# FEASIBILITY ASSESSMENT OF PRODUCTION OF LIQUID ORGANIC FERTILIZER (LOF) FROM FOOD WASTE FOR SUSTAINABLE WASTE MANAGEMENT

By

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## ABSTRACT

The increasing volume of food waste is responsible for the generation of potent greenhouse gases and is resulting in the wastage of valuable resources. In all regions of the world, the percentage of food waste in municipal solid waste is greater. Due to the lack of waste segregation at collection points and modern waste disposal methods in developing countries, organic waste is piling up in the dumpsites and landfills. Besides due to poor harvest and post-harvest procedures and inefficient supply chain, almost 55% of the cultivated crops do not even reach the consumers and get wasted. On the other hand, to feed the growing population, huge volumes of chemical fertilizers are being used, which is detrimental to the environment. The use of liquid organic fertilizer (LOF) produced from the waste can be a sustainable solution for these problems. This experimental work focused on the reduction of fruit and vegetable waste, by using the leachate generated from it as an alternative to chemical fertilizer. Wastes generated by the consumption of fruit and vegetables were stored in closed buckets and pH, nitrogen, phosphate, and potash content of the leachate produced were monitored for 28 days at 7 days intervals. For this experimental work, 10 fruits and 18 vegetables samples were used. Since, nitrogen, phosphate, and potash are major nutrients required for plant growth, the study was concentrated on these three. Data analysis showed that the leachate from the fruit and vegetable waste is respectively acidic and basic in nature and a mixture of these two produces neutral leachate. The leachates generated from both fruits and vegetables lack nitrogen content,

whereas these are rich in potash content. The phosphate content was found to be almost 20 % of the potash content. Similar trends were also seen for mixtures of fruit and vegetable waste. Thus, the leachate from the fruit and vegetable waste has the potential to fulfill the potash requirement of the soil and crops requiring a greater quantity of potash for higher yield. A simple equation and corresponding charts were proposed at the end of this study, which can be used to determine the mass of solid waste (fruit, vegetable, and mixed waste) required to produce the leachate that can fulfill the nutrient deficiency for a particular crop.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Solid waste management is a universal issue affecting every single person in the world. Governments and individuals all over the world have different approaches to waste management, that affect the health and productivity of communities. As countries develop from low-income to middle and high-income levels, their concerns about waste generation and its management evolve. Economic growth and shifting towards urban areas are linked to the increase in per capita waste generation. Figure 1-1 shows that the South Asia region generated 334 million tons of waste in 2016, at an average of 0.52 kilograms per person each day.

Municipal Solid Waste (MSW) management has become the subject of major concern due to its environmental and economic impacts. Though landfilling is the least preferred option in the integrated solid waste management hierarchy, it is still the most practiced approach of waste management (Environmental Protection Agency, 2018). This is demonstrated by the fact that 136 million tons of waste i.e. more than half (52.6%) of the total generated waste in the USA, was landfilled in 2014 (Environmental Protection Agency, 2018). In developing countries, most of the waste gets disposed of at the dumpsites. MSW consists of the degradable organic and nondegradable inorganic fractions. The percentage of organic waste produced in South Asian countries is shown in Figure 1-2. It shows that Bangladesh produces 71 % organic waste.

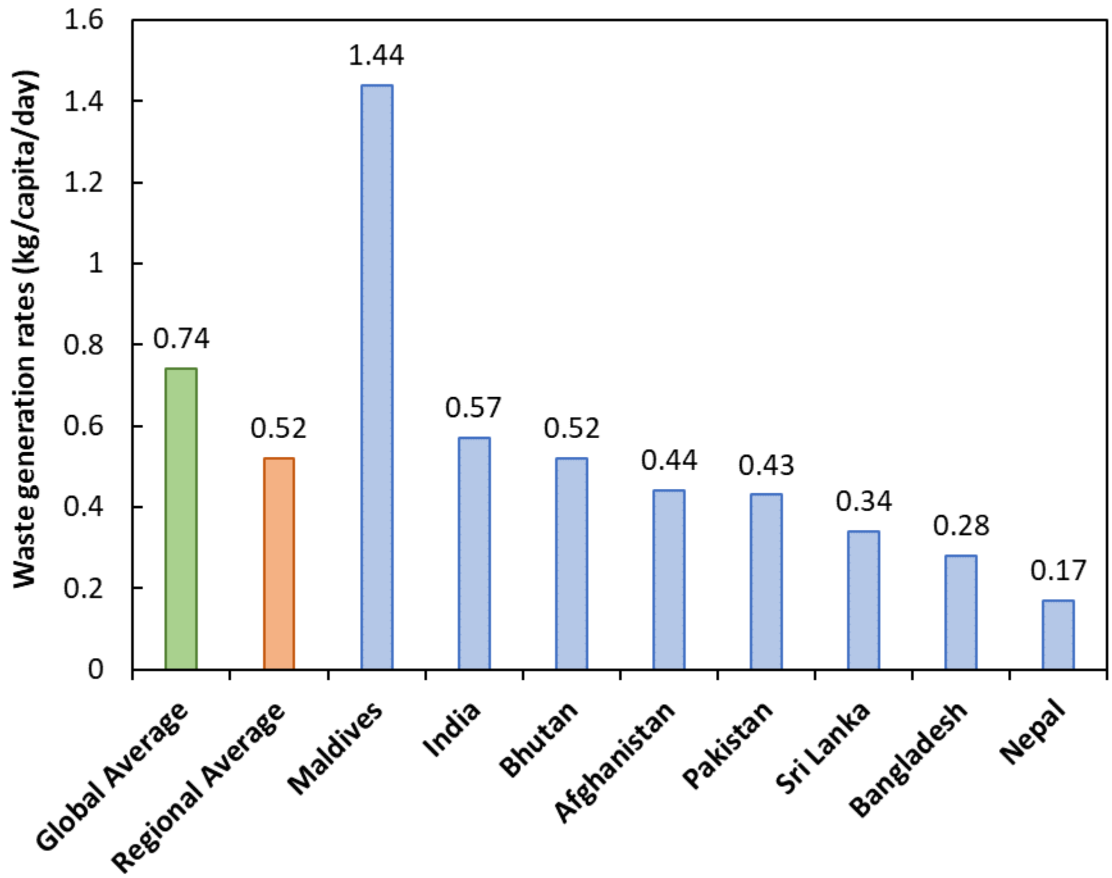



Figure 1-1 Waste Generation Rates: South Asia Region (kg/capita/day) (Kaza et al., 2018)

In Bangladesh, there is no integrated solid waste management system. The major portion of the waste generated is collected by the authority and transported to unsanitary dump sites (Abedin & Jahiruddin, 2015). This can spread diseases to the nearby area, spread odor, and leachate from the waste can seep into the groundwater and contaminate it. The presence of a larger portion of organic waste makes the problem more severe. The percentage of food waste in total MSW varies between 68.3% to 81.1% in Bangladesh (Islam, 2018).

In Bangladesh, 4.121 thousand tons of vegetables and 4.948 thousand tons of fruits were produced in the fiscal year 2017–18 (Bangladesh Bureau of Statistics (BBS), 2018). Unfortunately, 65% of this harvest was wasted at different stages of the distribution chain (Joardder et al., 2019a). This massive amount of food waste can be diverted from landfills and dumpsites by converting it into soil nutrients by composting or production of liquid fertilizer. Since chemical fertilizers are detrimental to the environment, compost or liquid fertilizer can be an inexpensive and eco-friendly alternative to chemical fertilizers.

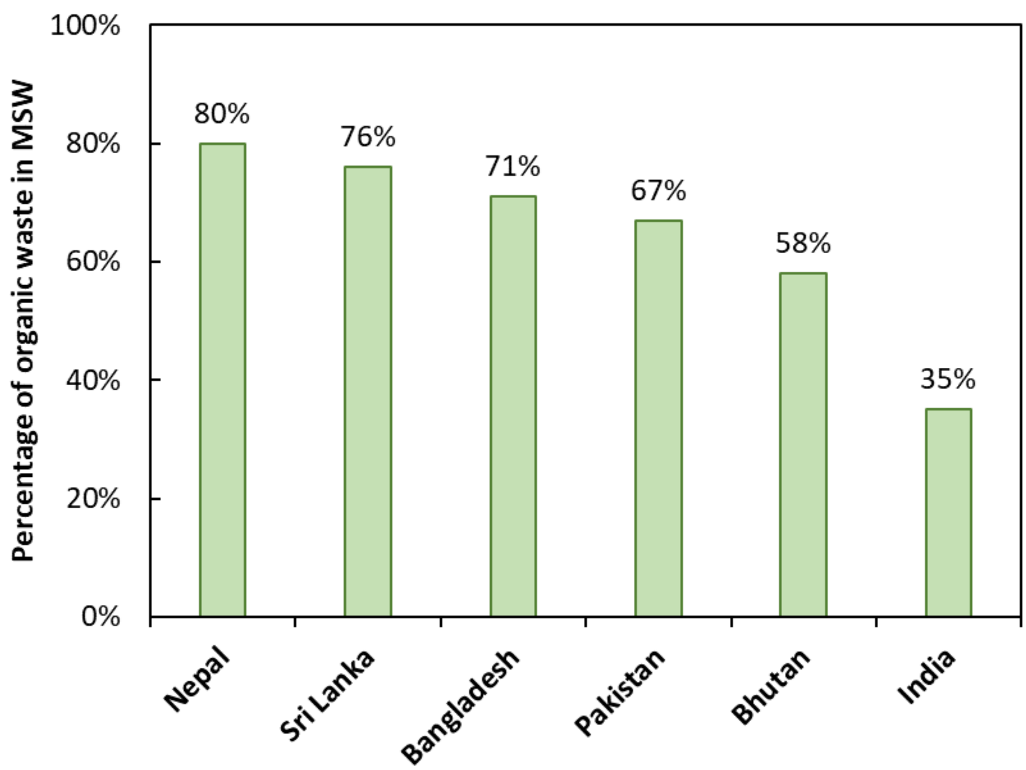



Figure 1-2 Percentage of organic waste in MSW for some South Asian countries (Hoornweg & Bhada-Tata, 2012)

## 1.2 Problem Statement

Organic wastes are produced from different stages of consumption of fruit and vegetables. All these wastes end up at the dumpsites due to a lack of a proper waste management system. This is a huge loss of valuable resources. The production of fruits and vegetables is expensive. Valuable resources such as soil, water, fertilizer, fuel, the labor of the farmers, etc. go into the production process.

Meanwhile, to meet the domestic demand for fruits and vegetables for the huge population, large volumes of chemical fertilizers are being poured into the soil. This is very alarming. The soil is losing its fertility and the poisonous chemicals are leaching into the groundwater contaminating it.

The use of leachate generated from the fruit and vegetable waste as a liquid organic fertilizer has the potential to solve these problems. Extracting the liquid from the waste will reduce the total volume of the waste. The extracted liquid can be directly applied to the soil to make it enriched with essentials nutrients. The separated solids can be used for composting. Applying this organic fertilizer prevents the introduction of chemical fertilizers to the soil. To develop a better understanding of the applicability of the leachate to improve the soil nutrient content, chemical tests were carried out. From the chemical tests, it will be possible to develop an idea about the presence of the necessary elements for plants in the leachate and formulate a mixture that can be beneficial for plant growth. This can be used as an alternative to chemical fertilizers.

### 1.3 Research Objectives

The objective of the current study is to develop a simple equation and relevant charts to determine the mass of solid waste required to fulfill the nutrient demand for a particular crop in certain soil conditions.

To achieve this, the pH, nitrogen, phosphate, and potash content of the leachate produced from the fruit and vegetable wastes were monitored for 28 days at 7 days interval. The fruits and the vegetables were selected based on their availability in different seasons.

### 1.4 Thesis Organization

The thesis is divided into five chapters that can be summarized as follows:

Chapter 1 introduces the study by presenting the problem statement and the objectives of the investigation.

Chapter 2 presents the literature review on some of the most pertinent information to this study such as the present picture of crop production in the country, fertilizer used, the volume of organic wastes generated from various sources, techniques employed for waste management and finally it presents a brief review of multiple related previous studies.

Chapter 3 describes the methodology followed for preparing a setup to collect the leachate from the waste and testing it.

Chapter 4 presents the figures and data obtained from the laboratory tests and their analysis.

Chapter 5 summarizes the results and presents the conclusions and recommendations for future studies derived based on the obtained results.

## CHAPTER 2

## LITERATURE REVIEW

### 2.1 Volume of Food Production

The climatic conditions are different all over the world, which causes the variation in food habits of the local population. Figure 2-1 shows the overall picture of food production in different regions of the world (FAO, 2021). From the figure, it is seen that cereals occupy a major portion of the world crop production. South and Southeast Asia led the world cereal production with 715 million tonnes

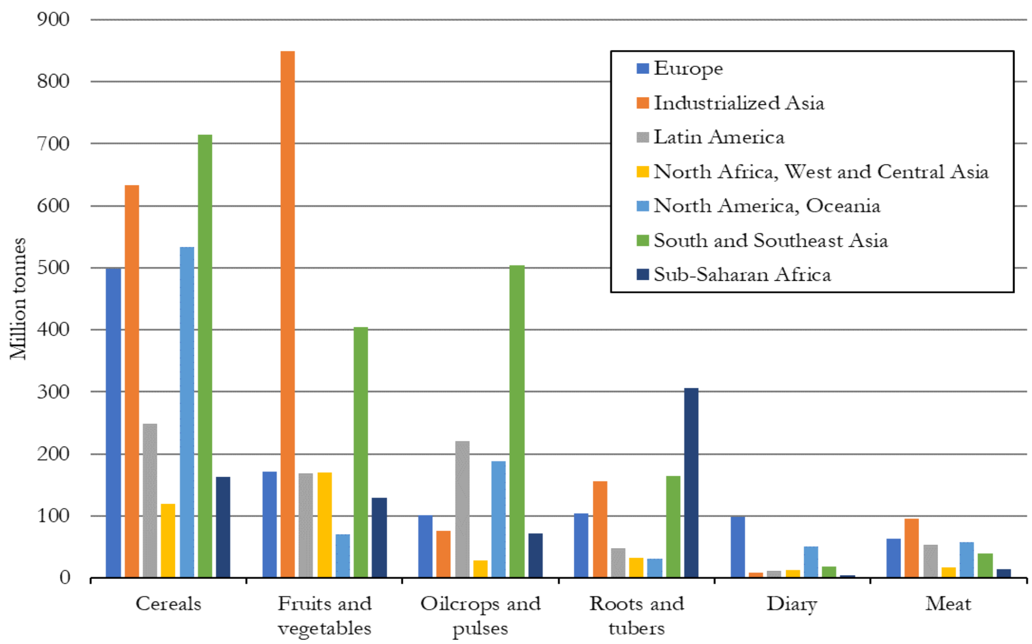



Figure 2-1 Production volumes of each commodity group, per region for the year 2019 (FAO, 2021)

Fruit and vegetable production is dominated by Industrialized Asia, which comprises East Asian countries. This region produced a total of 850 million tonnes of fruit and vegetables in the year 2019. There are vast dairy farms in Europe and Oceania region. As a result, this region has high production of various dairy goods. Meat and dairy productions are considerably less than other forms of food productions.

### 2.2 Food Loss and Waste

The issue of food losses is of high importance in the efforts to combat hunger, raise income and improve food security in the world's poorest countries (Gustavsson et al., 2011). On one hand, there is a huge demand for food for the large population of the world but, on the other hand, this population is generating gigantic volumes of food wastes. According to Buzby et al. (2014), food loss represents the amount of edible food, postharvest, that is available for human consumption but is not consumed for any reason. It includes cooking loss and natural shrinkage (e.g., moisture loss); loss from mold, pests, or inadequate climate control; plate waste; and other causes. Food waste is a component of food loss and occurs when an edible item goes unconsumed, such as food discarded by retailers due to blemishes or plate waste discarded by consumers. Again, according to Parfitt et al. (2010), food losses refer to the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption. Food losses take place at production, postharvest, and processing stages in the food supply chain. Food losses occurring at the end of the food chain (retail and final consumption) are rather called food waste, which relates to retailers' and consumers' behavior. It should be pointed out that the UN also considers food redirected to agricultural compost, animal feed, or bio-energy as food waste (Joardder et al., 2019a). The food wasted at the consumer end becomes part of the Municipal Solid Waste (MSW). The global Warming impact of the avoidable food waste was quantified between 2000 and 3600 kg CO2-eq. $t^{-1}$ (Gustavsson et al., 2011).

Due to insufficient knowledge of state-of-the-art technologies, production to retailer stage food waste in developing countries is much higher compared to the developed ones (Hasan Masud et al., 2020; Joardder & Masud, 2019). The percentage of food waste in total MSW varies between 68.3% to 81.1% in Bangladesh (Islam, 2018).

