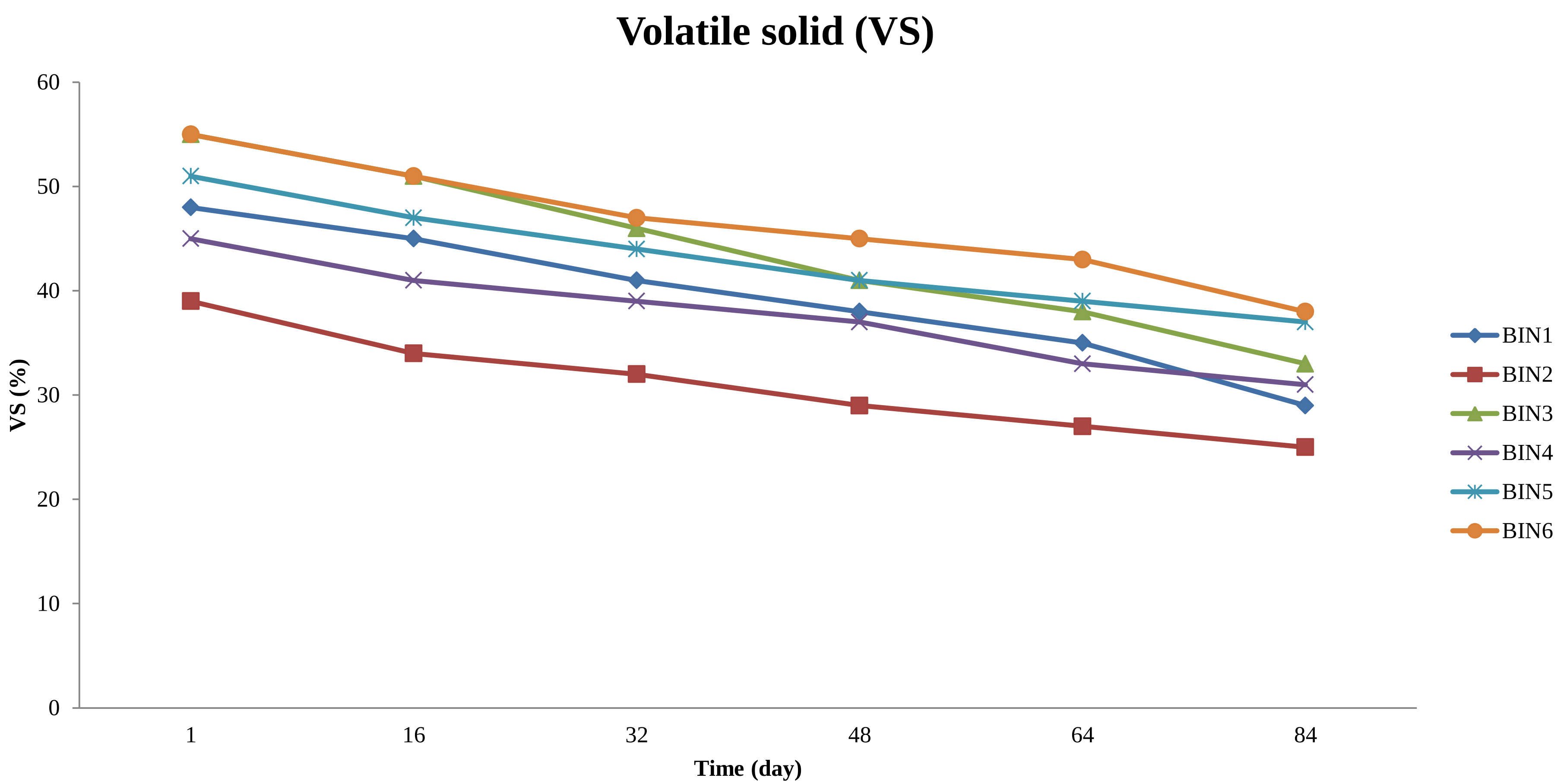


Figure 4.4: Time series chart of volatile solids during composting period

4.2.4. Total Solids

The values of total solid (TS%) for the experiment are presented in figure 4.4 . The initial TS content ware 28.14%, 27.93%, 31.8%, 32.66%, 31.6% and 28.45% in bins 1, 2, 3, 4, 5 and 6 respectively. At the end of thermophilic phase were 48.7%, 45.7%, 48.6%. 45.31%, 47.7% and 46.1% and at the end of maturation phase were 54.53%, 52.3%, 55.7%, 51.61%, 60.8%, and 58.9% in bins 1, 2, 3, 4, 5 and 6 respectively. It can be concluded that TS values were affected by the different ratios of composting materials in each bin and it also depended on moisture content. If moisture content was high then amount of total solid was low or vice-versa. The values of TS were differed at 5% level of significance (Appendix IV).

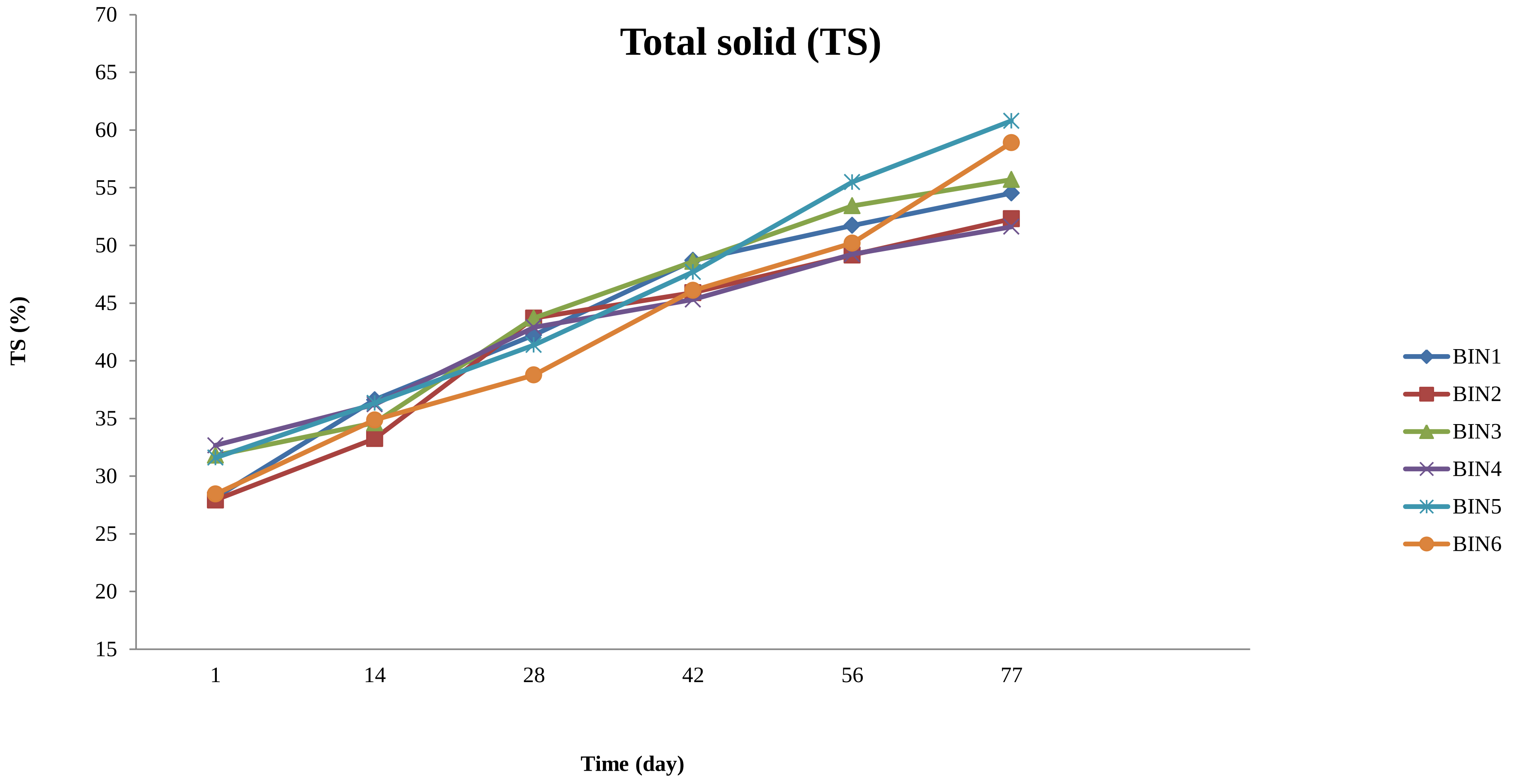


Figure 4.5: Time series chart of Total solids during composting period

4.2.5. Organic Matter

Table 4.1 presents OM content at the three composting stages. The initial OM content ware 67.52%, 65.62%, 67.12%, 63.42%, 62.05% and 67.39% in bins 1, 2, 3, 4, 5 and 6 respectively. At the end of thermophilic phase were 55.10%, 49.1%, 54.82%. 47.13%, 45.48% and 57.61% and at the end of maturation phase were 44.426%, 42.08%, 41.09%, 43.11%, 37.92%, and 41.7% in bins 1, 2, 3, 4, 5 and 6 respectively. The final composts of all bins had OM contents were ranging from 37.44% to 44.43%. Haydar and Masood, (2011) observed OM content at final compost 20.46% and 16.70%. The variations of organic matter values between the bins were due to the different OM contents of the initial materials used for the trial. The change in OM content was prominent in the thermophillic phase than the maturation phase, but Gigliotti *et al*. (2012) recorded greater OM change in the maturation phase than the thermophillic phase. However, OM is not only affected by concentration but also by composition. According to Haug (1993), easily degradable organic compounds, such as simple carbohydrates, fats and amino acids, are degraded quickly at the beginning of the process, while more resistant organic substrates such as cellulose, hemicellulose and lignin, are partially degraded and transformed slowly. Therefore, the organic matter content of compost depends on the nature of the materials used in the compost as well as the microbial activities occurring within it. All values of organic matter content for all bins were differed at 5% level of significance. (Appendix V).