## 2.3 Composition of Food Waste

Food waste is the discards generated along all stages of the food supply chain from production to the plate of the consumer which can be any solid or liquid food substance and can be cooked or uncooked. Food waste includes complex ingredients that have been discarded from the source material compared to other components of MSW. Based on the origin of the food, waste can be divided into two main groups (Galanakis, 2012):

- Originated from plants
- Originated from animals

These two main groups can be sub-categorized into seven groups, four are originated from the plant:

i) Cereals

ii) Roots & tubes

iii) Oil crops & pulses

iv) Fruits & vegetables

and three from animals:

v) Meat

vi) Fish & seafood

vii) Dairy

### 2.4 Types of Food Losses/Waste

The food grown on the farms arrives at the factories and households via a complex food supply chain. Thousands of people take an active part to form this supply chain. Wastage of food, both from plants and animals is observed at different stages of this process. According to FAO (2011), five system boundaries were distinguished in the food supply chains (FSC) of vegetable and animal commodities. Food loss/ waste was estimated for each of these segments of the FSC. The aspects considered are shown below in Table 2-1.

Table 2-1 Loss in different stages of the food supply chain

| **Vegetable commodities and products** | |
|---|---|
| Agricultural production | losses due to mechanical damage and/or spillage during harvest operation (e.g., threshing or fruit picking), crops sorted out post-harvest, etc. |
| Post-harvest handling and storage | including losses due to spillage and degradation during handling, storage, and transportation between farm and distribution. |
| Processing | including losses due to spillage and degradation during industrial or domestic processing, e.g., juice production, canning, and bread baking. Losses may occur |

| | |
|---|---|
| | when crops are sorted out if not suitable to process or during washing, peeling, slicing, and boiling, or during process interruptions and accidental spillage. |
| Distribution | including losses and waste in the market system, e.g., wholesale markets, supermarkets, retailers, and wet markets. |
| Consumption | including losses and waste during consumption at the household level. |

| **Animal commodities and products** | |
|---|---|
| Agricultural production | for bovine, pork, and poultry meat, losses refer to animal death during breeding. For fish, losses refer to discards during fishing. For milk, losses refer to decreased milk production due to dairy cow sickness (mastitis). |
| Post-harvest handling and storage | for bovine, pork, and poultry meat, losses refer to death during transport to slaughter and condemnation at the slaughterhouse. For fish, losses refer to spillage and degradation during icing, packaging, storage, and transportation after landing. For milk, losses refer to spillage and degradation during transportation between farm and distribution. |
| Processing | for bovine, pork, and poultry meat, losses refer to trimming spillage during slaughtering and additional industrial processing, e.g., sausage production. For fish, losses refer to industrial processing such as canning or smoking. For milk, losses refer to spillage during industrial milk treatment (e.g., pasteurization) and milk processing to, e.g., cheese and yogurt. |
| Distribution | includes losses and waste in the market system, e.g., wholesale markets, supermarkets, retailers, and wet markets. |
| Consumption | includes losses and waste at the household level. |

## 2.5 Global Scenario of Food Waste

Across global food systems, food loss and waste (FLW) are a widespread issue, posing a challenge to food security, food safety, the economy, and environmental sustainability. No accurate estimates of the extent of FLW are available, but studies indicate that FLW is roughly 30 percent of all food globally (FAO, 2015). This amounts to 1.3 billion tonnes per year. FLW represents a wastage of resources, including the land, water, labor, and energy used to produce food. It strongly contributes to climate change because greenhouse gases are emitted during food production and distribution activities, and methane is released during the decay of wasted food. FLW also affects food supply chains by lowering income for food producers, increasing costs for food.

Figure 2-2 shows that the per capita food loss in Europe and North America is 280-300 kg/year. In sub- Saharan Africa and South/Southeast Asia, it is 120-170 kg/year. The total per capita production of edible parts of food for human consumption is, in Europe and North America, about 900 kg/year and, in sub- Saharan Africa and South/Southeast Asia, 460 kg/year. Per capita food wasted by consumers in Europe and North America is 95-115 kg/year, while this figure in sub-Saharan Africa and South/Southeast Asia is only 6-11 kg/year. Food losses in industrialized countries are as high as in developing countries, but in developing countries, more than 40% of the food losses occur at post-harvest and processing levels, while in industrialized countries, more than 40% of the food losses occur at retail and consumer levels. Food waste at the consumer level in industrialized countries (222 million tons) is almost as high as the total net food production in sub- Saharan Africa (230 million tons).

In the United States, food waste is estimated at between 30-40 % of the food supply. This estimate, based on estimates from USDA's Economic Research Service of 31 % food loss at the retail and consumer levels, corresponded to approximately 133 billion pounds and $161 billion worth of food in 2010 (USDA, 2019). This amount of waste has far-reaching impacts on society:

- Wholesome food that could have helped feed families in need is sent to landfills.

- Land, water, labor, energy, and other inputs are used in producing, processing, transporting, preparing, storing, and disposing of discarded food.

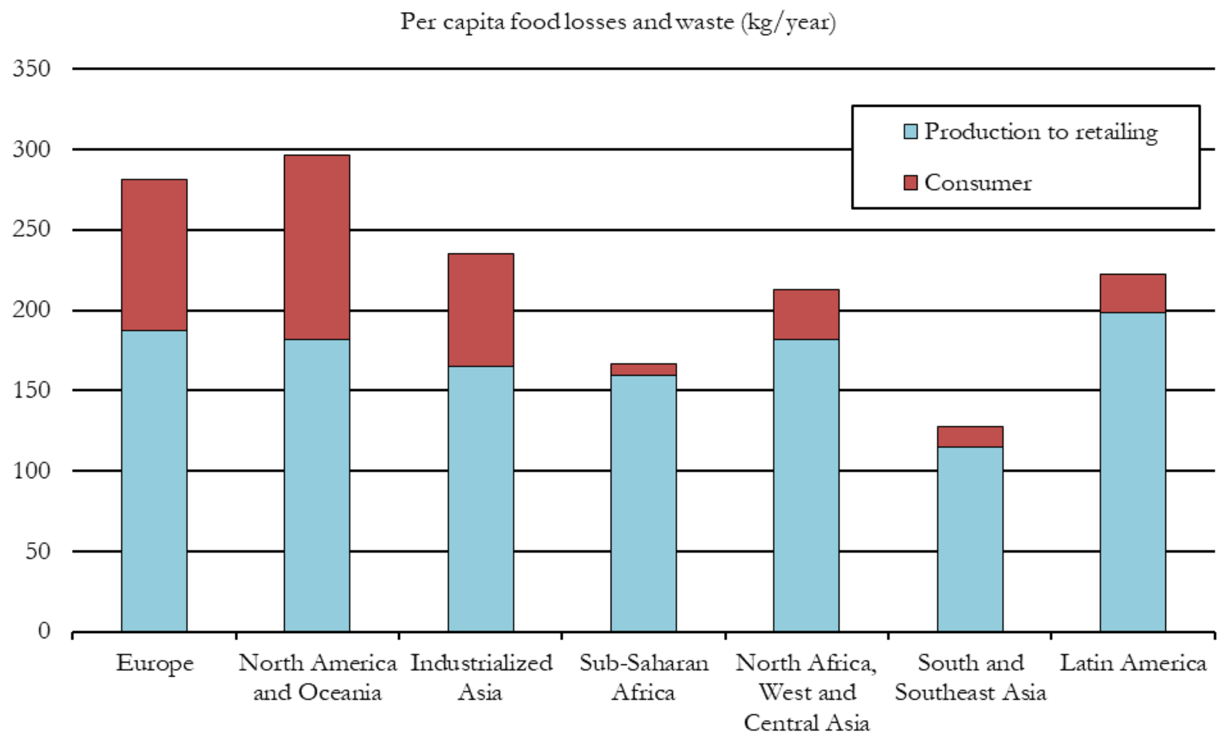



Figure 2-2 Per capita food losses and waste, at consumption and pre-consumptions stages, in different regions

Table 2-2 shades some light on the distribution of food losses in the United States for the year 2010. From the table, it can be observed that food waste is not produced from only one type of food material. There is some form of loss of every food type. In all cases, the loss at the consumer level is less than the retail. On average 30 % of the food loss occurs at these two levels. At the consumer end, in most cases, the whole of the fruit is not edible and parts like peel, seeds, or core are thrown away as waste. For example, the non-edible portion of the jackfruit was found to be 59.2% by weight (Subburamu et al., 1992), which includes non-edible perianth (18.5 %), outer prickly rind (30.6 %), and central core (10.1 %).

Although these are the most common constituents, the percentage of these varies significantly. The primary food waste generating stage is during agricultural production and secondarily the postharvest handling & storage while consumer-level wastage is minimum in the low income/developing countries. However, in industrialized countries, food loss occurs in both the agricultural and consumption stage where consumer-level wastage is the dominating one (Gustavsson et al., 2011).

Table 2-2 Estimated total food loss in the United States, 2010 (Buzby et al., 2014)

| | | **Losses from the food supply** | | | | | |
|---|---|---|---|---|---|---|---|
| **Commodity** | **Food Supply** | **Retail level** | | **Consumer-level** | | **Total retail and consumer level** | |
| | Billion pounds | Billion pounds | Percent | Billion pounds | Percent | Billion pounds | Percent |
| Grain products | 60.4 | 7.2 | 12 | 11.3 | 19 | 18.5 | 31 |
| Fruit | 64.3 | 6.0 | 9 | 12.5 | 19 | 18.4 | 29 |
| Fresh | 37.6 | 4.4 | 12 | 9.5 | 25 | 13.9 | 37 |
| Processed | 26.7 | 1.6 | 6 | 2.9 | 11 | 4.5 | 17 |
| Vegetables | 83.9 | 7.0 | 8 | 18.2 | 22 | 25.2 | 30 |
| Fresh | 53.5 | 5.2 | 10 | 12.8 | 24 | 18.0 | 34 |
| Processed | 30.4 | 1.8 | 6 | 5.3 | 18 | 7.1 | 24 |
| Dairy products | 83.0 | 9.3 | 11 | 16.2 | 20 | 25.4 | 31 |
| Fluid milk | 53.8 | 6.5 | 12 | 10.5 | 20 | 17.0 | 32 |
| Other dairy products | 29.1 | 2.8 | 10 | 5.7 | 19 | 8.5 | 29 |

| Commodity | Food Supply | Losses from the food supply | | | | | |
|---|---|---|---|---|---|---|---|
| | | Retail level | | Consumer-level | | Total retail and consumer level | |
| | Billion pounds | Billion pounds | Percent | Billion pounds | Percent | Billion pounds | Percent |
| Meat, poultry, and fish | 58.4 | 2.7 | 5 | 12.7 | 22 | 15.3 | 26 |
| Meat | 31.6 | 1.4 | 4 | 7.2 | 23 | 8.6 | 27 |
| Poultry | 22.0 | 0.9 | 4 | 3.9 | 18 | 4.8 | 22 |
| Fish and seafood | 4.8 | 0.4 | 8 | 1.5 | 31 | 1.9 | 39 |
| Eggs | 9.8 | 0.7 | 7 | 2.1 | 21 | 2.8 | 28 |
| Tree nuts and peanuts | 3.5 | 0.2 | 6 | 0.3 | 9 | 0.5 | 15 |
| Added sugar and sweeteners | 40.8 | 4.5 | 11 | 12.3 | 30 | 16.7 | 41 |
| Added fats and oils | 26.0 | 5.4 | 21 | 4.5 | 17 | 9.9 | 38 |
| **Total** | **430.0** | **43.0** | **10** | **89.9** | **21** | **132.9** | **31** |

## 2.6 Food Production in Bangladesh

Bangladesh is the most densely populated country in the world with an unfavorable land-population ratio and this has resulted in poor food security. Bangladesh is predominantly an agrarian country. Due to its very fertile land and favorable weather, varieties of crops grow abundantly in this country. The agriculture sector contributes about 14.23 % to the country's Gross Domestic Product (GDP) and employs around 40.60 percent of the total labor force (Bangladesh Bureau of Statistics (BBS), 2018). Food security is to a large extent associated with rice consumption and production and is the staple for 160 million Bangladeshi, who obtain more than 70% of their total calorie from rice. With an overall consumption of around 35.1 million metric tons, Bangladesh managed to avoid a shortage of rice during the food crisis(Bari, 2015).

Figure 2-3 gives another picture of Bangladesh's dependency on rice. Almost 75% of the cultivatable land is used for rice cultivation. All other crops make up the rest 25 %.

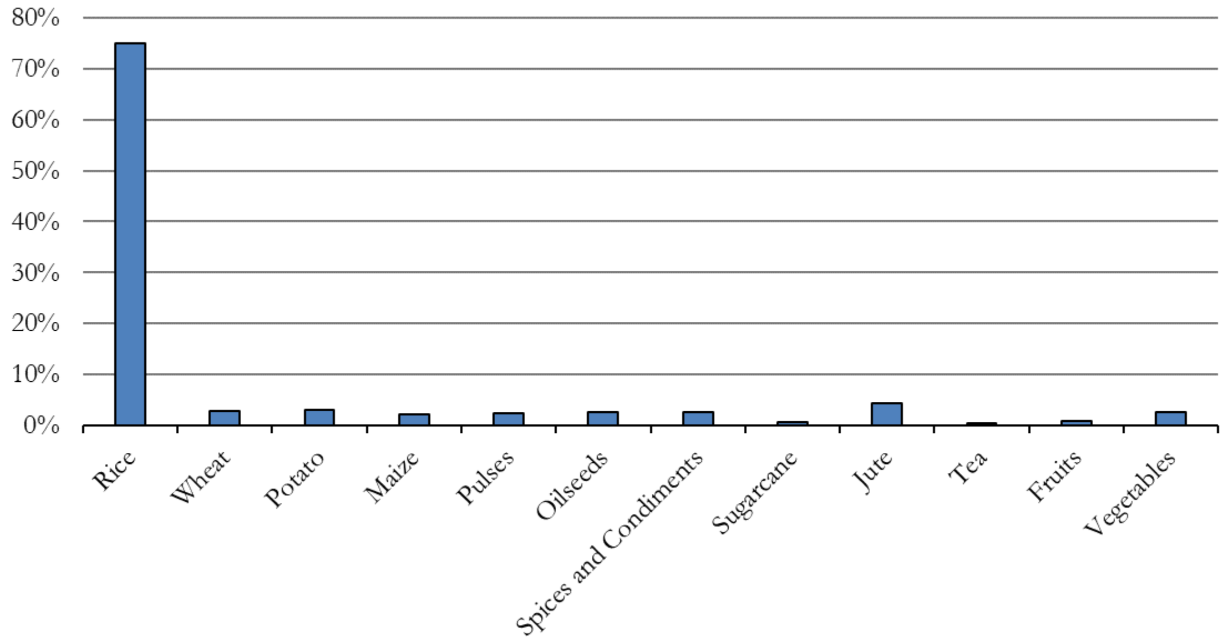



Figure 2-3 Area under Cultivation of different Crops in Bangladesh, 2015-2016 (Bangladesh Bureau of Statistics (BBS), 2018)

### 2.7 Fruit Production in Bangladesh

Though the land area under fruit cultivation in Bangladesh is less (only 1%), there is much variation in the fruits that are cultivated. The area cultivated, yield per year, production of both temporary and permanent fruits of Bangladesh for the fiscal years 2015-16, 2016-17, and 2017-18 is shown in APPENDIX A. In this period 4,948,000 metric tons of fruits were produced in Bangladesh. The yield rate was 9,271 kg per acre, which is 135 % more than the previous year (Bangladesh Bureau of Statistics (BBS), 2018). Fruits cultivated in Bangladesh are divided into temporary and permanent fruits. Temporary fruits are those which are both sown and harvested during the same agricultural year, sometimes more than once; permanent fruits are sown or planted once and not be replanted after each annual harvest (FAO, 2020). Out of the temporary fruits, the production of banana is the highest (16.73 %). Watermelon, pineapple, and melon are available on a seasonal basis. The major permanent fruits are mango, jackfruit, green coconut, guava, and papaya. Several fruits are available in Bangladesh on a seasonal basis.

### 2.8 Vegetable Production in Bangladesh

APPENDIX B shows the area cultivated, yield per year, production of both winter and summer vegetables of Bangladesh for the year 2017-18. In this period 4,121,000 metric tons of vegetables were produced in Bangladesh. A variety of vegetables are available around the year. During winter, the availability increases. Tomato, cabbage, radish, cauliflower, and beans are more available during the mid-winter due to higher production, consequently lower pricing.

### 2.9 Food Waste Generation in Bangladesh

Food wastes contribute 67.65% to the aggregated municipal solid wastes (MSWs) streams while the total MSWs generation rate is 19,361.73 tons/day and total solid waste (SW) generation is 58,963.15 tons/day in Bangladesh excluding agricultural wastes (Alam et al., 2015). This indicates an enhancing quota of MSW generation which is projected to reach 47, 064 tons/day by 2025 including 0.6 kg/cap./day (Alamgir & Ahsan, 2007; Yousuf & Rahman, 2007). Contrary, the total waste collection efficiency in major cities varies from 37% to 77 %. Among different compositions of MSW, organic waste occupies a major fraction as well as food wastes contributes 67.65% solely (WasteConcern, 2014). Table 2-3 demonstrates that the urban and rural regions in Bangladesh generate food waste at varying magnitudes and it also varies with the dry and wet seasons. It can also be noted that the capital city Dhaka has the highest per capita food waste generation rate (0.56 kg/capita/day), which is followed by the industrial city of Chittagong with 0.48 kg/capita/day. Seasonal variation is also an important factor in the food waste generation rate. In the wet season, there is a 46% increase.