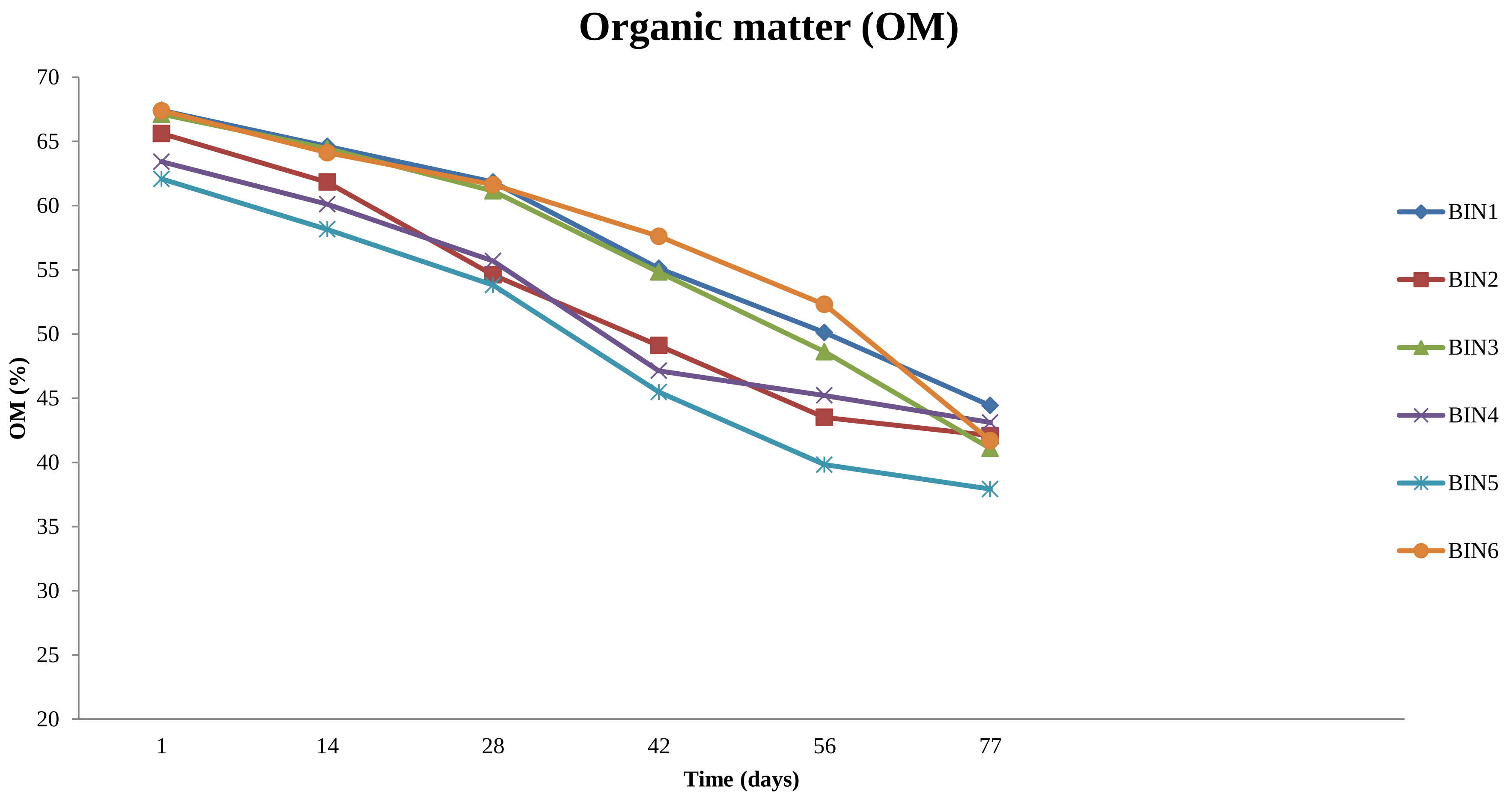


Figure 4.6: Organic matter contents during composting period

4.2.6. Total Organic Carbon

As composting progress, total organic carbon (TOC%) decreased in all the bins

In this experiment shown in Figure 4.7. The initial TOC content ware 39.1%, 38.05%, 38.92%, 36.78%, 36.006% and 39.08% in bins 1, 2, 3, 4, 5 and 6 respectively. At the end of the thermophillic phase were 31.96%, 28.42%, 31.49%, 27.33%, 26.3% and 33.41% and at the end of maturation phase were 25.76%, 24.4%, 23.83%, 25.003% 21.99% and 24.186% in bins 1, 2, 3, 4, 5 and 6 respectively. TOC contents of all mature composts ranged from 23.47 to 26.48%. Initial compost TOC contents varied due to the various materials and their different mixing ratios. Co-composting materials played an important role in decreasing TOC content during the thermophillic phase. All values of TOC contents were varied at 5% level of significance (Appendix VI).

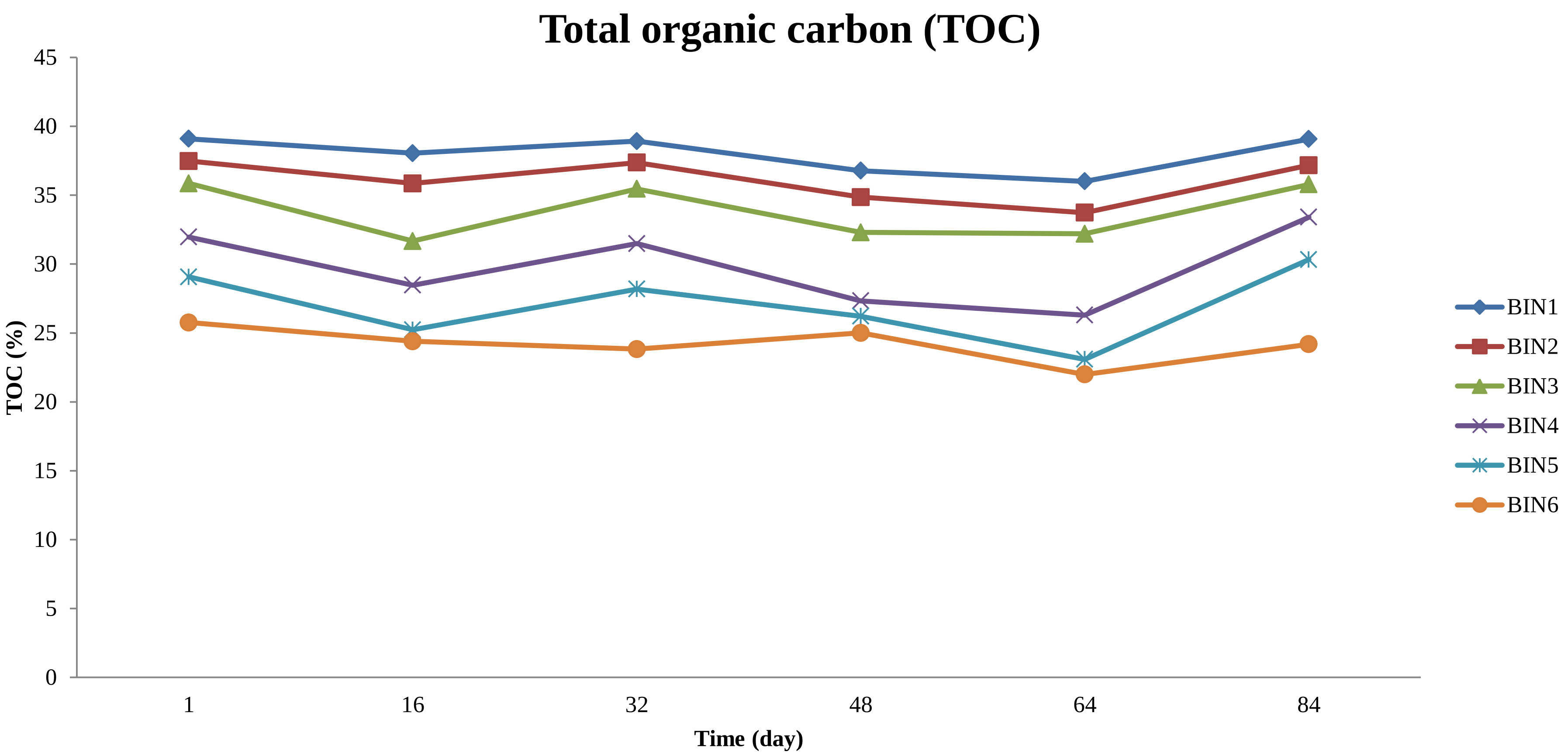


Figure 4.7: Total organic carbon during composting period

4.2.7. Total Kjeldahl Nitrogen

The Total Kjeldahl Nitrogen (TKN%) values increased during the composting process present in Figure 4.8. Total Kjeldahl Nitrogen values were increased in all bins after thermophillic and maturation phases. The initial values of TKN in bins 1,2,3,4,5 and 6 were 1.67%, 1.64%, 1.69%, 1.65%, 1.62% and 1.70%, respectively. The values of TKN in all bins were 1.53%, 1.50%, 1.57%, 1.54%, 1.49%, 1.56%, respectively at the thermophillic phase and 1.38%, 1.41%, 1.41%, 1.48%, 1.43% and 1.43%, respectively after maturation. The highest amounts (1.48%) of TKN were recorded in bin 4, whereas the lowest amount (1.38%) of TKN was found in bins 1 at matured compost. All values of TKN for all bins were differed at 5% level of significance. (Appendix VII).

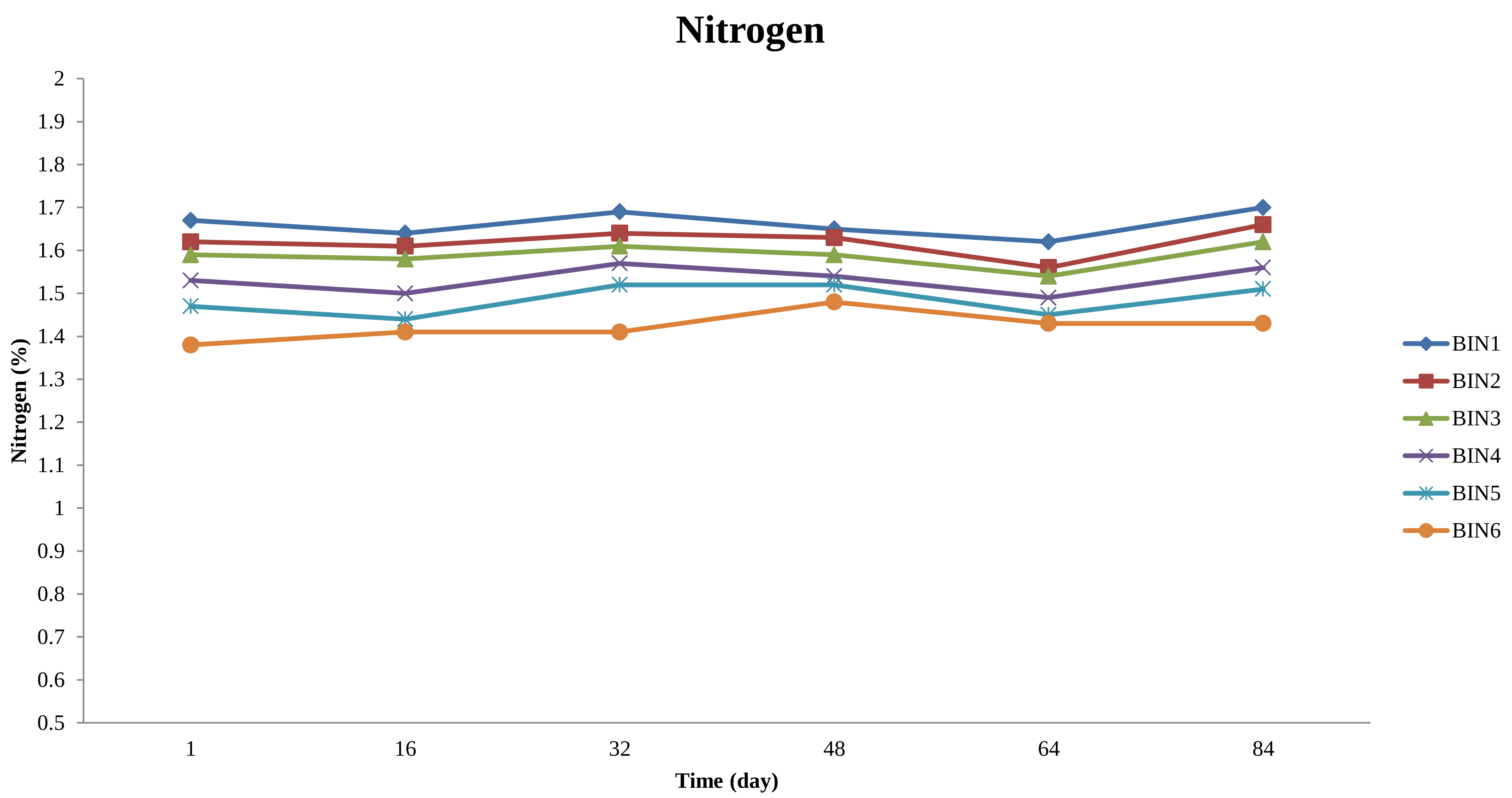


Figure 4.8: Total nitrogen content during composting period

4.2.8. Carbon-Nitrogen Ratio (C/N)

Table 4.1 present the C/N ratios recorded at the initial day, end of thermophillic phase and maturation phase. The initial C/N ratio content ware 23.41, 23.2, 23.02, 22.29, 22.23 and 22.98 in bins 1, 2, 3, 4, 5 and 6 respectively. At the end of thermophilic phase were 20.88, 18.98, 20.24, 17.74, 17.68 and 21.24 and at the end of maturation phase were 18.66, 17.3, 16.9, 16.83, 15.37 and 16.91 in bins 1, 2, 3, 4, 5 and 6 respectively. The reduction rate of the C/N ratios were greater in all bins of this experiment (kitchen waste, tea waste, saw dust, rice husk, egg shell and poultry litter), it is possible due to the different co-composting materials and the optimum moisture content (around 50%) enhanced microbial activities by creating favorable conditions for mineralization. During composting, carbonaceous materials such as carbohydrates, fats and amino acids, as well as cellulose, hemicelluloses, and lignin are partially mineralized, leading to carbon losses throughout the process (Bernal *et al.*, 2009). Additionally nitrogen increases due to the concentration effect of dry mass reduction upon biodegradation. All values of C/N ratios for all bins were varied at 5% level of significance (Appendix VIII).