As mentioned previously in section 2.3, the food materials are sourced from different plants and animals. The food from the plant can also be divided into grains and produce (fruits and vegetables). Food waste comprises wastes generated from the distribution and consumption of all foods from these sources. From Figure 2-4 we can see that in 2016-17 almost 15.85 million tons (7.82 million tons in harvest losses and 7.58 million tons in post-harvest losses) or 67% of total food waste occurred at post-harvest to consumer stage (BBS, 2020; Joardder et al., 2019b). Accounting for all the losses, 28.98 million tons (64.61% of the total available harvest) of food material reached end customers. Hence, 35.38% (15.873 million tons) of the total available harvest was wasted in the food processing and consumption supply chain. It is estimated that a total of 23.69 million tons of food was wasted in 2016-17 at different stages of the supply chain, as shown in Figure 2-5. Due to rapid population growth and urbanization, both food production and consumption rate are triggering throughout the world comparing with the development of living standards. Consequently, a huge volume of food waste is accumulating into the total solid waste (SW) streams. Besides, FOOD WASTEs are comprised of biodegradable compositions (Raven & Gregersen, 2007). Such a scale of waste generation from limited production negatively impacts the economy and the development of the country in general.

Table 2-3 Food waste generation data in Bangladesh (Ahsan et al., 2014; Alam & Qiao, 2020; Shams et al., 2017)

| **Regions** | **Food waste generation rate (Kg/capita/day) (no. of cities)** | **Food waste generation rate (tons/day)** | | **Food waste generation rate (tons/year)** | **Handling Capacity (%)** | **Ultimate disposal sites** | **Food Waste collection efficiency (%)** |
|---|---|---|---|---|---|---|---|
| | | Dry season | Wet Season | | | | |
| Dhaka | 0.56 (1) | 2764.53 | 4036.2 | 1241133.23 | 40 - 43.64 | 2 | 42 |
| Chittagong | 0.48 (1) | 938.48 | 1370.18 | 421330.45 | 39.29 - 41.67 | 2 | 70 |
| Khulna | 0.27 (1) | 143.39 | 209.35 | 64375.05 | 50 - 57.14 | 1 | 47.70 |
| Rajshahi | 0.44 (1) | 142.74 | 208.4 | 64083.05 | 37.5 - 38.1 | 1 | 56.67 |
| Barisal | 0.25 (1) | 70.14 | 102.41 | 31490.38 | 28.57 - 30 | 1 | 44.30 |
| Sylhet | 0.3 (1) | 112.71 | 164.57 | 50603.6 | 30 - 33.3 | 1 | 76.47 |
| Municipalities | 0.25 (308) | 3606.49 | 5265.47 | 1619132.7 | | | 54.42 |
| Other Urban Centers | 0.15 (208) | 643.04 | 938.84 | 288693.1 | | | 52 |
| **Total** | | **8421.52** | **12295.42** | **3780841.55** | | **8** | |

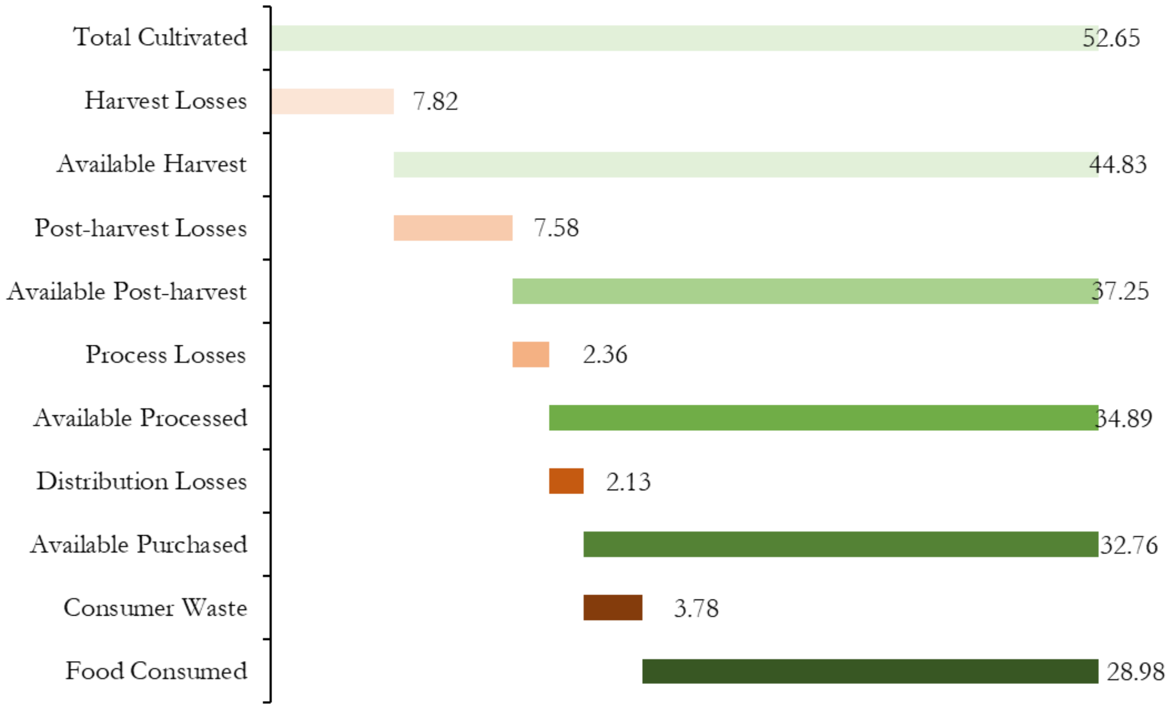



Figure 2-4 Different stages of food waste in food production and consumption supply chain (in million tonnes) (2016-17) (Adapted from (BBS, 2020; Joardder et al., 2019b))

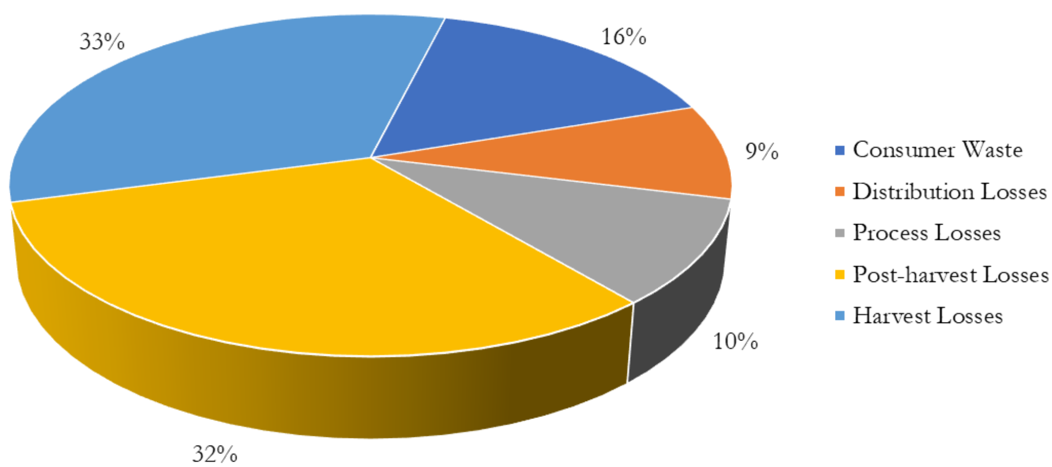



Figure 2-5 Distribution of food loss (Adapted from (BBS, 2020; Joardder et al., 2019b))

## 2.10 Sustainable Management of Food in developing countries

Food waste poses disposal and environmental problems, due to its high biodegradability. Besides, it represents a loss of valuable biomass and nutrients as well as an economic loss (Laufenberg et al., 2003). In general, waste management is the collection, transport, recovery, and disposal of waste, including the supervision of such operations, and the waste management system consists of the whole set of activities related to handling, disposing, or recycling waste materials. In the past, food waste was mixed into municipal waste streams and sent to landfills or incinerators (without energy recovery) for final disposal (Nawirska & Kwaśniewska, 2005). However, this is not a good option for fruit and vegetable waste, due to its high water content which is, in turn, responsible for microbiological instability, the formation of off-odors and leachate (Abu-Qudais, 1996; Lin et al., 2011; Zhang et al., 2007).

Sustainable Management of Food is a systematic approach that seeks to reduce wasted food and its associated impacts over the entire life cycle, starting with the use of natural resources, manufacturing, sales, and consumption and ending with decisions on recovery or final disposal (US EPA, 2020b). Five popular treatment methods have been widely applied in developing countries: animal feeding, composting (or organic fertilizer), anaerobic digestion, incineration, and landfills. Illegal open dumps and landfills are defined in the literature as primary (common) methods in use due to their high rate of use for treating food waste (Adhikari et al., 2006). Based on the documented data of current food waste treatments in developing countries, the common food waste treatment method presently is dumping/landfills (with there being an over 90% use rate for FW treatment), and the second most common method is composting (with a rate ranging from 1% to 6%). Anaerobic digestion (with a use rate of under 0.6%) and other treatments, such as incineration and animal feeding are rarely used.

### 2.10.1 Application I: Animal feeding

In some countries, which have a high demand for animal feedings, such as Japan, South Korea, and Taiwan, local laws encourage using food waste to feed animals, which composes 33%, 81%, and 72.1% of total food waste generation, respectively (Ishoka, 2006; Kim et al., 2011). In contrast, the separation and collection of food are not practiced in developing countries, and therefore almost all of the generated food is mixed with MSW, which could not be purified and utilized for animal feeding.

### 2.10.2 Application II: Anaerobic digestion

Anaerobic digestion is a process through which bacteria break down organic matter—such as manure—without oxygen (US EPA, 2020a). As the bacteria "work," they generate biogas. The biogas that is generated is made mostly of methane, the primary component of natural gas. The non-methane components of the biogas are removed so methane can be used as an energy source. Figure 2-6 shows the main elements of a biogas recovery system. For biogas production, the waste used must be sorted to facilitate gas production. The by-products of the gas recovery process can be used as plant nutrients. Anaerobic digestion (AD) has been widely applied for FOOD WASTE treatment in the European Union and in many Asian developed countries from 2006 onwards (Abbasi et al., 2012). However, conversely, it is acknowledged in developing countries that AD is still scarcely applied as a major treatment method for food waste management. In India and China, various institutes and NGO's have established different kinds of anaerobic digesters on household and commercial scales to develop AD technology for food waste treatment (Müller, 2007). For example, India implemented AD on a pilot scale and opened biogas plants that are used by various institutes. In China, although the full scale of food waste-based AD plants has not yet been developed, roughly twenty MSW, food waste, and manure co-fermentation- AD projects are under preparation or implementation. However, most of those anaerobic digesters might not function properly due to technical failures, inadequate operations, or management regulations (Müller, 2007). Vietnam, the Philippines, and Indonesia usually integrate AD with composting for the disposal of food waste in landfill sites (McDougall et al., 2008). Meanwhile, Jamaica and Thailand have significant achievements in integrating food waste treatment facilities using the AD and the aerobic composting process. The Rayong plant of Thailand uses MSW organic waste as food vegetable and fruit waste to generate organic fertilizer and biogas (Müller, 2007). Jamaica has the CaribShare Biogas Group which treats food waste via AD to generate electricity for supplying power in rural communities (Meghan, 2014).

### 2.10.3 Application III: Composting

Compost is organic material that can be added to soil to help plants grow. Composting is an efficient method for the disposal of food waste in developing countries. Among other environmental benefits, compost enriches the soil, helping retain moisture and suppress plant diseases and pests. It also reduces the need for chemical fertilizers (US EPA, 2019). Currently, there are more than 70 composting facilities in India treating mixed MSW, which recycles up to 5.9% of a total food waste amount to generate about 4.3 million tonnes of compost each year.

Almost all composting facilities handle mixed wastes, and two plants in Vijayawada, Andrah Pradesh, India, and Suryapet, Telangana is known to handle source-separated organic wastes (Annepu, 2012). In Thailand, composting is commonly used for organic solid waste treatment.

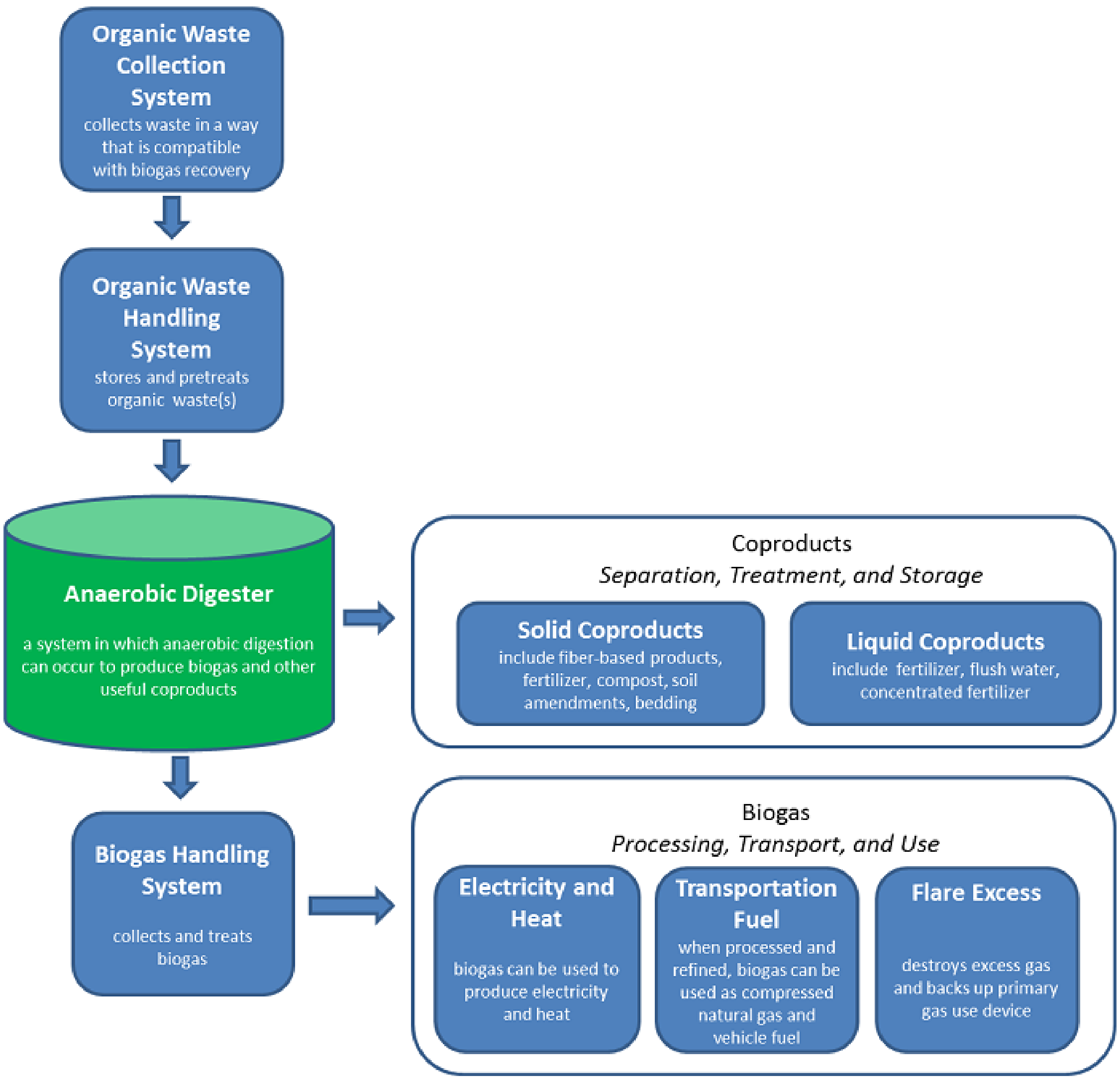



Figure 2-6 Diagram illustrating the elements of a biogas recovery system

Currently, according to the Pollution Control Department and the Ministry of Natural Resources and Environment (2010), the utilization system recycles about 0.59 million tonnes of food waste that had been composted to produce organic fertilizer and biogas. The National 3Rs Strategy mentioned implementing compost and AD to improve food waste utilization by 5% by 2016 (Sharp & Arun, 2012). Vermicomposting has been undertaken by the Malaysian government as a primary national plan to utilize food waste to produce bio-fertilizer (Jalil, 2010). However, there remain some inefficiencies of composting production caused by unpurified waste feedstock, which results from the incomplete source-separated food waste system in most developing countries. As a result, the composting market is weak, and food waste composts need to compete with various chemical fertilizers that cause dilemmas for the operations and investments of composting facilities. For example, although International NGO's have programs to subsidize the costs for developing countries to establish small scale composting to enhance awareness of food waste recycling in some African countries such as Benin, Cameroon, Kenya, Zambia, Nigeria, and Asian countries, the composting quality could not be improved (Marmolejo et al., 2012).

### 2.10.4 Application IV: Incineration

Incineration is an efficient way to reduce waste volume and demand for landfill space. Therefore, this method is used in many countries, including the United States and Singapore (Khoo et al., 2010). In comparison with other treatments, incineration is a costly method (high capital and maintenance cost). It also requires highly technical operations and costly instruments for controlling gas emission residues (Rand et al., 2000). In developing countries, incineration is uncommon for food waste treatment, with Brazil and Ukraine being examples (International Finance Corporation, 2015; Parfitt et al., 2010).