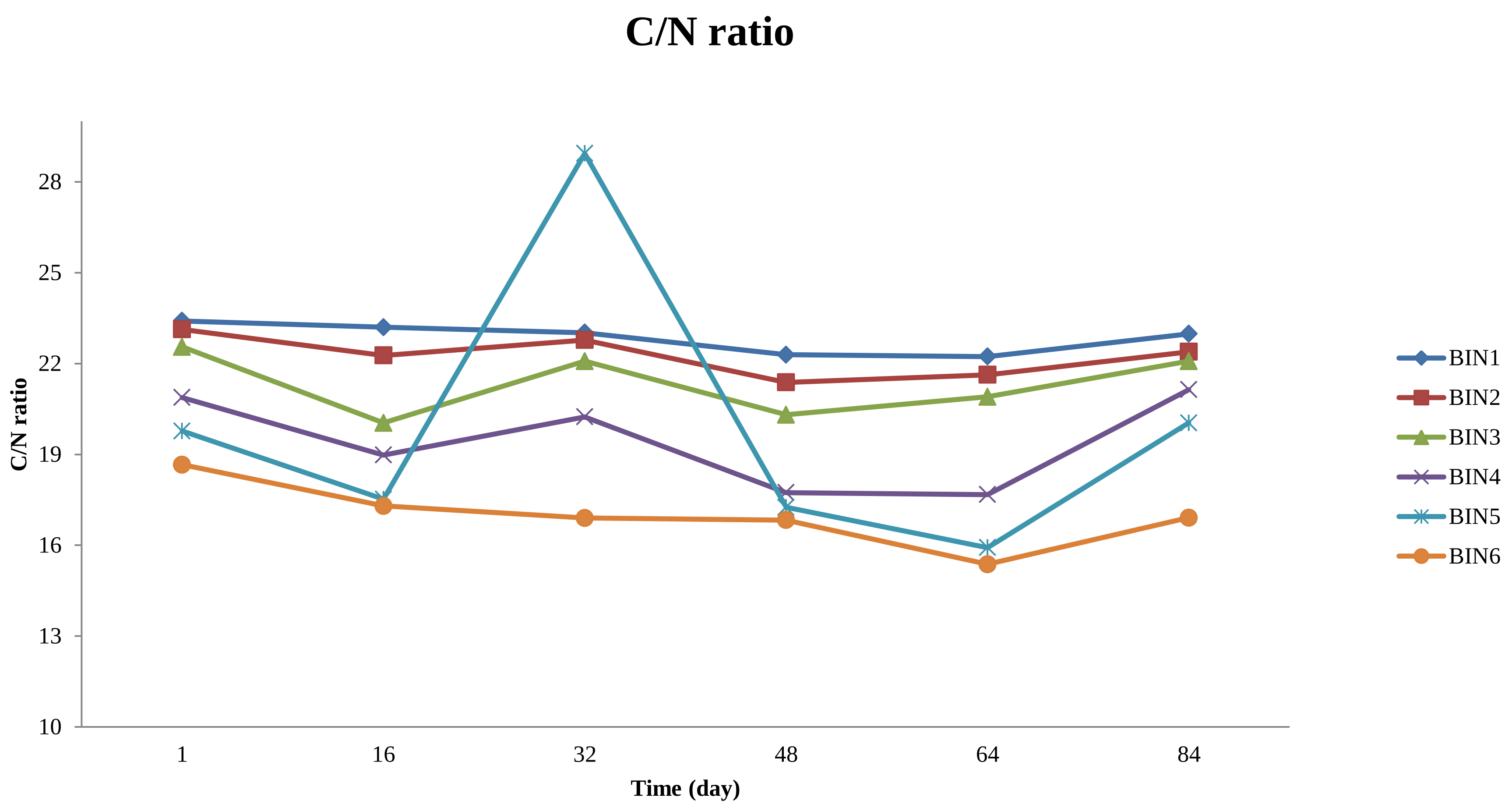


Figure 4.9: Carbon/nitrogen ratio during composting period

4.2.9. Mineral nutrients (Phosphorus and Potassium-K %)

Mineral nutrients are considered crucial when assessing compost quality. Together with OM and C/N ratios, mineral nutrients are important for plant growth and development. Table 4.1 and Figures 4.10 and 4.11 present the mineral nutrients recorded during the composting period. This experiment's initial P and K ranges were 0.753-1.1% and 0.385-0.498%, respectively and these reached to 0.729-1.036 and 0.415-0.482%, respectively in the final composting. Co-composting materials did not cause great variations in mineral nutrient contents. All values of P and K were differed at 5% level of significance (Appendices IX and X).

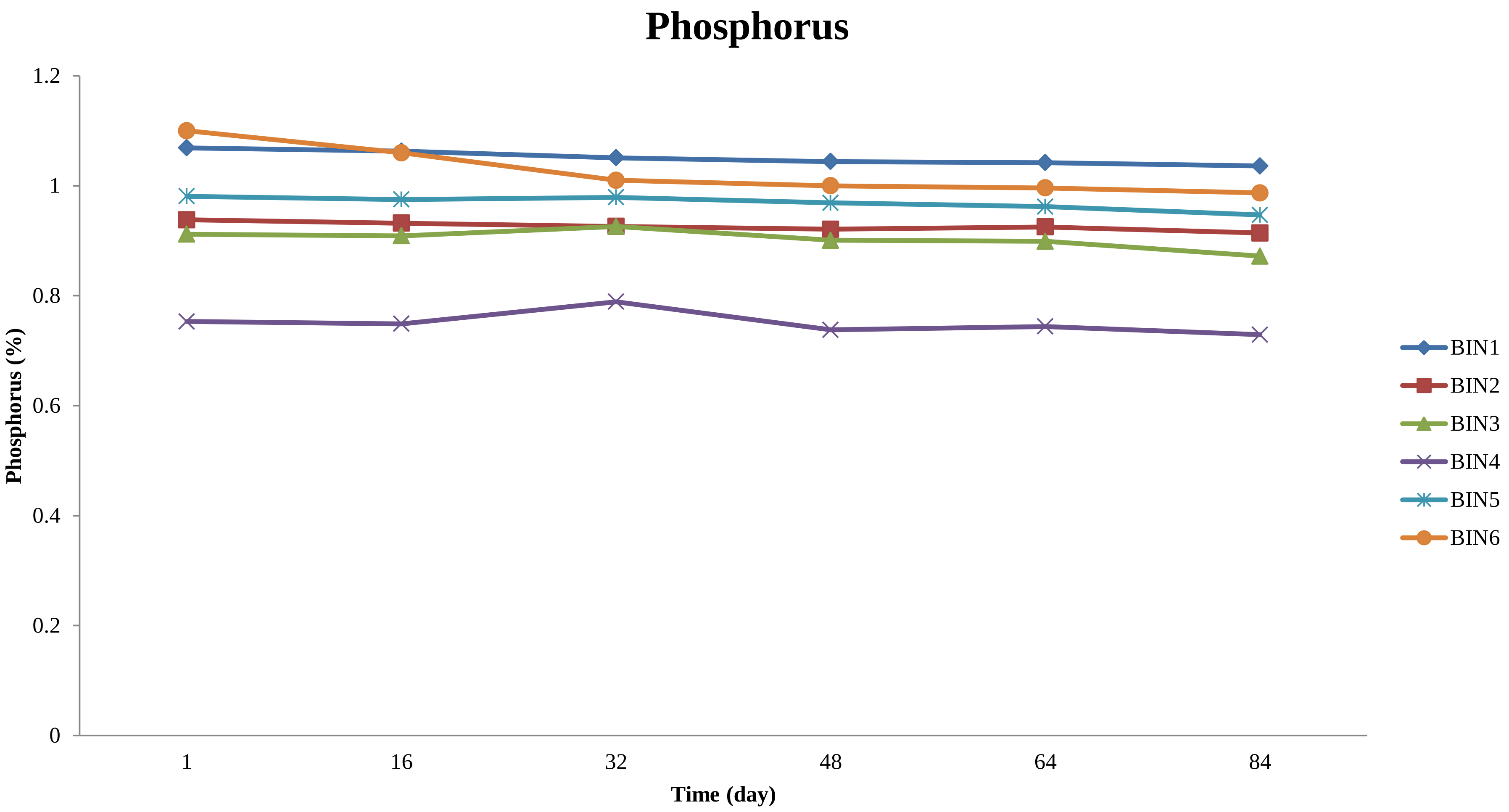


Figure 4.10: Total phosphorus content during composting period

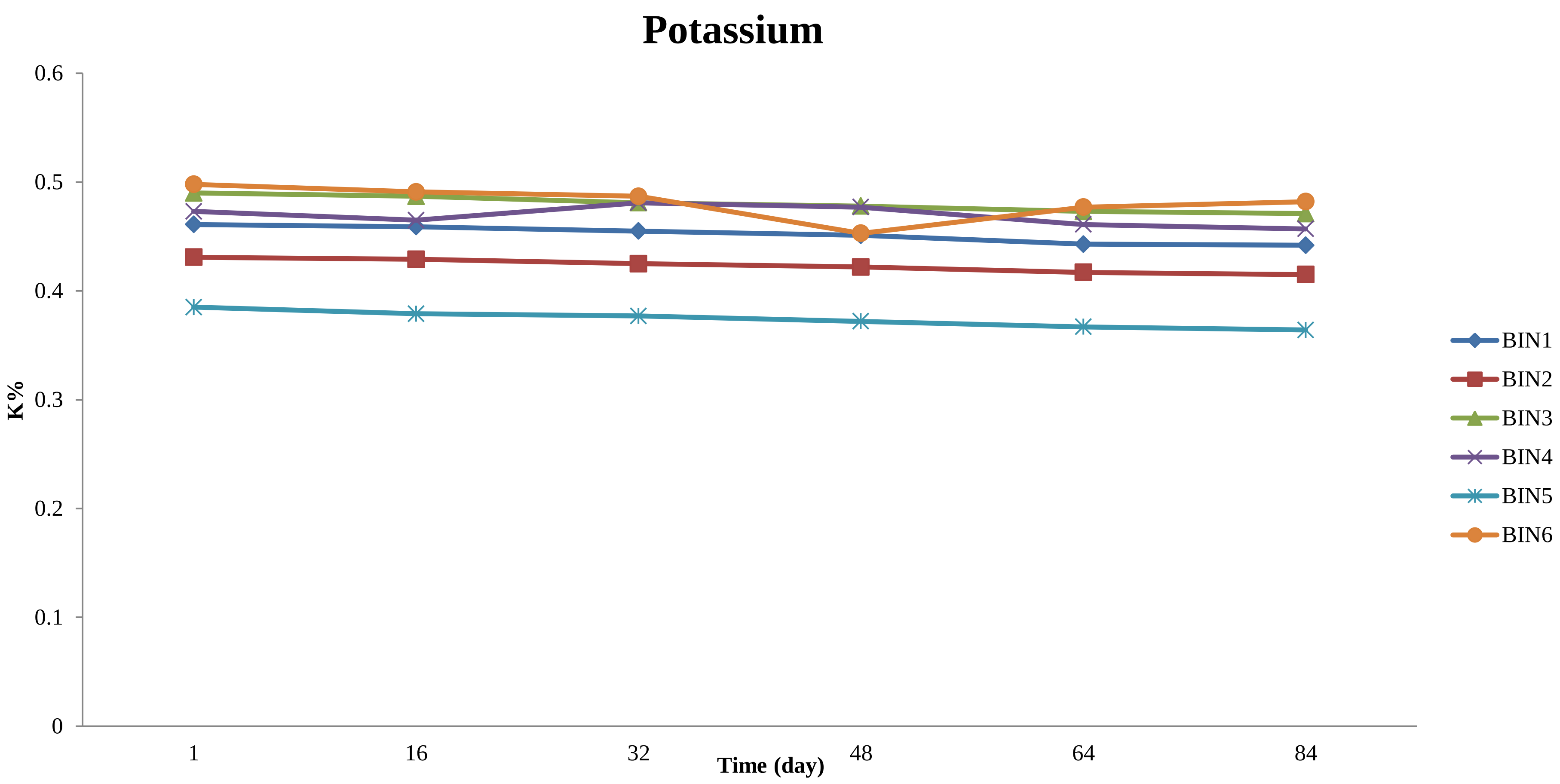
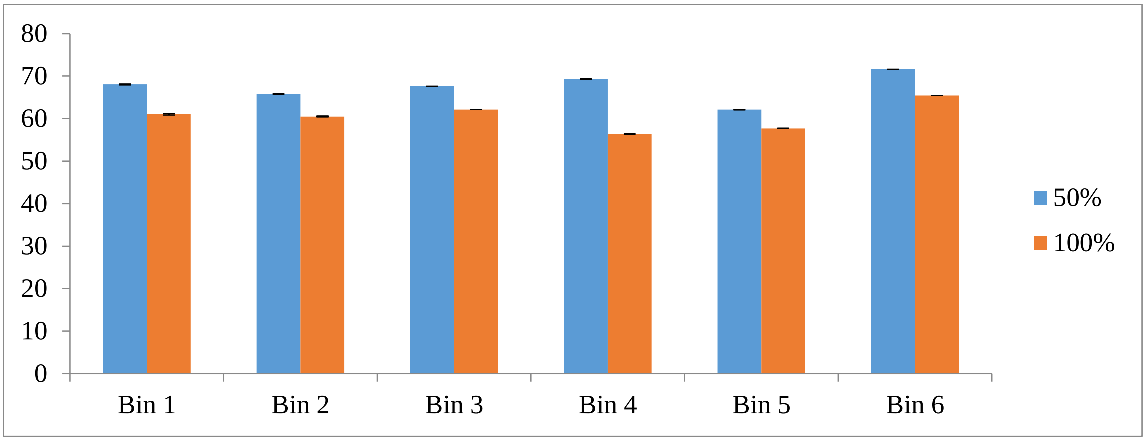