### 2.10.5 Application V: Landfill

Open dumps or landfills are the major food waste treatment methods in all developing countries, which are estimated to be around 90% of total food waste disposal by landfills. Many new landfills collect potentially harmful landfill gas emissions and convert the gas into energy (US EPA, 2014). A large number of countries, including Brazil, Turkey, Malaysia, Mexico, Costa Rica, Romania, South Africa, Belarus, China, Jamaica, Ukraine, Nigeria, and Vietnam are currently disposing of unsorted food waste by landfills, and an estimated 20%- 80% of global food waste has not yet been sorted from MSW (Adhikari et al., 2006). In the literature, landfill practice is not considered to be a feasible method for the treatment of FOOD WASTE because of its biodegradability, and FOOD WASTE in landfills can result in disease vectors (Louis, 2004). Additionally, landfilling food waste can increase greenhouse gas emissions at a rate of 8% (Adhikari et al., 2009)

## 2.11 Current Food Waste Management Process in Bangladesh

Food waste is usually mixed up with other household waste in Bangladesh which is hampering recycling potentiality. Then it is collected by community-based organizations (CBOs) who later discharge it into municipal dustbins. From these dustbins, a little amount is collected by some NGOs for making compost, and the major parts are collected by municipal that directly scrap-heap into dumping sites without any segregation or pre-treatment which is responsible for leachate and gaseous emissions (GHGs) (Ahsan et al., 2012; Moqsud et al., 2011). Thereto, collection frequency of FOOD WASTE is not regularly that create public health hazards. Contrary, in rural areas food waste is used for compost and biomass production but in an unscientific way. Anyhow, it is currently meeting the partial energy and fertilizers demands of rural people (Hasan et al., 2012; Matter et al., 2013; Zakir Hossain et al., 2014; Zurbrügg et al., 2005). Both in the urban and rural areas open burning is done for reducing a large volume of food waste along with others.

### 2.12 Fertilizer for plant growth

Plants contain more than 90 elements, but only 16 elements are recognized as essential. A list of these elements with their sources is shown in Table 2-4.

Table 2-4 Essential plant nutrients and their sources (Ahmed et al., 2018)

| **Macronutrients** | | **Macronutrients** |
|---|---|---|
| **Mostly from air and water** | **From Soil** | **From Soil** |
| Carbon (C) | Nitrogen (N) | Iron (Fe) |
| Hydrogen (H) | Phosphorus (P) | Manganese (Mn) |
| Oxygen (O) | Potassium (K) | Copper (Cu) |
| | Sulphur (S) | Zinc (Zn) |
| | Calcium (Ca) | Boron (B) |
| | Magnesium (Mg) | Molybdenum (Mo) |
| | | Chlorine (Cl) |

Except for carbon, hydrogen, and oxygen, all the 13 elements are taken up by plants from soils and they are called mineral nutrients. Plants obtain carbon, hydrogen, and oxygen from air and water. The nutrients can be divided into two groups based on the quantity required by the plants: macronutrients and micronutrients. Macronutrients are required relatively in larger quantities (usually above 0.1 % on a dry weight basis) while micronutrients are required in smaller quantities (usually below 100 ppm). Carbon, H, and O constitute 90-95% of plant dry matter weight.

Nitrogen, Phosphorus, and Potassium are called primary nutrients because of their large requirement, and Ca, Mg & S are called secondary nutrients. Due to various natural and man-made causes deficiency of one or more chemicals may occur. Inorganic fertilizers have been introduced in Bangladesh during the early 1950s as a supplemental source of plant nutrients. But their use started increasing steadily only from the mid-1960s along with the introduction and expansion of modern varieties accompanied by the development of irrigation facilities. The increasing trend of fertilizer use, particularly urea-N, continues as shown in Figure 2-7. Urea, which is 46 % N (Table 2-5) is by far the most used chemical fertilizer. It had a market share of 85 % in the year 2008-09. It is followed by Triple Super Phosphate, TSP. It is a mixture of phosphorus, sulfur, and calcium. It gets its name for the high phosphorus content. To reduce the potassium deficiency in the soil Muriate of Potash, MOP is applied. It can be noted from Figure 2-7, that nitrogen, phosphorus, and potassium enriched fertilizer are sold in a larger proportion. It is because, Nitrogen, phosphorus, and potassium, or NPK, are the “Big 3” primary nutrients in commercial fertilizers. Each of these fundamental nutrients plays a key role in plant nutrition (TFI, 2014).

## 2.13 Soil conditions causing nutrient deficiency of crops

The nutrients are taken up by plants in the form of cations and anions present in soil solution and are adsorbed on the exchange sites of soil colloids (clay and humus). The presence of nutrients in the soil does not necessarily indicate that they will be readily available for the plants to absorb. The availability of a nutrient in soil refers to that fraction of the nutrient which is accessible to plant roots. It is often observed that the total status of a particular nutrient in the soil is high, but the plants grown on this soil suffer from deficiency of that element. This indicates that the extent of availability is a big concern in the question of plant uptake and consequent growth. Thus, a portion of the total content becomes available for plant uptake depending on some soil conditions, viz, soil pH, soil texture, organic matter content flooding, nutrient interaction, temperature, etc (Ahmed et al., 2018).

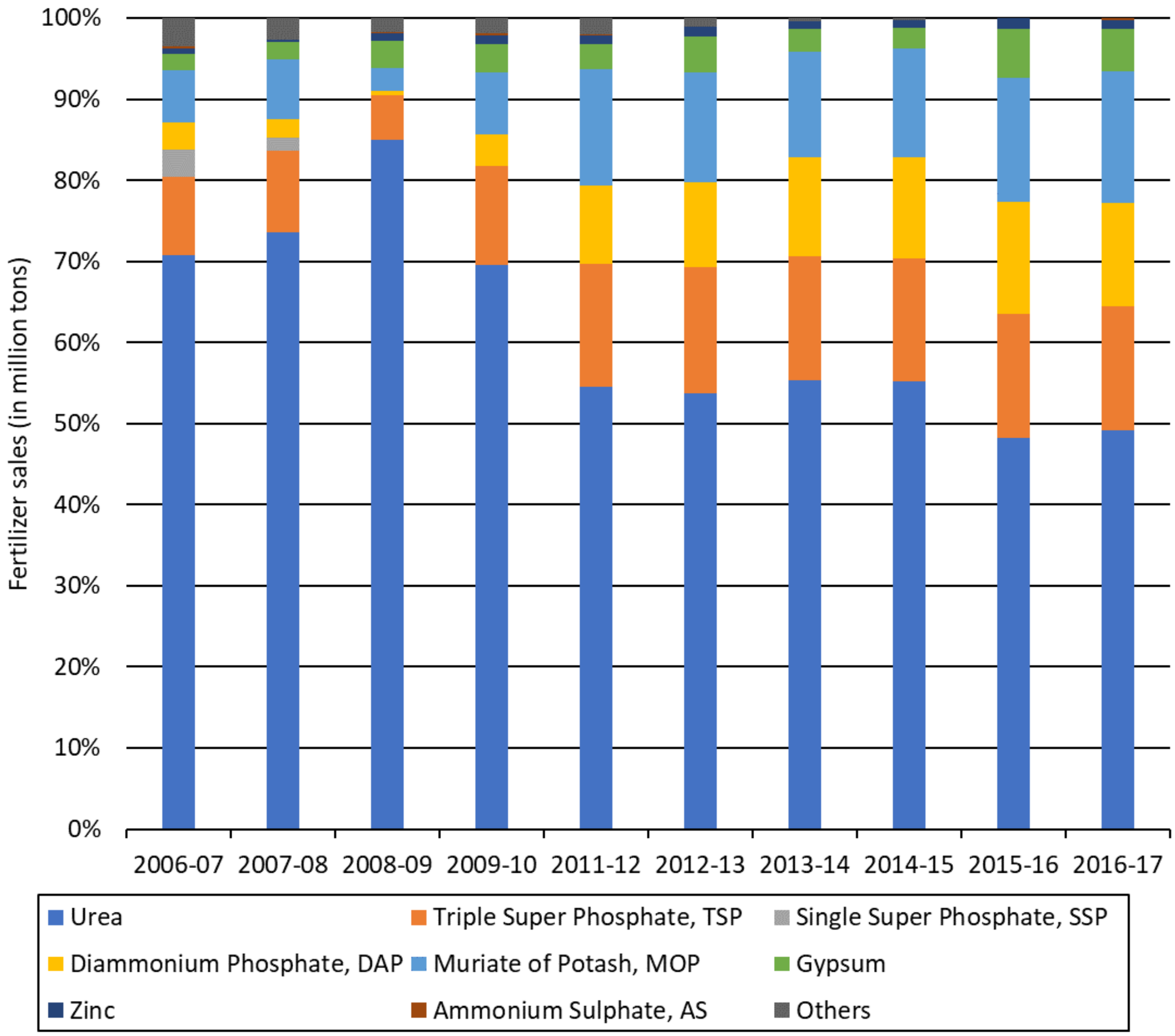



Figure 2-7 Fertilizer sales (in metric ton) by product and year from 2006-07 to 2016-17 in Bangladesh (Ahmed et al., 2018)

Soil pH is the most important controlling factor of nutrient availability in soil. Generally, macronutrients and Mo availability in the soil increases as soil pH increases and the reverse is true for micronutrients except for Mo. Again, P availability is low in acid as well as calcareous soils. In most cases, pH 6-7 is optimum for adequate availability of a nutrient in soils (Ahmed et al., 2018). Table 2-6 shows the soil conditions that cause different nutrient deficiencies.

Table 2-5 Nutrient compositions (%) of fertilizers (Ahmed et al., 2018)

| **Source** | **N** | **P** | **S** | **Ca** | **K** | **Zn** |
|---|---|---|---|---|---|---|
| Urea | 46 | - | - | - | - | - |
| Triple Super Phosphate, TSP | - | 20 | 1.3 | 14 | - | - |
| Single Super Phosphate, SSP | - | 8 | 12 | 20 | - | - |
| Diammonium Phosphate, DAP | 18 | 20 | - | - | - | - |
| Muriate of Potash, MOP | - | - | - | - | 50 | |
| Gypsum | - | - | 18 | 33 | - | - |
| Zinc Oxide | - | - | - | - | - | 78 |
| Ammonium Sulphate, AS | 21.1 | | 23.5 | - | - | - |

Table 2-6 Dominant soil conditions causing deficiency of different nutrient

| Nutrient | Dominant soil conditions causing nutrient deficiency |
|---|---|
| Nitrogen | Low soil organic matter (SOM), submerged soils, sandy soils |
| Phosphorus | Low SOM, acid soils, calcareous soils |
| Potassium | Low CEC, sandy soils, low mineral K |
| Calcium | Acid sandy soils, strongly acid peat soils |
| Magnesium | Acid sandy soils, strongly acid peat soils |
| Sulphur | Low SOM soils, submerged soils |
| Iron | Calcareous soils, acid soils with high soil Mn, Cu, and Zn contents |
| Manganese | Sandy soils, high soil Fe, Cu, and Zn contents |
| Zinc | Calcareous soils, saline soils, submerged soils, high P, Ca, Mg, and Cu contents |
| Copper | High soil N, P, and Zn contents, peat soils, calcareous soils |
| Boron | Sandy soils, calcareous soils, low SOM soils, peat soils |
| Molybdenum | Acid soils, sandy soils |

### 2.14 Nutrient uptake by crops

Nutrient uptake by a crop is the resultant product of the nutrient concentration of that crop and the level of yield including by-product. In general, higher is the yield, higher is the removal of nutrients. Modern varieties of crops absorb relatively higher amounts of nutrients than the traditional varieties as those are cultivated to get a higher yield than the traditional ones. Nutrient uptake by various crops is given in Table 2-7.

Table 2-7 Nutrient uptake by various crops at a particular level of yields

| Crop | Yield (t/ha) | Total nutrient uptake (kg/ha)* N | P | K | S |
|---|---|---|---|---|---|
| Rice (MV) | 6 | 108 | 18 | 102 | 11 |
| Wheat | 4 | 118 | 22 | 98.5 | 17 |
| Maize | 8 | 160 | 29 | 134 | 34 |
| Millet | 0.7 | 30 | 7 | 53 | 4 |
| Potato | 30 | 131 | 20 | 193 | 14 |
| Jute | 3 | 98 | 20 | 200 | 35 |
| Cotton | 10 | 26 | 9 | 70 | - |
| Tobacco | 2 | 130 | 18 | 199 | 10 |
| Sugarcane | 100 | 140 | 25 | 325 | 51 |
| Mustard | 1.5 | 82 | 15 | 91 | 32 |
| Groundnut | 2 | 170 | 13 | 91 | 15 |
| Soybean | 3 | 220 | 18 | 141 | 20 |
| Sesame | 1.2 | 62 | 10 | 53 | 14 |
| Sunflower | 3 | 120 | 26 | 199 | 15 |
| Chickpea | 1.5 | 91 | 6 | 47 | 13 |
| Lentil | 1 | 57 | 6.5 | 18 | - |
| Black gram | 1.5 | 118 | 10 | 82 | - |
| Mungbean | 1 | 106 | 21 | 59 | - |
| Pigeon pea | 1.2 | 85 | 8 | 16 | 9 |
| Cabbage | 70 | 110 | 11 | 120 | 24 |
| Cauliflower | 50 | 100 | 18 | 116 | 20 |
| Tomato | 50 | 140 | 29 | 158 | 30 |
| Carrot | 30 | 125 | 24 | 167 | - |
| Cucumber | 40 | 70 | 22 | 100 | - |
| Brinjal | 60 | 175 | 17 | 250 | - |
| Pumpkin | 50 | 90 | 31 | 133 | - |
| Radish | 20 | 120 | 26 | 100 | - |
| Sweet potato | 40 | 190 | 33 | 283 | - |
| Spinach | 25 | 120 | 20 | 166 | - |
| Onion | 35 | 120 | 22 | 133 | 26 |
| Banana | 40 | 250 | 26 | 350 | 15 |
| Pineapple | 50 | 185 | 24 | 290 | 2 |
| Tea | 2 | 128 | 17 | 60 | - |

** Total nutrient uptake (kg/ha) includes nutrient uptake by main product and crop residues.

## 2.15 Nutrient balance

Nutrient balance is the sum of nutrients inputs minus the sum of nutrients outputs; the balance may be positive or negative. Nutrient Balance may also be termed as Nutrient Budget or Nutrient Audit (Ahmed et al., 2018). A positive balance indicates nutrient accumulation and a negative balance shows nutrient depletion (mining). To achieve sustainability, the quantity of nutrients inputs, and outputs could be equal. Nutrient mining may eventually cause soil degradation and affect crop production. On the other hand, excess nutrient accumulation may lead to soil and water pollution. With the advancement of time, nutrient balance is becoming more negative as shown in Figure 2-8. On the other hand, the addition of organic manure may help reduce negative balances; the magnitude depends on the types and amounts of manure. Any reduction of removal of crop residues would have a positive influence on nutrient balance and this is especially important for K (Ahmed et al., 2018).

Although the nutrient balance value tells us little about the available nutrient status of soils, it has important implications when considering the future long-term total status of nutrients in soils. To minimize nutrient depletion, it is not justified to just increase the use of inorganic fertilizers, rather the organic sources of plant nutrients, especially cow dung, poultry manure, solid waste, etc. need to be considered.

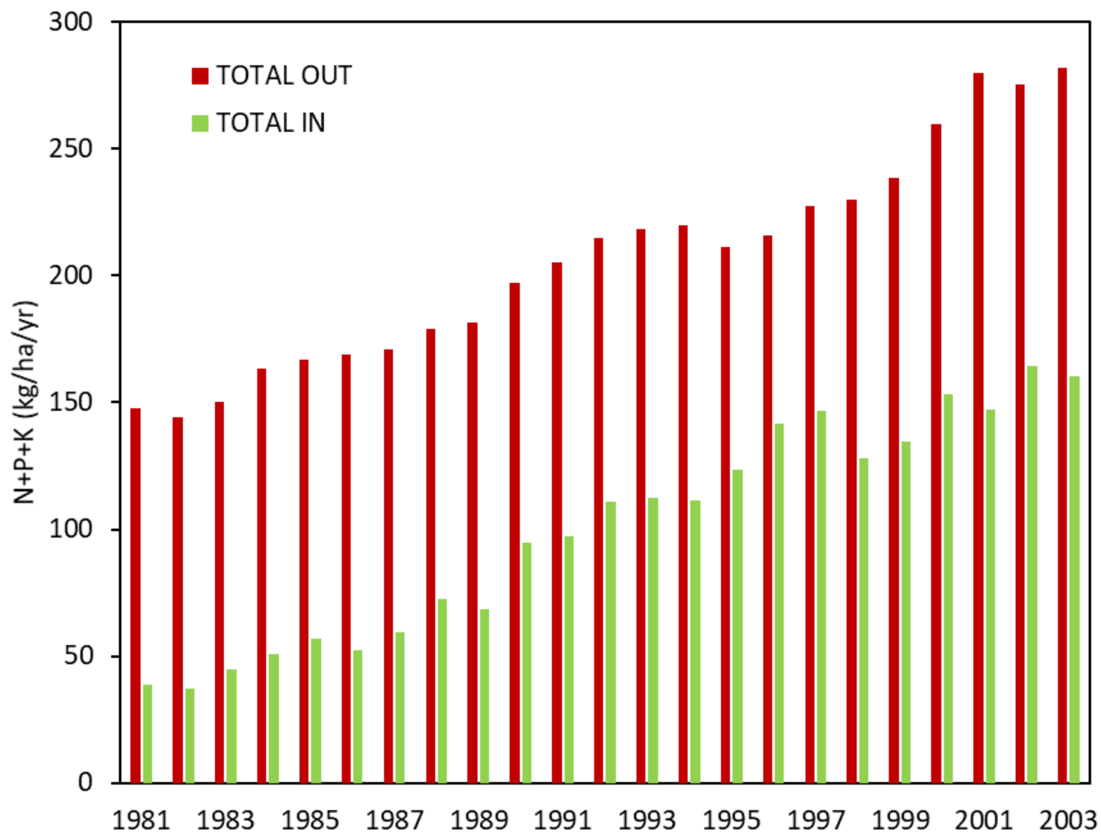



Figure 2-8 Total N+P+K Input and output in Bangladesh

### 2.16 Effect of chemical fertilizer

The effect of chemical fertilizer was studied by (Savci, 2012). The authors found that soil salinity, heavy metal accumulation, water eutrophication, and accumulation of nitrate increased due to excessive use of chemical fertilizers. Shamim Uddin & Kurosawa (2011) reported that there were high levels of arsenic under high ammonium nitrogen concentration in the groundwater in Bangladesh. The source of this nitrogen was nitrogen-based fertilizers. Roy et al. (2016) found that the continuous application of fertilizer in agricultural lands reduces soil fertility evolving nutrient deficiency in the soil; resulting in reduced crop productivity.

### 2.17 Potential for Organic Liquid Fertilizer

Liquid organic fertilizer is one type of artificial fertilizer that is derived from living organisms and can be soluble easily in the soil as well as contains some important particles for growing the plant (Govere et al., 2011). This fertilizer has not been fully used by farmers who still depend on chemical fertilizers which can acidify the soil and cause irreparable damage (Chen, 2006). As for Sopha & Uhan (2013) expresses that the compact organic fertilizer such as manure and compost has also left with some disadvantage such as their low density and low nutrient content. While advantages of liquid organic fertilizer, according to Govere et al. (2011)and Sopha & Uhan (2013), can improve the physical properties, chemical properties, and biological properties of the soil as well as it leads to faster nutrient supply than compact organic fertilizers do.

### 2.18 Organic Liquid Fertilizer from Food waste

Govere et al. (2011) assessed the nutrient content of three organic liquid fertilizers made from Water Hyacinth (*Eichhornia Crassipes*), Russian Comfrey (*Symphytum officinale*), and Pig Weed red-root (*Amaranthus retroflexus*) plants. The liquid manures were made by shredding plant materials and fermenting them in water for 30 days. Samples were analyzed weekly for nitrogen, phosphate, and potassium (NPK) and trace elements. Water Hyacinth liquid manure had significantly high N (3.72%) and P (2.86%) contents indicating its suitability as a macronutrient fertilizer. All liquid manures had high K contents, particularly Russian Comfrey (3.90%), hinting against the direct foliar application. Pig weed had high levels of Ca, Zn, and Mg suggesting its suitability as a sufficient micronutrient fertilizer. All liquid manures were found to have NPK contents greater than common solid organic fertilizers such as cattle manure. Akib & Setiawati (2017) utilized whey waste through an anaerobic process as an organic liquid fertilizer. The results showed that the fermented whey waste on the different fermentation time and yeast concentration had increased the organic C and C/N ratio, but decreased $P_2O_5$ and $K_2O$ contents. The utilization of whey combined with solid or other liquid wastes gave a chance to produce a quality organic liquid fertilizer. The research works of Jamilah (2017) concluded that Crocober organic fertilizer product derived from *Chromolaena odorata* is the best liquid organic fertilizer (LOF) type and has better quality than commercial LOF which is distributed in the market.

Ranasinghe et al. (2019) assessed the nutrient release potential and the weight loss dynamics during leaching of *Tithonia diversifolia*, *Sphagneticola trilobata*, *Mikania scandens*, *Lantana camara*, *Chromolaena odorata*, *Panicum maximum,* and *Mimosa pigra* weeds to utilize them as organic liquid fertilizers. 30 samples from each species of oven-dried leaves (5 g) were placed separately in 1 L of distilled water. Three samples of each species were randomly collected at 1, 3, 5, 7, 14, 28, 42, 56, 70, and 84 days and the mass-loss, electrical conductivity (EC), pH, and nutrient contents of the leachates were determined. It was found that nutrient contents of the leachates of *Tithonia diversifolia*, *Mikania scandens,* and *Chromolaena odorata* were higher than those of *Panicum maximum*. The results are suggestive of the potential of utilizing *Tithonia diversifolia*, *Mikania scandens,* and *Chromolaena odorata* for the formulation of organic fertilizers which would, in turn, be a low-cost strategy for effective control of these weeds. Ranasinghe et al. (2019) also assessed the potential of fish waste hydrolyzed with fruit wastes of papaw (*Carica papaya*) and pineapple (*Ananas comosus*) to enhance the nitrogen content of organic liquid fertilizers. They were mixed separately with 400g of powdered fish waste and incubated for two days at room temperature. Six different fertilizer combinations were prepared by mixing enzymatically digested fish waste with eight-week decomposed plant leaves and immature stems of *Tithonia diversifolia*, *Mikania scandens*, *Chromolaena odorata,* and *Gliricidia sepium* with coconut husk ash and allowed to decompose for another two weeks. Results revealed that, the nitrogen content was higher in fertilizers enriched with fish waste hydrolyzed by papain (0.49%), bromelain (0.38%) and the mixture of both enzymes (0.35%) compared to the control (0.30%). Findings of this study recommend the use of the above organic waste in production of organic liquid fertilizers which would in turn be a low-cost and an eco-friendly alternative for the chemical fertilizers while helping for the sustainable nutrient management and recycle of wastes.

In the study by Sunarti & Untailawan (2020), tofu waste and sago pulp were used as liquid organic fertilizer through the fermentation process with the addition of EM4 liquid and the determination of nitrogen and phosphorus elements by the Kjeldahl method and spectrophotometry. Based on the research results obtained Nitrogen levels in tofu waste, sago pulp, and liquid organic fertilizer in a row: 2.2558%; 0.4236%, and 0.0382%. While the phosphorus content in a row: 0.024%; 0.014%; and 0.012%. The results of the application of liquid organic fertilizer on mustard plants gave a tendency to increase plant height, leaf length, leaf width of mustard plants, but there was no addition of leaf blade for 14 days after planting. Utama et al., (2017) worked on a combination of whey (cheese-making wastes) with napa cabbage wastes, which showed great potential for bioconversion into ethanol and organic liquid fertilizer as a way to reduce the pollution load.

Economic feasibility is determined by calculating the joint cost allocation with the approach of the market price method and the breakeven point (BEP). The results showed that bioconversion of cheese whey and napa cabbage waste resulting savings of wastes disposal costs, the financial benefits up to US$ 3,816.96 per month, reduce the variable cost of the main product by 14.73% and attained the breakeven point in 3.53 months. From the previous research, it is seen that the different types of food waste have the potential to be used as liquid organic fertilizer.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

A laboratory test program was carried out to assess the feasibility of using the leachate from the fruit and vegetable wastes as liquid organic fertilizer. The test program had the following steps:

- Preparation of leachate collection buckets
- Preparation of samples
- Testing of the leachate generated
- Analysis

## 3.2 Preparation of Leachate Collection Buckets

For each fruit, a two-gallon plastic bucket with a lid was used as a leachate collection bucket. A strainer with an elastic top was suspended inside. The strainer had a mesh size of 600 microns (0.6 mm), which was enough to hold back the solid waste from mixing with the leachate collected at the bottom. The components used to prepare the leachate collection bucket and the final setup is shown in Figure 3-1.


Figure 3-1 Bucket for leachate collection; (a) 2-gallon plastic bucket; (b) bucket lid; (c) elastic top strainer; (d) strainer strapped on the top of the bucket with a rubber band; (e) final setup of the leachate collection bucket.

## 3.3 Sample Preparation

Among the common fruits and vegetables of Bangladesh listed in APPENDIX A and APPENDIX B, some are selected were selected for the study as on their availability on the local market. A list of the fruits and vegetables used is given in Table 3-1. The fruits and vegetables were washed properly, peeled, and cut into bite-size pieces with a knife and peeler Figure 3-2.

Table 3-1 List of fruit and vegetables samples used

| FRUITS | VEGETABLES |
|---|---|
| Apple | Ash Gourd |
| Banana | Bitter Melon |
| Cantaloupe | Broccoli |
| Durian | Cauliflower |
| Durian | Cabbage |
| Jackfruit | Carrot |
| Jackfruit | Cucumber |
| Jackfruit | Eggplant |
| Mango | Green Beans |
| Mango | Green Papaya |
| Orange | Lemons. |
| Pineapple | Okra |
| Rambutan | Potato |
| Watermelon | Pumpkin |
| Apple | Radish |
| Banana | Spinach |
| | Cilantro |
| | Tomato |

The wastes generated from the fruits and vegetables were mostly inedible peels (Figure 3-3 to Figure 3-5). Other than that, there were some leafy parts of both fruit and vegetable that are not edible (Figure 3-6 and Figure 3-7). Images of some wasted parts of jackfruit and durian are shown in Figure 3-8 and Figure 3-9

Figure 3-2 Preparation of the fruits for consumption

Figure 3-3 Wastes from pineapple - peels

Figure 3-4 Wastes from oranges - peels

Figure 3-5 Peeling vegetables

Figure 3-6 Throwing away leaf of pineapple

Figure 3-7 Cutting vegetables into smaller pieces

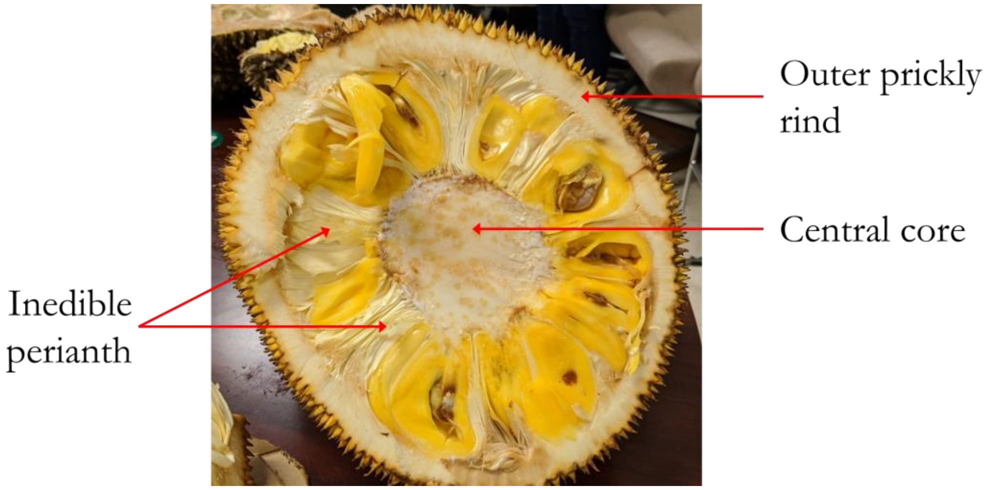



Figure 3-8 Inedible parts of the jackfruit

(a)

(b)

Figure 3-9 Wastes produced from (a) jackfruit and (b) durian.

The wastes generated during preparation and after consumption were collected in several marked buckets as shown in Figure 3-10 and Figure 3-11. The wastes generated from the fruits like apple, banana, and orange were dry and were easier to collect. The wastes from the rest of the fruits were wet. Except for tomato, all the vegetables were dry.


Figure 3-10 Buckets prepared for waste collection

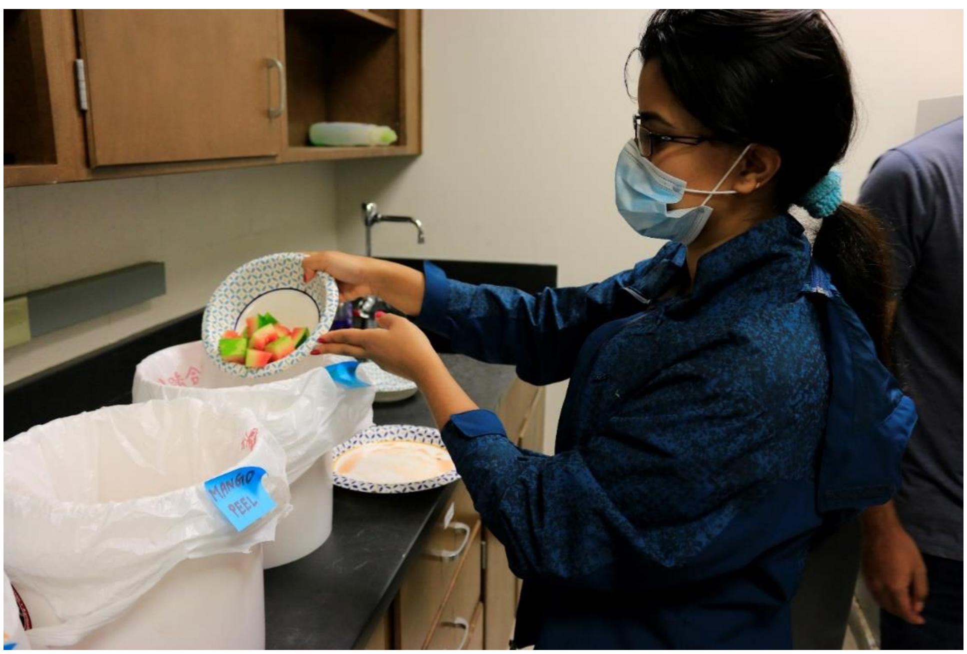



Figure 3-11 Collection of fruit wastes in separate marked buckets

### 3.4 Filling Up Leachate Collection Buckets

Since shredding of waste improves waste decomposition, the fruit wastes collected in the separate buckets were shredded into smaller pieces. Then the fruit wastes were weighed separately and transferred to leachate collection buckets one by one. A schematic diagram of the cross-section of the leachate collection bucket is provided in Figure 3-12. The waste was suspended with the strainer in such a way that there will be sufficient separation between the wastes and the leachate at the bottom. Figure 3-13 shows all the buckets after those are filled up. Then the lids were tightly fitted, and the buckets were labeled. Finally, the buckets were kept at room temperature (77 °F or 25 °C) as presented in Figure 3-14 and Figure 3-16. The buckets were kept in this condition for 28 days and every 7 days the following chemical properties of the leachate were monitored:

- pH
- nitrate content
- phosphate content
- potassium content

To accelerate the process of leachate generation, 500 mL of distilled water was added to the dry wastes.

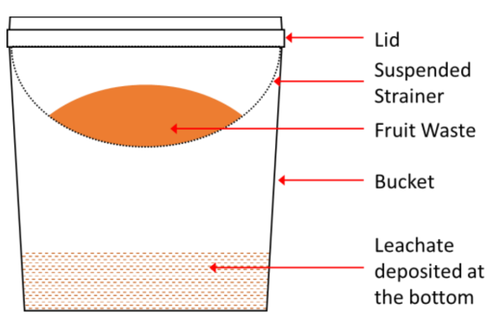



Figure 3-12 Schematic diagram of the cross-section of the leachate collection bucket filled.

(i)
Apple – Peel, flesh, and seeds

(ii)
Banana – Peel and flesh

(iii)
Cantaloupe - Peel, flesh, and seeds

(iv)
Durian – Flesh and seeds

(v)
Durian – Husk

(vi)
Jackfruit – Inedible flesh

(vii)
Jackfruit – Rind

(viii)
Mango – Peel, flesh, and seed (Rotten)

(ix)
Mango – Peel, and seed

(x)
Orange – Peel, and seed

(xi)
Pineapple – Leaves, Peel and Core

(xii)
Rambutan – Peel, and seeds

(xiii)
Watermelon – Peel and seeds

Figure 3-13 Fruit wastes inside the leachate collection buckets.


Figure 3-14 Leachate collection buckets from phase - 1 kept on racks at room temperature

(i)
Ash Gourd - Whole

(ii)
Bitter Melon - Whole

(iii)
Broccoli + Cauliflower - Whole

(iv)
Cabbage - Whole

(v)
Carrot - Whole

(vi)
Cucumber - Whole

(vii)
Eggplant - Whole

(viii)
Green Beans - Whole

(ix)
Green Papaya - Whole

(x)
Lemons - Whole

(xi)
Okra - Whole

(xii)
Potato - Whole

(xiii)
Pumpkin - Whole

(xiv)
Radish - Whole

(xv)
Spinach + Cilantro - Whole

(xvi)
Tomato - Whole

(xvii)
Jackfruit - Leftover

(xviii)
Jackfruit - Peel

(xix)
Mixed Vegetable - 1

(xx)
Mixed Vegetable - 2

(xxi)
Fruits + Vegetable (50-50 Mix)

(xxii)
Fruits - All peel

(xxiii)
Fruits - All leftover

Figure 3-15 Vegetable wastes inside the leachate collection buckets


Figure 3-16 Leachate collection buckets from Phase 2 kept on racks at room temperature.