Figure 4.11: Total potassium content during composting period

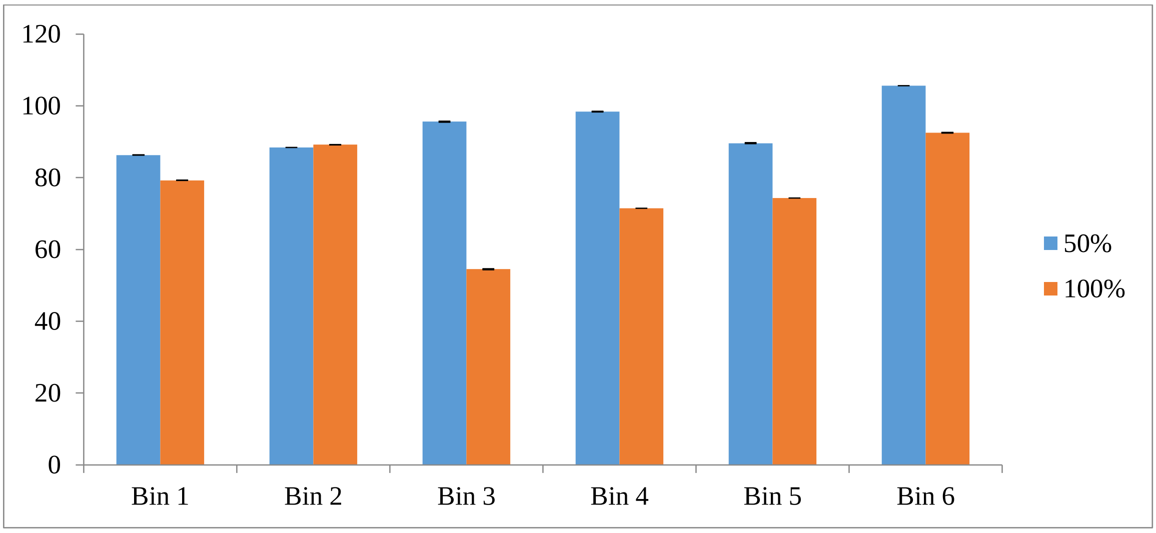
4.3. Phytotoxicity during Composting Process

4.3.1. Germination Index (GI, %)

The Germination Index is one of the parameters used to assess toxicity and the degree of compost maturity. Results of the seed bioassays used to evaluate changes in compost phytotoxicity during the composting process are given in Figure 4.12 and Table 4.1. The results showed that after the thermophillic phase the composts were not phytotoxic. The initial GI (at 100% concentration) values were 61.05%, 60.5%, 62.1%, 56.36%, 57.72% and 65.42% for bins 1, 2, 3, 4, 5 and 6 respectively and at 50% concentration GI values were 68.1%, 65.8% 67.64%, 69.28%, 62.10% and 71.62%. During composting the phytotoxicity effect was eliminated and the final GI values were 119.18%, 130.59%, 121.33%, 110.89%, 121.92%, 129.11% and 134.89 % at 100% concentration and 134.2%, 137.77%, 127.40%, 127.72%, 126.02% and 127.53% at 50% concentration, respectively for all bins after maturity. Bin 2 showed highest (137.77%) value at 50% concentration and (134.89%) at 100% concentration. This was due to the different materials and their mixing ratios. No negative impact of co-composting materials was observed on the phytotoxicity of the mature composts.



a



b

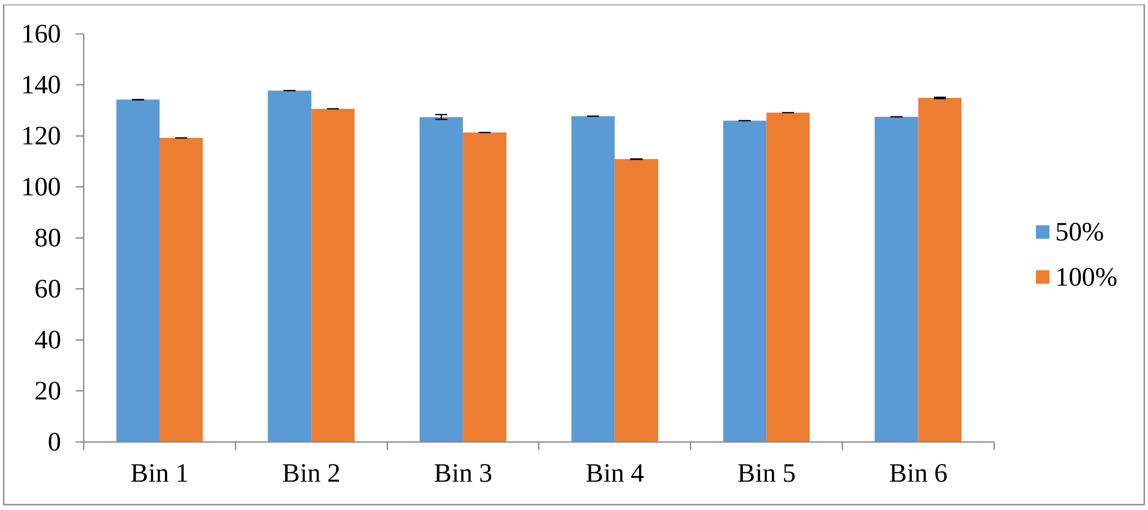


Figure 4.12: Germination index of the compost s in this experiment (a. at initial day, b. end of thermophillic phase, c. end of maturation phase.)

4.4. Full-Scale Scenario for Agro-industrial and Municipal Solid Waste Composting

In this study agro-industrial and municipal solid waste were successfully composted. Based on this experiment result, a full scale composting unit could be made using following information. Every 30 days 7000-7500 L (by volume) kitchen wastes are produced in an urban area from 500-600 families. An area of 10-12 m^2 for 6 bins (of each total 1.65 m^3 volume) is required to compost year round kitchen waste generation.

CHAPTER-5

SUMMARY AND CONCLUSION

An experiment was conducted to evaluate the agro-industrial and municipal waste using various materials such as: poultry litter (PL), rice husk (RH), saw dust (SD), Kitchen waste (KW), eggshell (ES) and tea waste (TW). The kitchen waste (KW) was collected from nearby urban area (Dinajpur); rice husk was obtained from the local rice husking mill and saw dust was obtained from a local wood processing industry. Tea waste was collected from the local tea stalls. Poultry litter was collected from local poultry farm. Six square-shaped composting bins were made with 0.83 m height, 0.95m length and 0.93 m width and a total volume of 0.733 m^3. Bin 1 was filled with kitchen waste, saw dust, tea waste and eggshell, bin 2 with kitchen waste, rice husk, tea waste and eggshell, bin 3 with kitchen waste, saw dust, and eggshell, bin 4 with kitchen waste, saw dust, and tea waste, bin 5 kitchen waste, rice husk, and tea waste and bin 6 with kitchen waste , rice husk, saw dust, tea waste, eggshell and poultry using different ratios (60:20:10:10, 70:10:10:10, 50:40:10, 60:30:10, 50:25:25, and 50:10:10:10:10:10), respectively. The proportions of raw materials were chosen according to their C/N ratio and moisture content. The experiment was carried out at the research field area of the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur from July to October, 2018.

To observe the composting process and evaluate compost quality, some physicochemical parameters such as temperature, moisture content, pH, electrical conductivity, organic matter, volatile solids, total solid, total organic carbon, totalnitrogen, total phosphorus, potassium were measured at different phases of composting. Mechanical turning (hand turner) was used for aeration (helps in microbial activity) and mixing materials which took place daily for the first three once every four days during the thermophillic phase, and once a week during days, the maturation phase. In bins 1,4,5 thermophillic temperature was recorded after 8 days, in bin 2 after 9 days, and in bin 6 the thermophillic temperature was recorded after 6 days respectively. The thermophillic phase was remained 51 days for bins 1, 3,4 and 5 respectively, for bin 2 it was 38 and for bin 6 it was 44 days. This might be occurred for different mixing ratios and different initial moisture content among the materials. The duration of composting period was 80 to 85 days initial moisture content of bins 1, 2, 3, 4, 5 and 6 was 71.86%, 72.07%, 68.20%, 67.34%, 68.4% and 61.3%, respectively and final moisture content was 45.5%, 47.7%, 44.3%, 48.4%, 39.2% and 41.1%,respectively. The pH values of all bins were near to neutral or above neutral (8.02-8.54). The final EC was ranged from 2550ppm-2872ppm. The matured compost's organic matter (OM) content of bins 1,2,3,4,5 and 6 were 44.42%,42.08%, 41.09%, 43.11%, 37.92 and 41.7% respectively. Total organic carbon (TOC) of bins 1, 2, 3, 4, 5 and 6 were 25.76%, 24.4%, 23.83%,25.003%, 21.99% and 24.186%, respectively at final composts. The highest OM was observed in bin 1 (44.42%) than bins 2, 3, 4, 5, and 6 and the highest TOC was also observed in bin 1 (25.76%) than bins 2,3,4,5 and 6 . Total kjeldahl nitrogen (TKN) were 1.38% 1.41%, 1.41%, 1.48%, 1.43% and 1.43% respectively for all bins after maturation. The highest TKN content was observed in bin 4 (1.48%) than others bin. After maturation the C/N ratio of bins 1, 2, 3, 4, 5 and 6 were 18.66, 17.3, 16.9, 16.83, 15.37 and 16.91 respectively. On the other hand better C/N ratio (15.37) was recorded in bin 5 than other bins. Since around 20 C/N ratio is good for soil application. The amount of phosphorus content was maximum in bin 1 (1.036%) and lowest in bin 4 (0.729%). The amount of potassium content was more or less similar in all bins. Total phosphorus (P) and potassium (K) contents for bins 1, 2, 3, 4, 5 and 6 were 1.036%, 0.914%, 0.872%, 0.729%, 0.947%, 0.987% and 0.442%, 0.415%, 0.471%, 0.457%, 0.364%, 0.482%, respectively. Germination indices (GI) at 100% concentration of compost were 119.18%, 130.59%, 121.33%, 110.89%, 121.92%, 129.11% and 134.89% and at 50% concentration of compost were 134.2%, 137.77%, 127.40%, 127.72%,126.02% and 127.53% for bins 1, 2, 3, 4, 5 and 6, respectively.

Conclusion:

It could be concluded that agro-industrial and municipal waste could be managed by the aerobic decomposition. The best mixing ratio of composting materials was 50:10:10:10:10:10 (Kitchen waste, Poultry Litter, Rice husk, Saw dust, Tea waste and Eggshell). Final composts from agro-industrial and municipal waste contains good amount of organic matter and nutrient (nitrogen, phosphorus, potassium etc.) content rendering it a high quality soil amender. Germination index (GI) of compost showed that the final product was free from toxicity.

A full-scale compost unit could be designed based on the experimental results. Therefore, an urban area consisting of 500-600 families requires about 10-12 m^2 area to compost the entire annual kitchen wastes production.

Recommendations for Future Research:

Although quality composts were produced from the kitchen wastes with different co-composting materials in this research. Some points should be investigated thoroughly before using these composts for sustainable agricultural practices.

Therefore, future research effort could be focused on the following topcis.

1. Emission of greenhouse gases during the composting process.
2. Short-term and long-term effects of composts on crop production and soil properties.
3. The use of these composts in soilless cultivations such as for mushrooms and flowers etc.
4. For composting kitchen waste co-composting materials such as rice ash, rice strw, biochar, residue of different crops etc, could be tested.

REFERENCES

Agnew J. M. and J. J. Leonard. 2003. The physical properties of compost. Compost sci. util. 1: 238-264.

Ahmad R., M. Khalid, M. Naveed, S. M. Shahzad, Z. A. Zahir and S. N. Khokhar. 2008. Comparative efficiency of auxin and its precursor applied through compost for improving growth and yield of maize. Pak. J. Bot. 40: 1703-1710.

Alabadan, B. A., P. A. Adeoye and E. A. Folorunso. 2009. Effect of different poultry wastes on physical, chemical and biological properties of soil.

Albasha M. O., P. Gupta and P. W. Ramteke. 2015. Management of Kitchen Waste by Vermicomposting Using Earthworm, *Eudrilus Eugeniae*. International Conference on Advances in Agricultural, Biological & Environmental Sciences (AABES-2015) July 22-23, London (UK).

Alfano G., C. Belli, G. Lustrato and G. Ranalli. 2008. Pile composting of two-phase centrifuged olive husk residues: technical solutions and quality of cured compost. Bioresource Technol. 99: 4694-4701.

Banegas V., J. L. Moreno, J. I. Moreno, C. Garcia, G. Leon and T. Harnandez. 2007.Composting of anaerobic and aerobic sewage sludges using two proportions of sawdust. Waste Manage. 27: 1317-1327.

BARC. 1999. Land Degradation Situation in Bangladesh. Soil Division. Bangladesh Agril. Res. Coun., Farmgate, Dhaka.

Bari Q. H. and A. Koenig. 2002. Measuring solid waste compost maturity: a review and practice. Bangladesh Environ. 2: 7-12.

Beck-Friis B., S. Smars, H. Jonsson and H. Kirchmann. 2001. Emissions of carbon dioxide, ammonia and nitrous oxide from organic household waste in a compost reactor under different temperature regimes. J. Agril. Engg. Res 78(4): 423- 430.

Bernal M. P., J. A. Alburquerque and R. Moral. 2009. Composting of animal manures and chemical criteria for compost maturity assessment. A review Bioresource Technol. 100.

Bertoldi M. de and P.A. Vallini. 1983. The biology of composting: A review. Waste Manage. Res. 1: 157-176.

Bertoldi, M. de. F. Zucconi and M Civilini. 1988. Temperature, pathogen control and product quality. Bio. Cycle. 29(2): 43-50.

Bharadwaj K. K. R. 1995, Improvements in microbial compost technology: A special reference to microbiology of composting. In: Wealth from waste.

Bhattacharya A. N. and J. C. Taylor. 1975. Recycling of animal waste as a feedstuff: A review. J. Anim. Sci. 1438: 1457.

Bird N. A. 1982. Poultry manure handling systems. In: The Manure Management Handbook, Ont. Soil and Crop Imp. Ass., Ont. Min. of Agriculture and Food, Ont. Agricultural College, Canada. G1-G17 pp. 5444-5453.

Bishop P. L. and C. Godfrey. 1983. Nitrogen transformations during slud composting. Bio. Cycle. 24: 34-39.

Bollen G. J. D. Volker and A. P. Wijnen. 1989. Inactivation of soil-borne plant pathogens during small scale composting of crop residues. Neth. J. Plant Pathol. 95(suppl. 1): 19-30.

Bolt G. H., and M. G. M. Bruggenwert. 1988. Soil chemistry A. Basic elements, 4th ed. Elsevier, Amsterdam.

Bowman A., K. Mueller and M. Smith. 2000. Increased animal waste production from concentrated animal feeding operations: potential implications for public and environmental health. Occasional Paper Series, No. 2. Omaha, USA Nebraska Centre for Rural Health Research.

Burge W.D. 1983. Monitoring pathogen destruction. Bio. Cycle. 24(2): 48-50.

Cambardella C. A., T. L. Richard and A. Russell. 2003. Compost mineralization in soil as a function of composting process conditions. Eur. J. Soil. Biol. 39:117-127.

Castaldi P., G. Alberti, R. Merella., and P. Melis. 2005. Study of the organic matter evolution during municipal waste solid composting aimed at identifying suitable parameters for the evaluation of compost maturity. Waste Manage 25: 209-213.

Chowdhury A. K. M. M. B., C. S. Akratos, D. V. Vayenas and S. Pavlov. 2013. Olive mill waste composting: a review. Int. Biodeterior. Biodegrad. 85: 108-10.

Chowdhury, A. K. M. and M. Bari. 2014. Composting of agro-industrial wastes. Laboratory Environmental Systems, Department of Environmental and Natural Resources Management. Ph.D. Thesis. School of Engineering, University of Patras, Greece.

Cooper R.C. and C. G. Golueke. 1977. Public health aspects of on-site waste treatment. Compost Sci. 18(3): 8-11.