## 3.5 Monitoring the chemical properties of the leachate generated

### 3.5.1 Collection of Leachate

The leachate deposited at the bottom of the bucket (Figure 3-17) was collected by removing the lid and the strainer from the top of the bucket. 40 mL of the sample liquid was taken for testing by inverting the bucket. After the required quantity of liquid is taken out, the strainer and the lid were replaced.

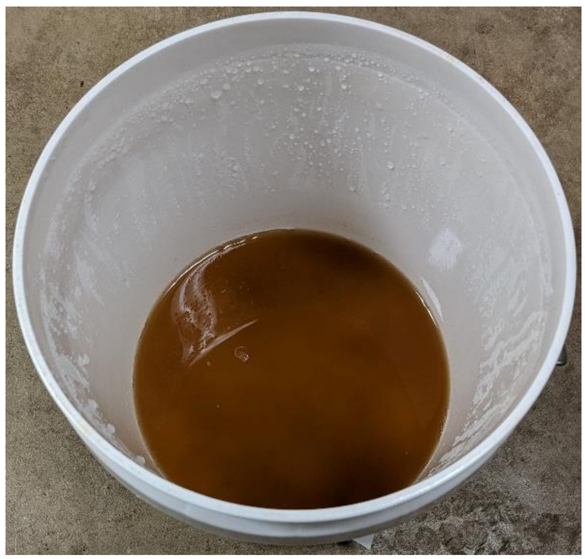


Figure 3-17 Leachate collected from apple waste.

### 3.5.2 Determination of pH

The pH of the collected leachate was measured using Benchtop Oakton pH 700 meters. The pH meter was calibrated using a three-point calibration method. The pH buffer solutions of pH 4.00 ± 0.01, pH 7.00 ± 0.01, and pH 10.00 ± 0.01 were used for calibrating the probes. Figure 3-18 shows pH measurement using Oakton pH 700 meters. The probe was dipped in the collected leachate. When the value of pH on the display stabilized, the reading was recorded.

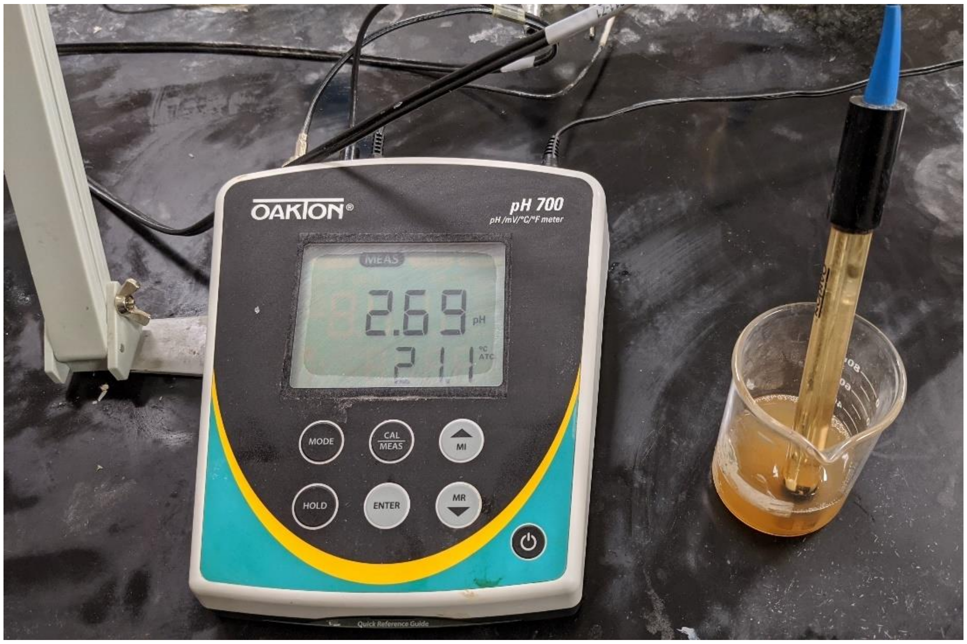



Figure 3-18 Measurement of pH

### 3.5.3 Determination of Nitrate content

LAQUAtwin-NO3-11 pocket meter from HORIBA Advanced Techno Co., Ltd. (shown in Figure 3-19) was used to find the nitrate content of the leachate. It directly measures nitrate ion concentrations in a 0.3 mL sample. It uses the Ion Selective Electrode principle, where the activity of a specific ion dissolved in a solution is converted into an electrical potential for measurement. Before measurement, the pocket meter is calibrated with two standard solutions of 150 ppm and 2000 ppm, shown in Figure 3-20. First, the meter is turned on and the cover is opened to pour enough sample to cover the flat sensor as shown in Figure 3-21. The cover is closed. The data is recorded after the value on the display stabilizes. Then the sensor is washed with distilled water for further testing. The meter has a Nitrate ($NO_3^-$) measurement range of 6 to 9900 ppm (mg/L).


(a) (b)

Figure 3-19 LAQUAtwin-NO3-11 pocket meter for measuring Nitrate content; (a) Light shield closed; (b) light shield opened.


(a) (b)

Figure 3-20 Standard Nitrate solution (a) 150 ppm and (b) 2000 ppm


Figure 3-21 Measuring Nitrate content of leachate with LAQUAtwin-NO3-11 pocket meter.

### 3.5.4 Determination of Potassium content

LAQUAtwin-K-11 pocket meter from HORIBA Advanced Techno Co., Ltd. (shown in Figure 3-22) was used to find the potassium content of the leachate. It uses the Ion Selective Electrode principle, where the activity of a specific ion dissolved in a solution is converted into an electrical potential for measurement. Before measurement, the pocket meter is calibrated with two standard potassium ion solutions of 150 ppm and 2000 ppm, shown in Figure 3-23. First, the meter is turned on and the cover is opened to pour enough sample to cover the flat sensor as shown in Figure 3-24. The cover is closed. The data is recorded after the value on the display stabilizes. Then the sensor is washed with distilled water for further testing. the meter has a potassium ion measurement range of 4 to 9900 ppm (mg/L).


(a) (b)

Figure 3-22 LAQUAtwin-K-11 pocket meter for measuring Potassium content (a) Light shield closed; (b) light shield open.


(a) (b)

Figure 3-23 Standard Potassium solution (a) 150 ppm and (b) 2000 ppm.

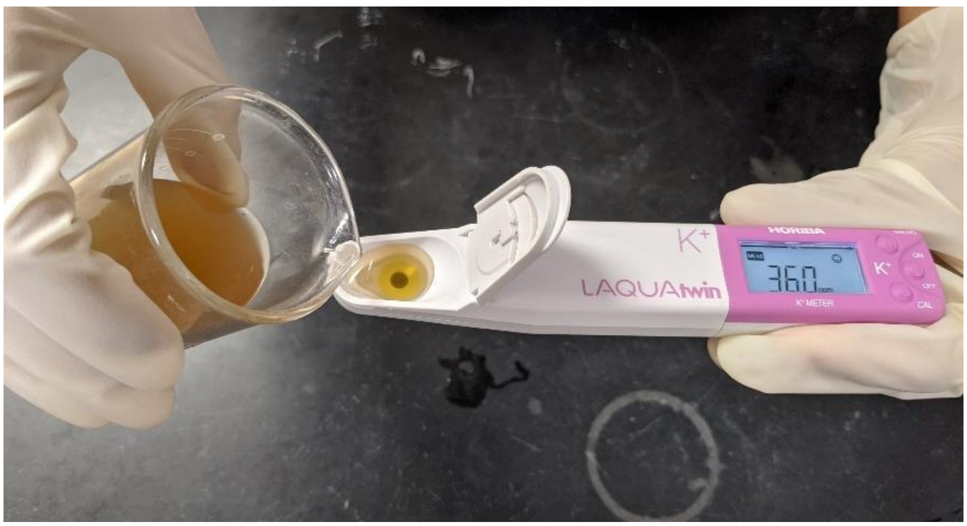
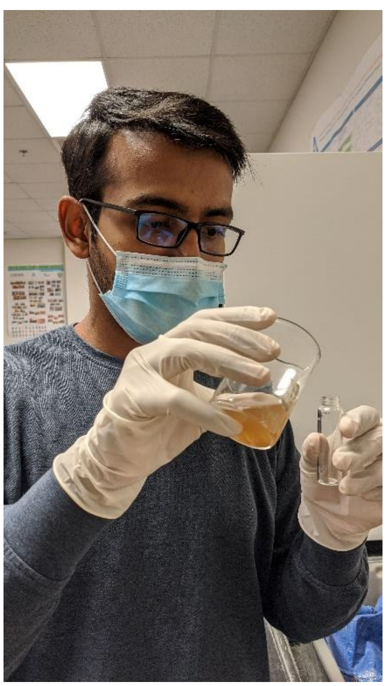



Figure 3-24 Measuring Potassium ion content of leachate with LAQUAtwin-K-11 pocket meter.

### 3.5.5 Determination of Phosphate content

For determining the phosphate content of the leachate, HI717 Phosphate High Range Checker from Hanna Instruments was used. It uses the Heteropoly-molybdenum Blue method, an adaptation of the Standard Methods for the Examination of Water and Wastewater ($18^{th}$ edition), to determine phosphate content. The reaction between orthophosphate (reactive phosphorus) and the reagent causes a blue tint in the sample. The device has a measurement range of 0.0 to 30.0 ppm.

At first, the leachate is poured in the 10 mL cuvette (Figure 3-25 (i)), provided with the instrument. The cap is closed, and the cuvette is placed inside the meter (Figure 3-25 (ii)). The black button on the meter is pressed to check if enough light passes through the sample. After that, 10 drops of HI717AS reagent and the content of one packet of HI717B-0 reagent are added (Figure 3-25 (iii) - (iv)). The reagents are mixed well, and the cuvette is again placed in the meter and the black button is pressed and held until the timer starts. The reading is shown on the display after 5 minutes (Figure 3-25 (v)). Figure 3-26 shows that the color of the sample changes with the proportion of phosphate present.

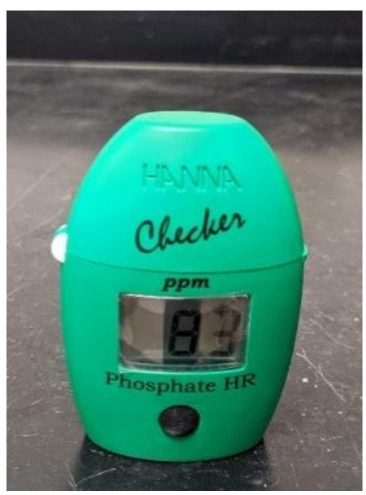


(i)


(ii)


(iii)


(iv)




(v)

Figure 3-25 Measurement of Phosphate content of the leachate with HI717 Phosphate High Range Checker


(a) (b)

Figure 3-26 Color of sample (a) before and (b) after the test is completed.

## CHAPTER 4

## RESULTS AND DISCUSSIONS

### 4.1 Physical condition and chemical properties of Fruit Wastes

The physical condition and chemical properties of the fruit wastes were monitored weekly.

### 4.1.1 Apple waste (Peel, flesh, and seeds)

#### 4.1.1.1 Physical condition

Figure 4-1 shows the degradation of apple waste. It is seen that the light-yellow color of the fleshy part has changed to brown. Comparing the picture from Day - 01 and Day - 28, it can be observed that the pieces shrunk noticeably losing moisture over time.

Day - 01

Day – 07


Day – 14


Day – 21


Day - 28

Figure 4-1 Degradation of Apple waste (Peel, flesh, and seeds)

#### 4.1.1.2 pH

Figure 4-2 shows the weekly variation pH of apple waste. The typical pH value for an apple is 3.3 - 4 (PickYourOwn.org, 2020). On the day - 1 the pH for apple was found to be 4.73. The value went down over time and on the day - 28, the value was 2.92. This indicates that with decomposition the apple waste became more acidic.

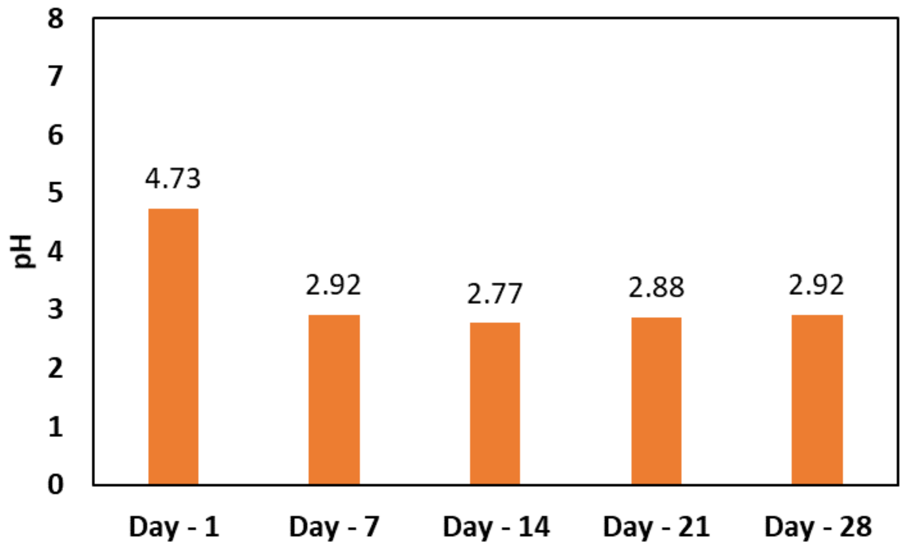



Figure 4-2 Weekly variations of pH of Apple waste (Peel, flesh, and seeds)

#### 4.1.1.3 N-P-K Content

In Figure 4-3 the N-P-K content (in percentage) of the apple waste is shown. It is observed that K content of the apple waste is significantly higher than N and P. The % K was also consistent over 28 days. %N went up and % K went down over time. Existing data (*Mineral Content of Fruit and Vegetables*, 2020) show that % of nitrogen is negligible and % of P and K are 6.52% and 88.54% respectively. The value of % P obtained from the current study is lower than this value but the value of % K is very close.

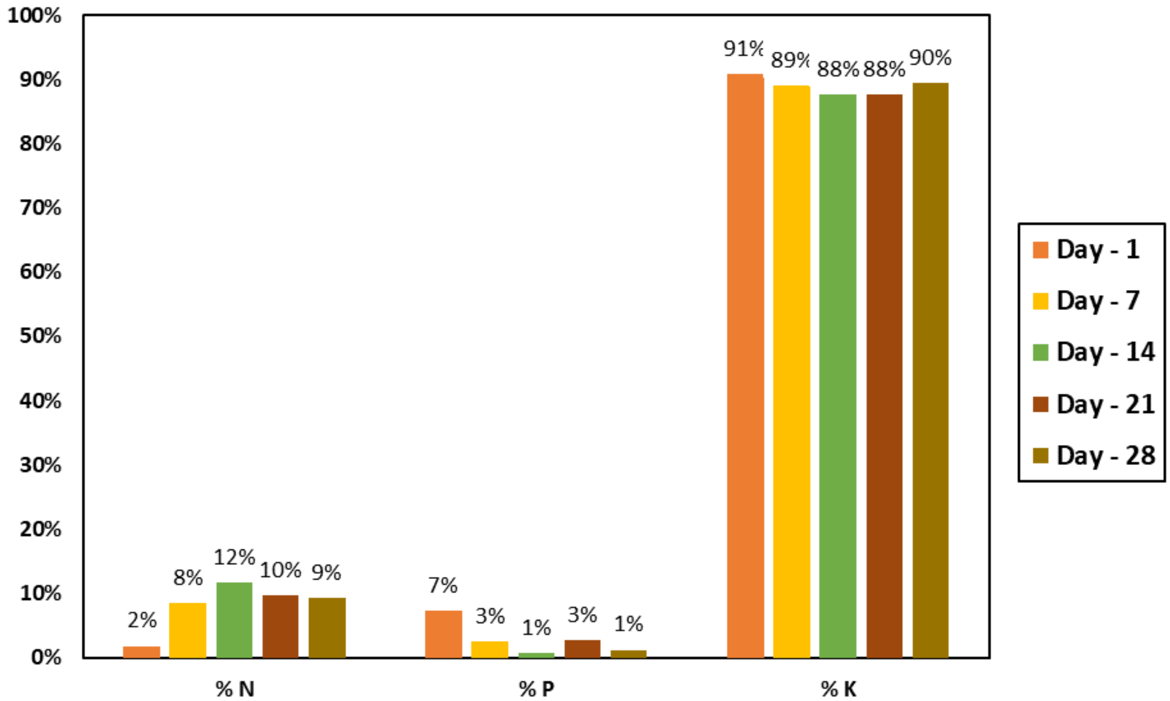



Figure 4-3 Percent distribution of N-P-K for Apple waste (Peel, flesh, and seeds)

### 4.1.2 Banana waste (Peel and flesh)

#### 4.1.2.1 Physical condition

Figure 4-4 shows the degradation of the Banana waste. The yellow color of the outer side of the banana peel turned black and the inner part turned brown over time. Due to loss of moisture the volume of the waste shrunk over time.

Day - 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-4 Degradation of Banana waste (Peel and flesh)

#### 4.1.2.2 pH

The pH for bananas can vary from 4.5 to 5.2 (PickYourOwn.org, 2020). In the current study, the pH value is close to this range as shown in Figure 4-5.