Cooperband L. 2002. The Art and Science of Composting: A Resource for Farmers and Compost Producers, University of Wisconsin-Madison.

Dahal B. N. 1993. The Poultry waste and its fate on environment. J. Agr. Sci. 4: 35.

Das K. and H. M. Keener. 1997. Moisture effect on compaction and permeability in composts. J. Environ. Eng-asce. 123: 275-281.

De Bertoldi M., G. Vallini and A. Pera. 1983. The biology of composting: a review Waste Manage. Res. 1: 157-176.

Domingo J. L. and M. Nadal. 2009. Domestic Waste Composting Facilities: A review of health risks. Environ. Int. 35: 382-389.

Epstein E. 1997. The science of composting. Technomic Publishing, Lancaster, PA.

FAO. 2008. Poultry in the 21st century: avian influenza and beyond. The Proceedings of the International Poultry Conference, Bangkok, 5-7 Nov. 2007, edited by O. Thieme and D. Pilling FAO Animal Production and Health Proceedings No. 9. Rome.

Federici E., M. Pepi, A. Esposito, S. Scargetta, L. Fidati, S. Gasperini, G. Cenci and R. Altieri. 2011. Two-phase olive mill waste composting: Community dynamics and functional role of the resident microbiota. Bioresource Technol. 102: 10965-10972.

Fernandes L., W. Zhan, N.K. Patni and P.Y. Jui. 1994. Temperature distribution and variation in passively aerated static compost piles. Bioresource Technol. 48:257-26.

Finstein M. S. and M. L. Morris. 1975. Microbiology of municipal solid waste composting. Adv. Appl. Microbiol. 19: 113-151.

Finstein M. S., F. C. Miller, S. T. MacGregor and K. M. Psarianos.1985. The Rutgers strategy for composting: process design and control, Project Summary (EPA 600/S2-759 85/059). EPA, Washington.

Finstein M.S., F.C. Miller, J.A. Hogan and P.F. Strom 1987. Analysis of EPA guidance on composting sludge, Part I-Biological heat generation and temperature. Bio. Cycle. reprinted from January. February, March and Apri 1987.

Gajalakshmi S. and S. A. Abbasi. 2008. Solid waste management by composting state of the art. Critical Reviews. Environ. Sci. Technol. 38:311-400.

Gigliotti G., P. Proietti, D. Said-Pullicino, L. Nasini. D. Pezzolla,L. Rosati, P. R Porceddu. 2012. Co-composting of olive husks with high moisture contents Organic matter dynamics and compost quality. Int. Biodeter. Biodegr. 67: 8-14.

Golueke C. G. 1992. Bacteriology of composting. Bio.Cycle, 33: 55-57.

Guerra-Rodríguez E., M. Díaz-Ravina and M. Vázquez. 2001. Co-composting of chestnut burr and leaf litter with solid poultry manure. Bioresource Technol 78, 107-109.

Hall K.D., J. Guo, M. Dore and C.C. 2009 Chow. The Progressive increase of food waste in America and its environmental impact, Plos One 4.

Haug R. T. 1993. The Practical Handbook of Compost Engineering. Lewis Publishers, Florida.

Haydar S. and J. Masood. 2011. Evaluation of Kitchen Waste Composting and its Comparison with Compost Prepared from Municipal Solid Waste. Pak. Engg. Appl. Sci. 8: 26-33.

Huda N. K. 2002. Municipal Solid Waste Management–Dhaka City Perspective. Bangladesh Environment. 2: 732-746.

Islam M. R., M. Z. Abedin, M. Z. Rahman and A. Begum. 2009. Use of some selected wastes as sustainable agricultural inputs. Progress. Agric. 20(1 & 2): 201-206.

Kapetanois E.G., M. Loizidu and G. Vakanas. 1993. Compost production from Greek domestic refuse, Bioresource Technol. 43: 13-16.

Keener H. M., W. A. Dick and H. A. J. Hoitink. 2000. Composting and beneficial utilization of composted by-product materials, In: Land Application Agricultural, Industrial, and Municipal By-Products, W.A. Dick (Ed.). pp. 315-341. Soil Science Society of America Inc., Madison.

Khanna, S. and K. Mohan (Eds.), Tata Energy Research Institute, New Delhi. pp. 115-135.

Kirchmann H. and P. Widen. 1994. Separately collected organic household wastes chemical composition and composting eristics. Swed. J. Agr. Res. 24:3-12.

Kwon S. H. and D. H. Lee. 2003. Evaluation of Korean food waste composting with fed-batch operations II: Using properties of exhaust gas condensate. Process Bio. 39: 1047-1055.

Lopez-Real J. and M. Foster. 1985. Plant pathogens survival during composting of organic wastes. In: Gasser, J.K.R. (Ed.), Composting of agricultural and other wastes, Elsevier Applied Science, London. pp. 291-299.

Marin L, C. Ehaliotis, M. Kotsou, I. Chatzipavlidis and D. Georgakakis. 2005. Use of sulfur to control pH in composts derived from olive processing by-products Compost sci. util. 13: 281-287.

Martin O. and T. Dewes. 1992. Loss of nitrogenous compounds during composting of animal wastes. Bioresource Technol. 42: 103-11.

Miller F. C. 1992. Composting as a process based on the control of ecologically selective factors, In Soil Microbial Ecology. Applications in Agricultural and Environmental Managemen, F. B. J. Metting (Ed.), pp. 515-544. Marcel Dekker Inc., New York.

Nagy G., Á. Wopera and T. Koos. 2014. Physical and chemical analysis of canteen Wastes for syngas production. Mater. Sci. Eng. 39(2): 59-67.

Nakasaki K., H. Yaguchi, M. Sasaki and H. Kubota. 1993. Effects of pH control on composting of garbage. Waste Manage. Res. 11: 117-125.

Poincelot R.P. 1974. A scientific examination of the principles and practice of Composting Sci. 15: 24-31.

Raviv M;Y. Oka,J.Katan, Y. Hadar, A. Yogev, S. Medina, A. Krasnovsky and H.Ziadan.2005. High- nitrogen compost as a medium for organic container grown crops. Bioresource Technol.96: 419-427.

Regassa N., R. D. Sundaraa and B. B. Seboka. 2011. Challenges and Opportunities in Municipal Solid Waste Management: The Case of Addis Ababa City Central Ethiopia, J. Hum. Ecol. 33: 179-190.

Richard R., H. V. M. Hamelers, A. H. M. Veeken and T. Silva. 2002. Moisture relationships in composting processes. Compost Sci. Util. 10: 286-302.

Robinson J. B. and E. G. Beauchamp. 1982. The resource conservation ethic applied to manure management. In: The Manure Management Handbook, Ont. Soil and Crop Imp. Ass., Ont. Min. of Agriculture and Food, Ont. Agricultural College, Canada. B1-1 to B1-2 pp.

Ryckeboer J., J. Mergaert, J. Coosemans, K. Deprins and J. Swings. 2003a Microbiological aspects of biowaste during composting in a monitored compost bin. J. Appl. Microbiol. 94: 127-137.

Rynk, R., M. Van de Kamp, G. B. Willson, M. E. Singley, T. L. Richard, J. J. Kolega and H. A. Hoitink. 1992. On-Farm Composting Handbook (NRAES 54). Northeast Regional Agricultural Engineering Service (NRAES).

Sanchez-Monedero M. A., A. Roig, J. Cegarra, and M. P. Bernal. 1999. Relationships between water-soluble carbohydrate and phenol fractions and the humification indices of different organic wastes during composting Bioresource Technol. 70: 193-201.

Schapper J. and S. Chan. 2010. Food waste in Australia. Food Aust. 62: 307-310.

Sharma, V.K., M. Canditelli, F. Fortuna and G. Cornacchia. 1997. Processing of urban and agro-industrial residues by aerobic composting: Review. Energ. Convers. Manage.38:453-478.

Sinha, A. H. M. M. and I. Enayetullah. 2000. Study on Resource Recovery from Solid Waste in Khulna City, Dhaka: Water and Sanitation Program-South Asia, 2000

Tanksali A.S., S. S. Angadi and A. Arwikar. 2014. Treatment of kitchen waste by microbial culture. Int. J. Res. Eng. Tech. 3(6):37-44.

Tiquia S. M. and N. F. Y. Tam. 2000. Co-composting of spent pig liter and sludge with forced-aeration. Bioresource Technol. 72: 1-7.

Tortosa G., J. A. Alburquerque, G. Ait-Baddi and J. Cegarra. 2012. The production of commercial organic amendments and fertilisers by composting of two-phase olive mill waste ("alperujo"). J. Clean. Prod. 26:48-55.

Tuomela M., A. Vikman, M. Hatakka and M. Itavaara. 2000. Biodegradation of lignin in a compost environment: a review. Bioresource Technol. 72: 169-183.

U.S. Environmental Protection Agency. 1999, Biosolids generation, use and disposal in the United States, U.S. Environmental Protection Agency, Municipal and Industrial Solid Waste Division, Office of Solid Waste, EPA530-R-99-009, U.S. Environmental Protection Agency, Washington, DC.

Vinneras B., A. Bjorklund and H. Jonsson. 2003. Thermal composting of faucal matter as treatment and possible disinfection method-lab scale and pilot scale Technol. 88: 47-54.