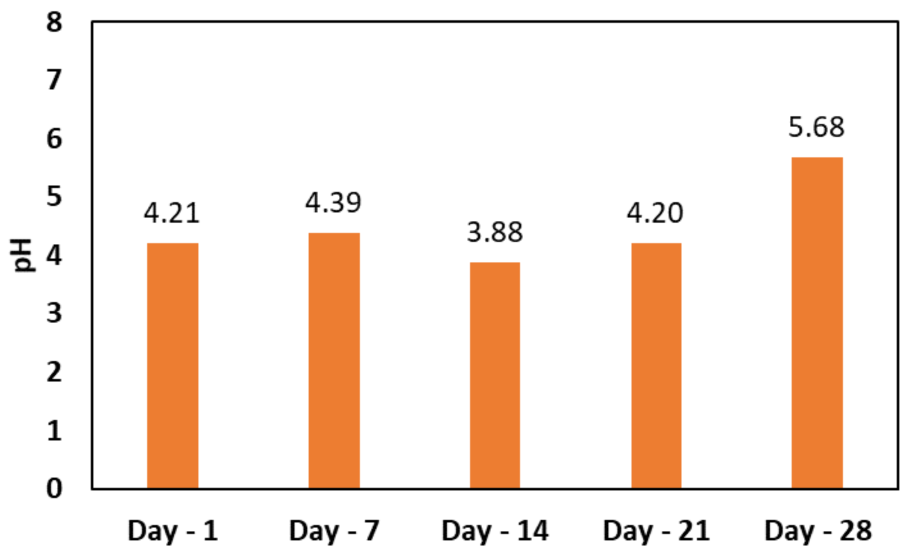



Figure 4-5 Weekly variations of pH of Banana waste (Peel and flesh)

#### 4.1.2.3 N-P-K content

In Figure 4-6 the N-P-K content (in percentage) of the banana waste is shown. The % N and % P for banana is low (< 10 %) and % K is very high in the range of 90 %. There is less variation of these percentages. Existing data (*Mineral Content of Fruit and Vegetables*, 2020) show that % of nitrogen is negligible and % of P and K are 6.40% and 84.89% respectively. In the current study the % of N and P are similar and % K is close to the previously reported value.

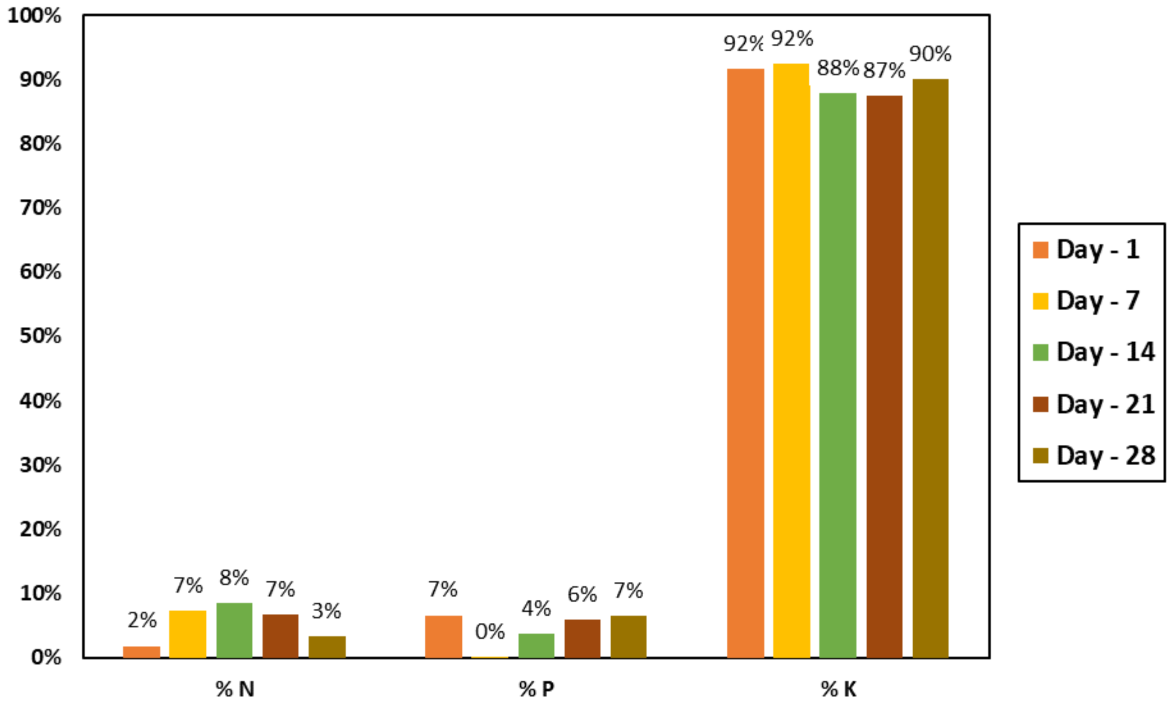



Figure 4-6 Percent distribution of N-P-K for Banana waste (Peel and flesh)

### 4.1.3 Cantaloupe waste (Peel, flesh, and seeds)

#### 4.1.3.1 Physical condition

**Figure 4-7** shows the gradual degradation of cantaloupe waste over 28 days. It was observed that the volume of the waste was reduced due to loss of moisture. White fungus started developing on the surface of the waste. Within 28 days the whole waste was covered with fungus. The color of the waste became pale.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-7 Degradation of Cantaloupe waste (Peel, flesh, and seeds)

#### 4.1.3.2 pH

From the existing data (PickYourOwn.org, 2020) it was seen that the pH of cantaloupe remains between 6.13 to 6.58. So naturally cantaloupe is less acidic. In the current study, it was seen that the pH of the cantaloupe waste was 4.06 on day - 1 and it increased over time i.e. the waste became less acidic (Figure 4-8).

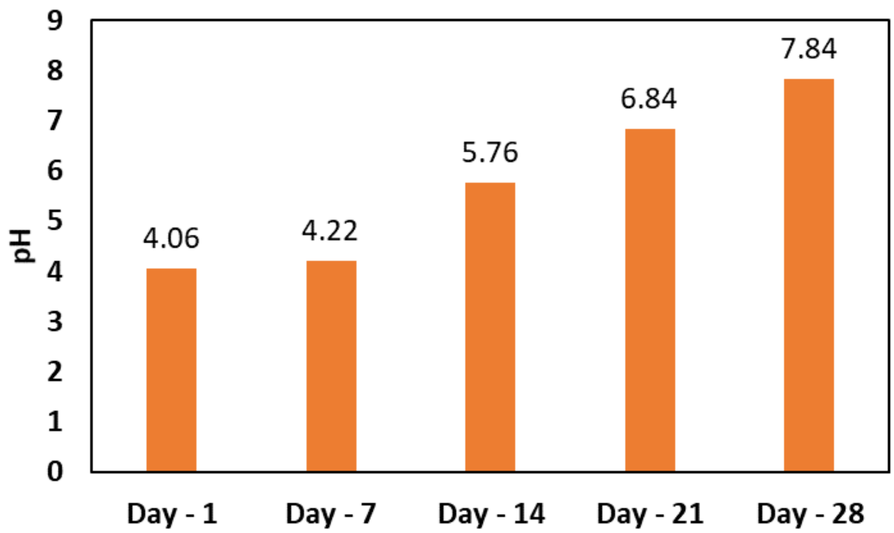



Figure 4-8 Weekly variations of pH of Cantaloupe waste (Peel, flesh, and seeds)

#### 4.1.3.3 N-P-K content

The existing data on the mineral content of cantaloupe shows that the amount of nitrogen present is negligible and the fruit has a very high proportion of K (95 %) and some amount of phosphorus (5.32 %) (PickYourOwn.org, 2020). A similar trend can be seen in the data obtained from the current study (shown in Figure 4-9). The % K is significantly higher than % N or % P.

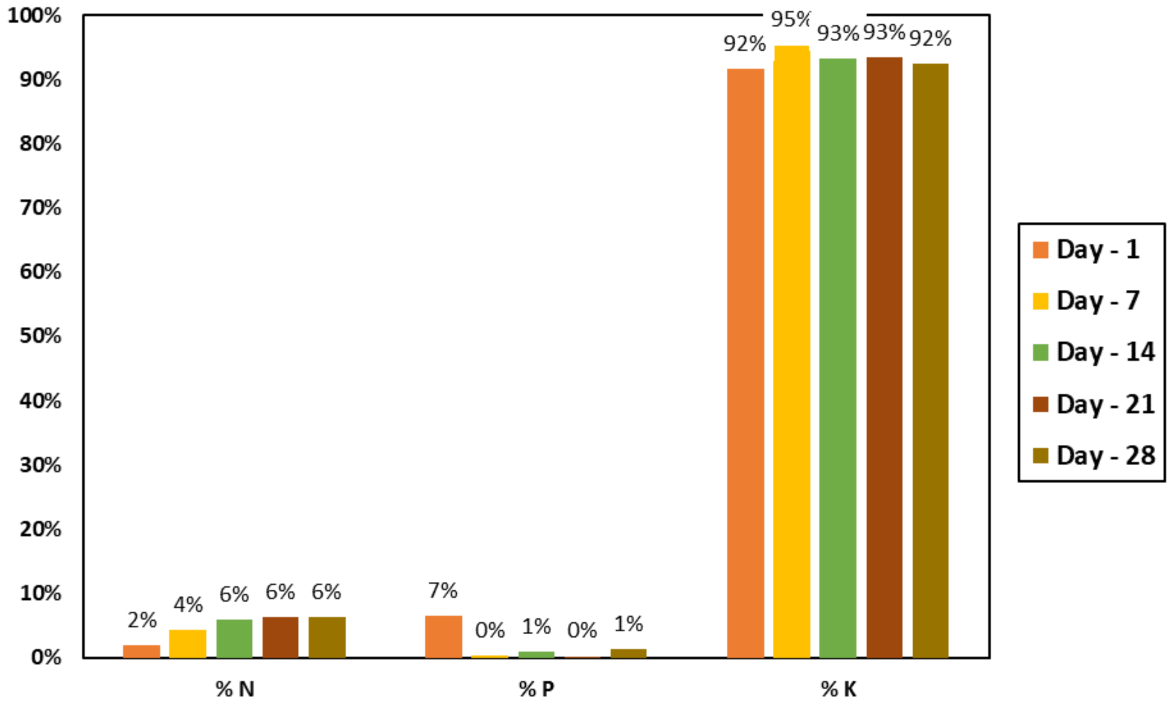



Figure 4-9 Percent distribution of N-P-K for Cantaloupe waste (Peel, flesh, and seeds)

### 4.1.4 Durian waste (Flesh and seeds)

#### 4.1.4.1 Physical condition

The degradation of the durian waste (Flesh and seeds) is shown in Figure 4-10. From the 1 st day white fungus developed on the surface of the waste. The fungus spread over the 28 days and covered the waste entirely.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-10 Degradation of Durian waste (Flesh and seeds)

#### 4.1.4.2 pH

The pH variation for Durian waste (Flesh and seeds) is shown in Figure 4-11. Leisner et al.(2001) reported that the pH of fresh durian ranged pH between 6.63–6.83. From the experimental data, it was seen that on the 1st day pH of the durian waste was 4.73, which is acidic. With gradual degradation, the pH raised to 7.56. The pH range observed in the experiment is much wider than suggested from the previous research.

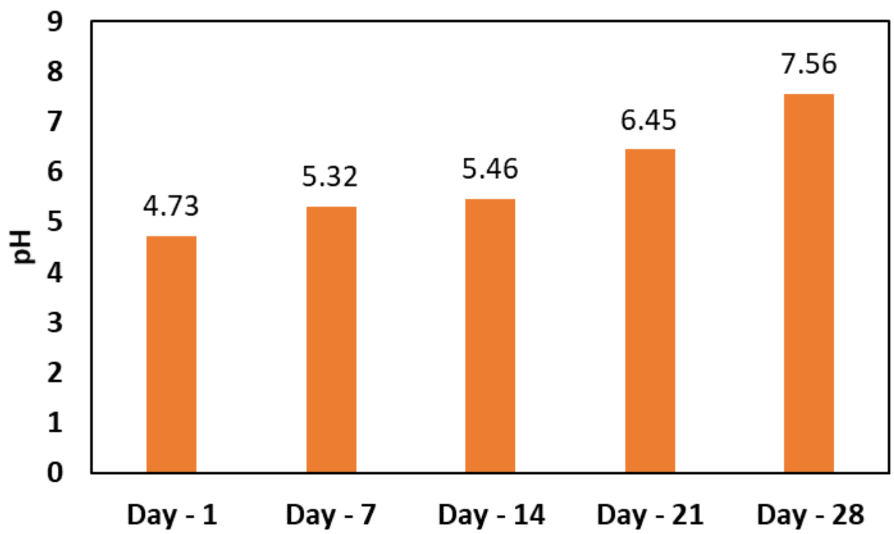



Figure 4-11 Weekly variations of pH of Durian waste (Flesh and seeds)

#### 4.1.4.3 N-P-K content

Figure 4-12 shows the % of N-P-K obtained from the study. It shows that % K is significantly greater than % P and % N. From existing data it was found that the % P is 8.21% and % K 91.79% in raw durian (USDA, 2007), whereas, % N is negligible. In the current study, the amount of Nitrogen on the last day was found to be 13 %.

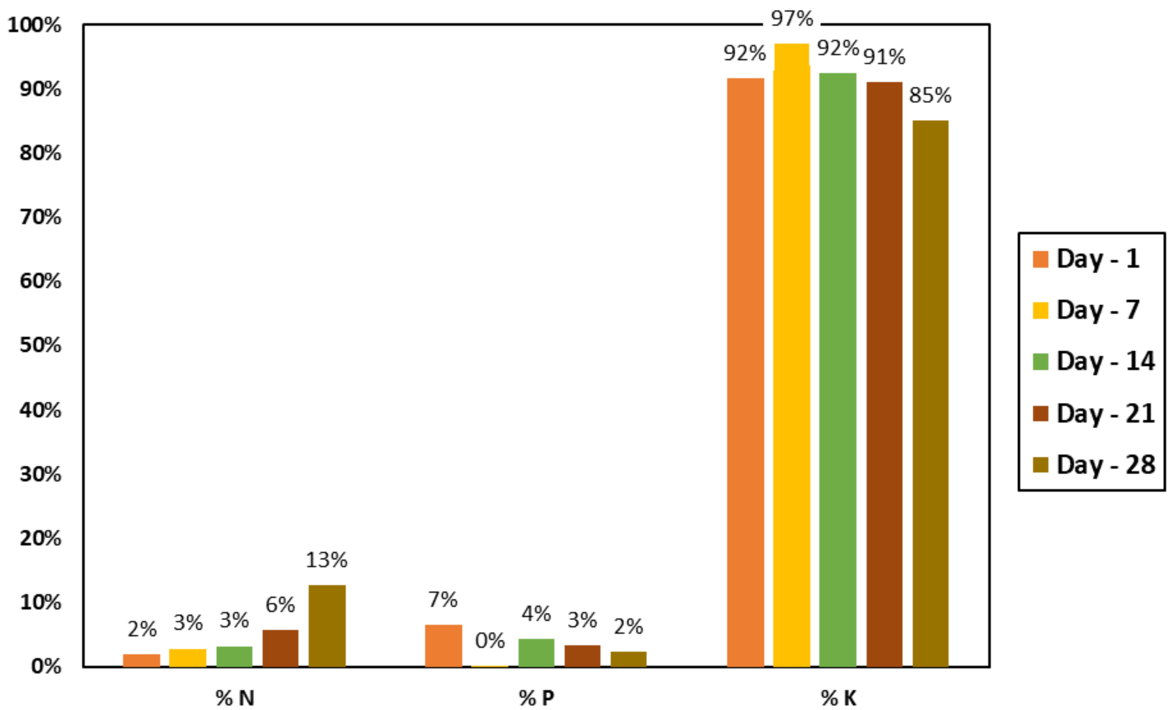



Figure 4-12 Percent distribution of N-P-K for Durian waste (Flesh and seeds)

### 4.1.5 Durian waste (Husk)

#### 4.1.5.1 Physical condition

Figure 4-13 shows the change in durian husk waste over 28 days. Over this period, the degradation of waste is very less and so there was no noticeable change of volume of the waste. Only there was the presence of some white fungus on the waste.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-13 Degradation of Durian waste (Husk)

#### 4.1.5.2 pH

It was reported in section 4.1.4.2, that the pH of fresh durian ranged between 6.63–6.83. Comparing Figure 4 11 and Figure 4-14 we can see that the pH variation for flesh and seed waste and husk were different. Similar to durian flesh and seed waste the pH of the husk waste did not increase gradually. The final pH for durian flesh and seed waste (7.84) was higher than for the husk (6.46).