Zorpas, A. A., D. Arapoglou and K. Panagiotis. 2003. Waste paper and clinoptilolite as a bulking material with dewatered anaerobically stabilized primary sewage sludge (DASPSS) for compost production. Waste Manage. 23: 27-35.

Zucconi F., M. Forte, A. Monaco, M. De Bertoldi. 1981. Biological evaluation of compost maturity. Bio.Cycle. 22: 27-29.

APPENDICES

Appendix I: Composting of pH during the experiment

Bin no.	pH									
	1	2	3	4	5	6	7	8	9	10
1	8.45b	8.25f	8.4c	9.34b	8.81c	8.92c	9.05b	9.08a	9.19a	9.06b
2	8.04c	8.55b	8.61b	9.62a	9.04a	9.33a	9.26a	9.17a	9.19a	8.79c
3	7.65e	8.33e	8.04e	9.2c	8.92b	9.11b	9.24a	9.03a	8.92b	9.29a
4	7.45f	8.4d	8.72a	8.62d	8.52d	8.72d	8.29c	8.4b	8.35c	8.63d
5	7.95d	8.85a	7.87f	8.28e	8.25e	8.45e	7.96e	7.3d	7.56e	8.29e
6	8.63a	8.46c	8.16d	8.11f	8.12f	8.04f	8.02d	7.87c	8.09d	9.35a
SE	0.092	0.05	0.08	0.13	0.08	0.11	0.14	0.17	0.15	0.09
CV (%)	4.77	2.41	3.80	6.51	4.19	5.01	6.68	8.47	7.20	4.23

Means followed by same or without letters did not differ significantly at 5% level of significance.

Appendix II: Changes of Electrical conductivity during composting period

Bin no.	EC(μS/cm)									
	1	2	3	4	5	6	7	8	9	10
1	2600f	2763b	2775ab	2767b	2771b	2651e	2776ab	2550e	2650e	2707f
2	2663d	2783a	2770b	2779b	2786a	2653e	2788a	2647c	2677d	2719e
3	2643e	2610e	2780a	2725cd	2686f	2676d	2713d	2617d	2724b	2795b
4	2685b	2712cd	2710e	2724cd	2745d	2728b	2754c	2661b	2747a	2834a
5	2675c	2725cd	2735c	2872a	2730e	2702c	2746c	2612d	2730b	2780c
6	2770a	2726c	2725d	2736c	2752c	2742a	2782ab	2697a	2709c	2761d
SE	7.78	13.35	6.62	12.45	6.20	8.52	12.51	11.14	8.06	10.59
CV (%)	1.20	2.08	1.02	2.01	0.95	1.34	1.99	1.780	1.27	1.63

Means followed by same or without letters did not differ significantly at 5% level of significance.

Appendix III: Volatile solid content during composting period

Bin no.	Volatile solid					
	1	2	3	4	5	6
1	48.02c	44.89c	40.95c	37.98c	35.09c	29.01d
2	39.08e	34.02e	32.07e	29.02d	27.1e	25.04e
3	55.07a	51.04a	46.09a	40.93b	38.06b	33.03b
4	45.03d	41.2d	39.2d	36.97c	33.23d	30.92c
5	51.08b	47.24b	44.1b	40.92b	38.89 b	37.01a
6	55.05a	51.13a	46.85a	45.02a	43.08a	38.10a
SE	1.51	1.57	1.38	1.35	1.37	1.25
CV (%)	13.12	14.88	14.06	14.92	16.25	16.53

Means followed by same or without letters did not differ significantly at 5% level of significance.

Appendix IV: Changes of total solid during composting period

Bin no.	Total solid					
	1	2	3	4	5	6
1	28.14c	36.62a	42.23c	48.7a	51.73c	54.53d
2	27.93d	33.25d	43.7a	45.9c	49.17d	52.3e
3	31.8b	34.62c	43.7a	48.6a	53.43b	55.7c
4	32.66a	36.21b	42.9b	45.31d	49.24d	51.61e
5	31.6b	36.33b	41.36d	47.7b	55.49a	60.8a
6	28.45c	34.87c	38.77e	46.1c	50.2c	58.9b
SE	0.48	0.29	0.41	0.33	0.56	0.81
CV(%)	6.69	3.47	4.17	2.94	4.61	6.13

Means followed by same or without letters did not differ significantly at 5% level of significance

Appendix V: Changes of organic matter during composting period

Bin no.	Organic matter					
	1	2	3	4	5	6
1	67.42a	64.62a	61.84a	55.109b	50.119b	44.426a
2	65.62c	61.83c	54.61c	49.1c	43.5d	42.08c
3	67.12ab	64.44ab	61.15ab	54.82b	48.62c	41.09d
4	63.42d	60.11d	55.69c	47.13d	45.21	43.11b
5	62.08e	58.16e	53.81c	45.48e	39.82e	37.92e
6	67.39ab	64.12ab	61.63ab	57.61a	52.3a	41.7b
SE	0.51	0.59	0.84	1.10	1.02	0.49
CV(%)	3.27	4.04	6.14	9.02	9.31	4.96

Means followed by same or without letters did not differ significantly at 5% level of significance

Appendix VI: Changes of Total organic matter during composting period

Bin no.	TOC					
	1	2	3	4	5	6
1	39.1a	37.48a	35.86a	31.96b	29.07b	25.78a
2	38.05c	35.86c	31.67d	28.47c	25.23e	24.41c
3	38.92ab	37.37ab	35.46ab	31.49b	28.19c	23.83d
4	36.78d	34.86d	32.3c	27.33d	26.22d	25.003b
5	36.01e	33.73e	32.2c	26.23e	23.09f	21.99e
6	39.08ab	37.18ab	35.78ab	33.41a	30.33a	24.186d
SE	0.29	0.34	0.45	0.63	0.59	0.28
CV(%)	3.26	4.01	5.58	8.98		4.95

Means followed by same or without letters did not differ significantly at 5% level of significance

Appendix VII: Changes of Total Kjaldhal Nitrogen during composting period

Bin no.	TKN					
	1	2	3	4	5	6
1	1.67c	1.62d	1.59c	1.53d	1.47c	1.38c
2	1.64e	1.61e	1.58d	1.5e	1.44e	1.41b
3	1.69b	1.64b	1.61b	1.57a	1.52a	1.41b
4	1.65d	1.63c	1.59c	1.54c	1.45d	1.43a
5	1.62f	1.56f	1.54e	1.49f	1.45d	1.43a
6	1.70a	1.66a	1.62a	1.56b	1.51b	1.43a
SE	0.0067	0.0075	0.0061	0.0070	0.0074	0.0040
CV(%)	1.73	1.97	1.64	1.95	2.15	1.31

Means followed by same or without letters did not differ significantly at 5% level of significance

Appendix VIII: Carbon Nitrogen ratio during composting period

Bin no	C/N					
	1	2	3	4	5	6
1	23.41a	23.23a	22.55a	20.88a	19.77a	18.66b
2	23.2b	22.37c	20.04e	18.98c	17.52c	17.3c
3	23.02c	22.78b	22.08b	20.24b	18.94b	16.9a
4	22.29d	21.38e	20.31d	17.74d	17.25d	16.83a
5	22.23d	21.63d	20.90c	17.675d	15.92e	15.37d
6	22.98c	22.39c	22.08b	21.14a	20.04a	16.91a
SE	0.107	0.145	0.230	0.340	1.039	0.233
CV(%)	1.99	2.77	4.57	7.42	22.16	5.82

Means followed by same or without letters did not differ significantly at 5% level of significance

Appendix IX: Total Phosphorous during composting period

Bin no.	P%					
	1	2	3	4	5	6
1	0.442d	1.063a	1.051a	1.044a	1.042a	1.036a
2	0.415e	0.932c	0.926d	0.921d	0.925d	0.914d
3	0.471b	0.909c	0.926d	0.901e	0.899e	0.872e
4	0.457c	0.749d	0.789e	0.738f	0.744f	0.729f
5	0.364f	0.975b	0.979c	0.969c	0.962c	0.947c
6	0.482a	1.06a	1.01b	1b	0.996b	0.987b
SE	0.0096	0.025	0.021	0.024	0.023	0.024
CV (%)	9.32	11.60	9.13	10.87	10.47	10.98

Means followed by same or without letters did not differ significantly at 5% level of significance

Appendix X: Total Potassium during composting period

Bin no.	K					
	1	2	3	4	5	6
1	0.461c	0.459b	0.455b	0.451b	0.443c	0.442d
2	0.431d	0.429c	0.425c	0.422c	0.417d	0.415e
3	0.490a	0.487a	0.481a	0.478a	0.473a	0.471b
4	0.473b	0.465b	0.481a	0.477a	0.461b	0.457c
5	0.385e	0.375d	0.377d	0.372d	0.367e	0.364f
6	0.498a	0.491a	0.487a	0.453b	0.477a	0.482a
SE	0.0094	0.0093	0.0096	0.0089	0.0093	0.0096
CV (%)	8.71	8.76	8.90	8.86	8.96	9.32

Means followed by same or without letters did not differ significantly at 5% level of significance