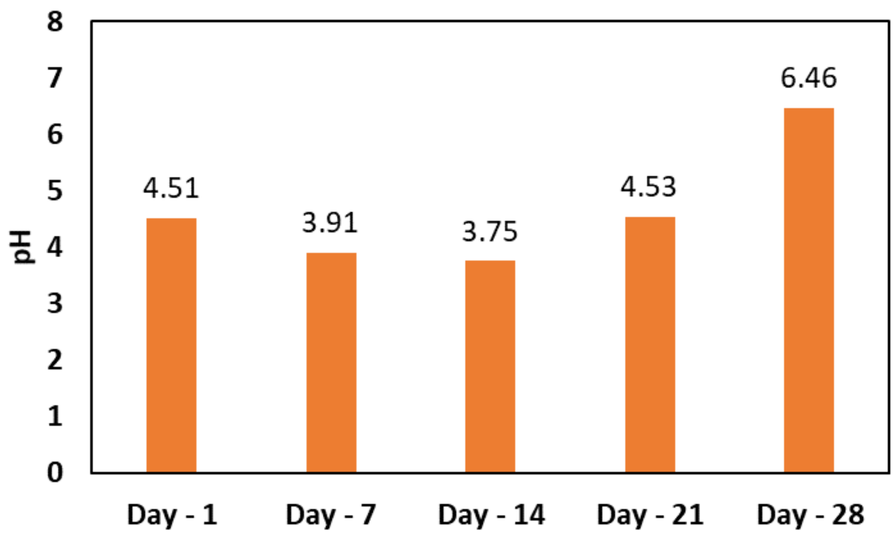



Figure 4-14 Weekly variations of pH of Durian waste (Husk)

#### 4.1.5.3 N-P-K content

N-P-K content for the durian husk waste (Figure 4-15) showed a similar pattern to that on durian peel and seed waste (Figure 4-12).

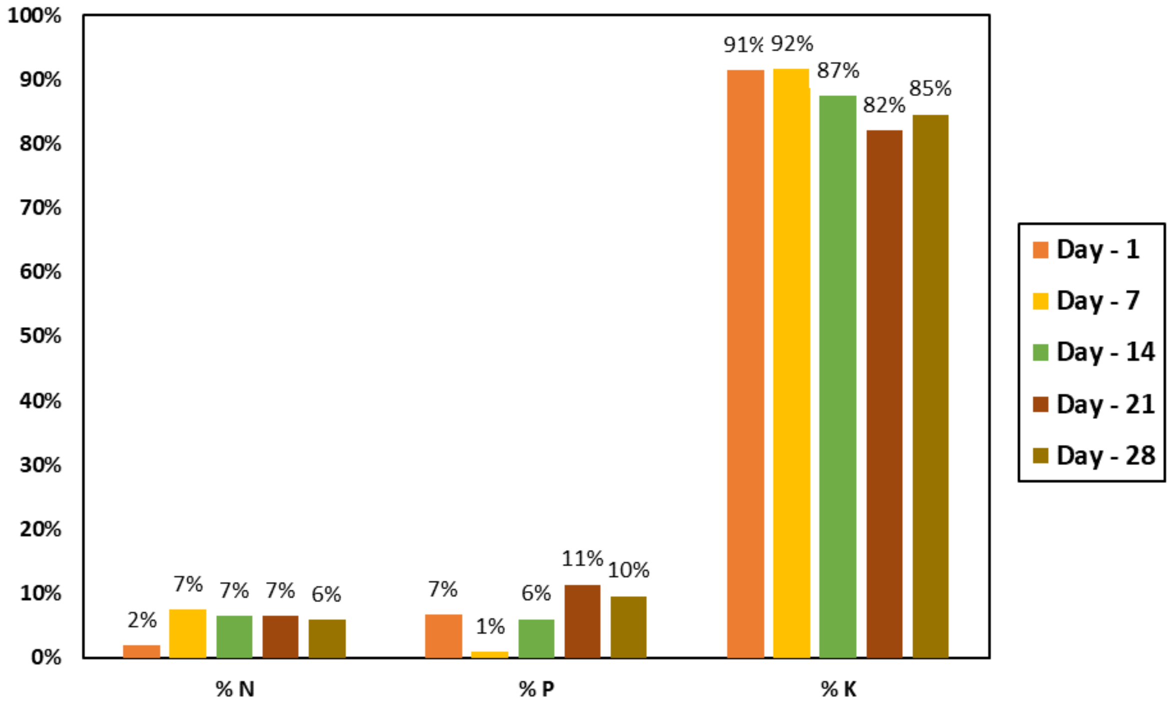



Figure 4-15 Percent distribution of N-P-K for Durian waste (Husk)

### 4.1.6 Jackfruit waste (Inedible flesh)

#### 4.1.6.1 Physical condition

In Figure 4-16 it is seen that as the inedible parts of jack fruit degraded over time, the bright yellow color of the waste was lost. Like other samples growth of the white fungus was observed on the surface.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-16 Degradation of Jackfruit waste (Inedible flesh)

#### 4.1.6.2 pH

The pH of raw Jackfruit can vary from 4.8 to 6.8 (PickYourOwn.org, 2020). **Figure 4-17** shows the variation of pH of the jackfruit waste over the period of 28 days. The pH value remained close to 4.2 for 21 days. The last pH value was found to be 5.95. The leachate was getting less acidic over time.

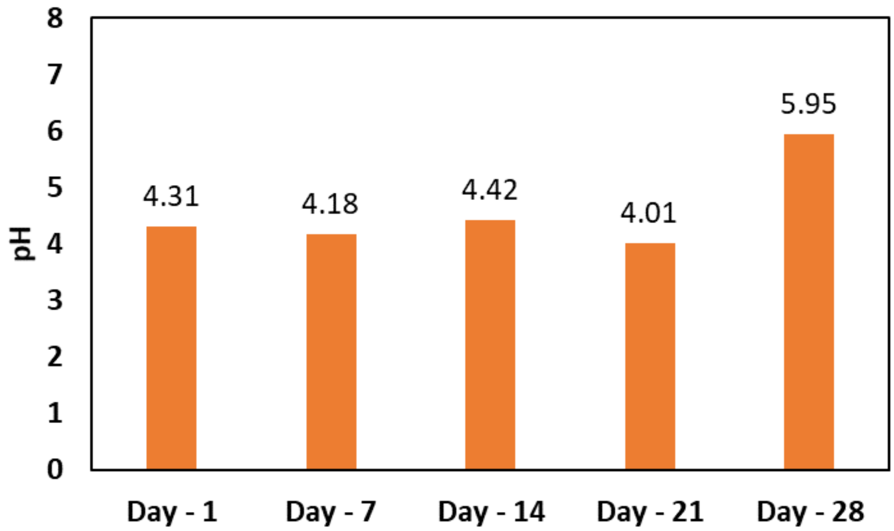



Figure 4-17 Weekly variations of pH of Jackfruit waste (Inedible flesh)

#### 4.1.6.3 N-P-K content

The N-P-K percentage for jackfruit flesh waste is shown in Figure 4-18. The % N increased over time. But the maximum portion of the fruit contained potassium, as represented by the high percentage % K (maximum of 95 %). Existing data shows that the % P and % K in raw jackfruits is 4.48% and 95.52%, respectively (USDA, 2007).

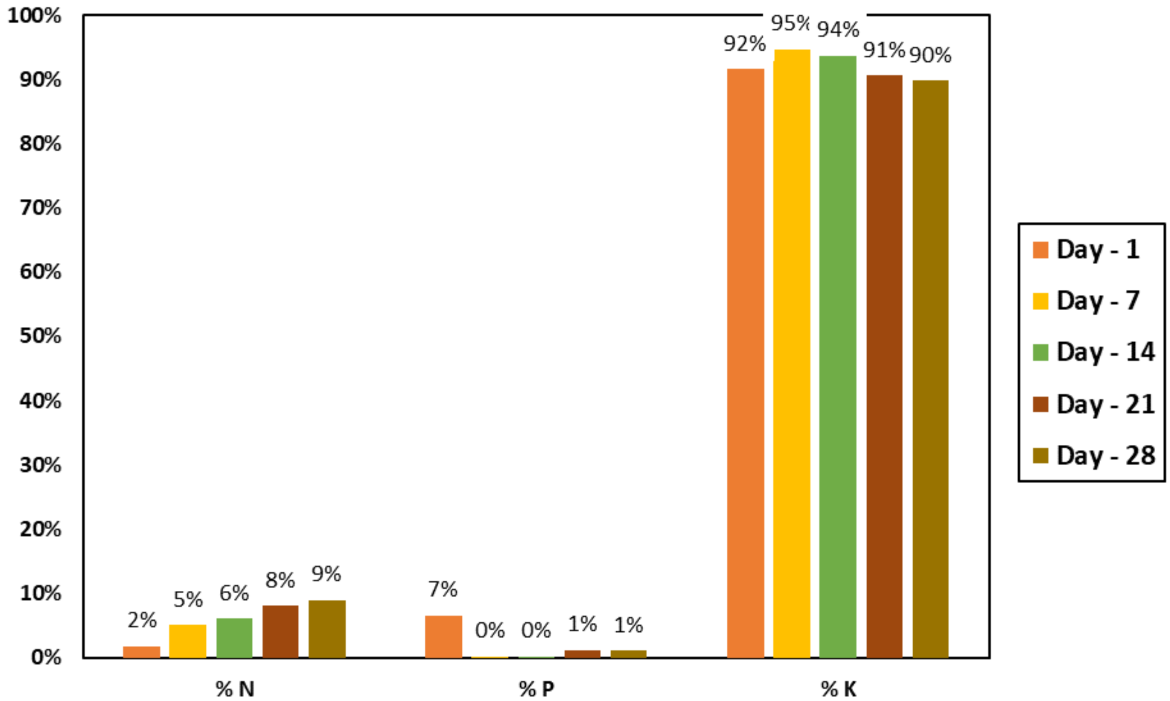



Figure 4-18 Percent distribution of N-P-K for Jackfruit waste (Inedible flesh)

### 4.1.7 Jackfruit waste (Rind)

#### 4.1.7.1 Physical condition

The condition of the jackfruit rind waste is shown in Figure 4-19. The waste gradually degraded and became dark-colored. The whole of the waste was covered by fungus, which spread over time.

Day – 01 Day – 07

Day – 14 Day – 21

Day - 28

Figure 4-19 Degradation of Jackfruit waste (Rind)

#### 4.1.7.2 pH

The pH of raw Jackfruit can vary from 4.8 to 6.8 as mention in the previous section. From Figure 4-20 it can be observed that the pH of the jackfruit rind gradually went up. The fruit waste was acidic on day - 01 but on day - 28. it passed pH 7,

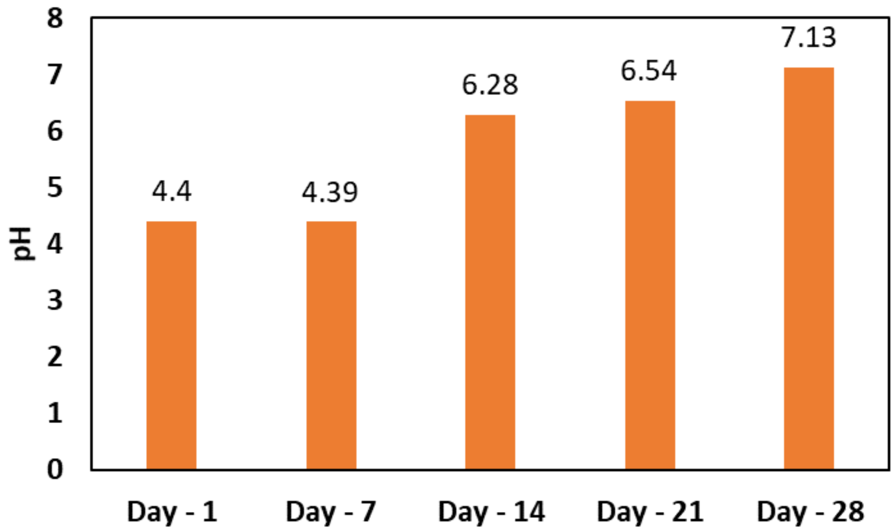



Figure 4-20 Weekly variations of pH of Jackfruit waste (Rind)

#### 4.1.7.3 N-P-K content

The N-P-K % for the jackfruit rind waste, shown in Figure 4-21 is similar to Figure 4-18. Jackfruit rind has a lower amount of Nitrogen and Phosphorus. The amount of potassium is the highest (92 %).

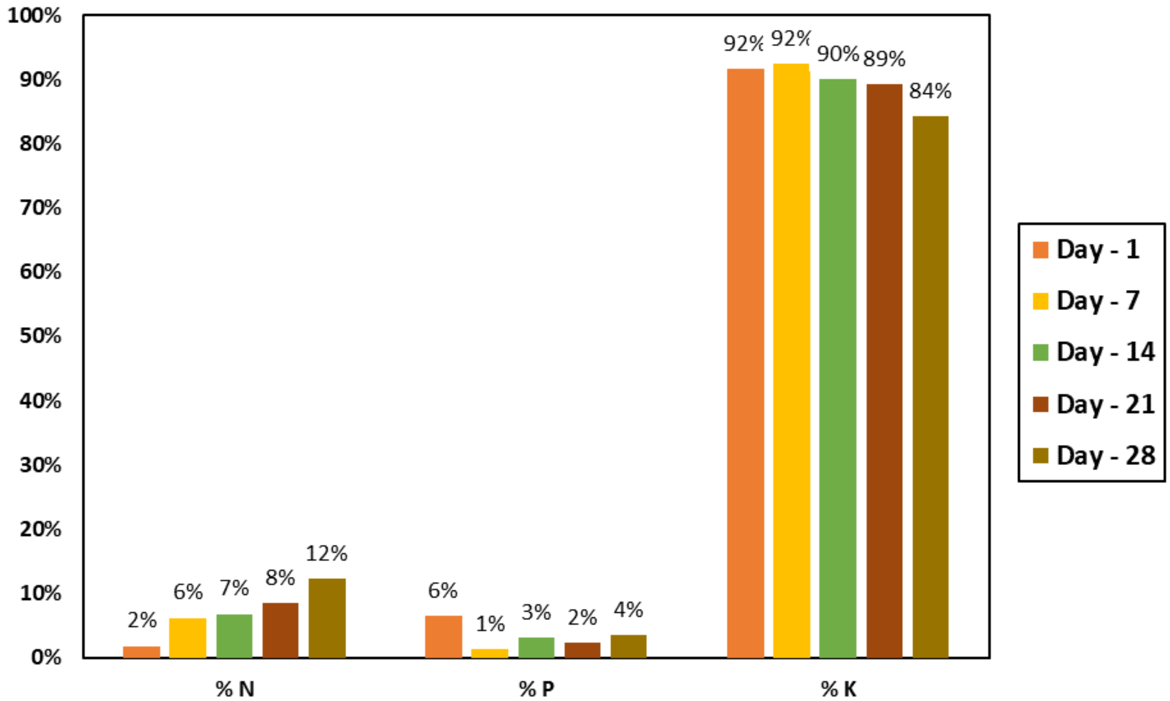



Figure 4-21 Percent distribution of N-P-K for Jackfruit waste (Rind)

### 4.1.8 Mango waste (Peel, flesh, and seeds (Rotten))

#### 4.1.8.1 Physical condition

The sample used (shown in Figure 4-22) was kept aside for 3 days before transferring into the bucket. So, the sample was already rotten. The peel became dark-colored. The fleshy parts became very soft and could not hold their shape.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-22 Degradation of Mango waste (Peel, flesh, and seeds (Rotten))

#### 4.1.8.2 pH

From the existing data, it was found that the pH of mango is between 5.8 - 6 (PickYourOwn.org, 2020). **Figure 4-23** shows the pH variation of mango waste. The pH was near to 4, indicating the waste was always acidic.

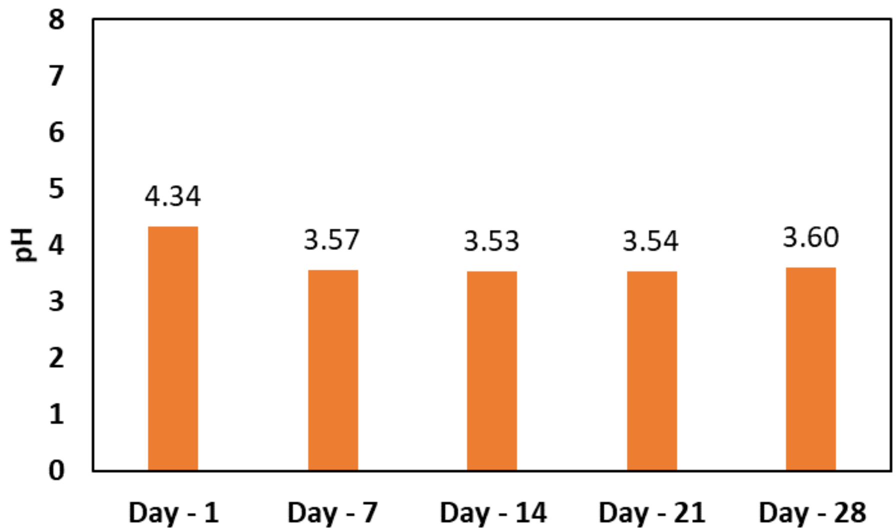



Figure 4-23 Weekly variations of pH of Mango waste (Peel, flesh, and seeds (Rotten))

#### 4.1.8.3 N-P-K content

From the existing data, it was seen that the percentage of phosphorus and potassium were 11.97% and 74.40% respectively (*Mineral Content of Fruit and Vegetables*, 2020). The experimental data in Figure 4-24 shows that the sample had some nitrogen content and like the previous samples. Potassium content is very high. There is also a small amount of phosphorus.

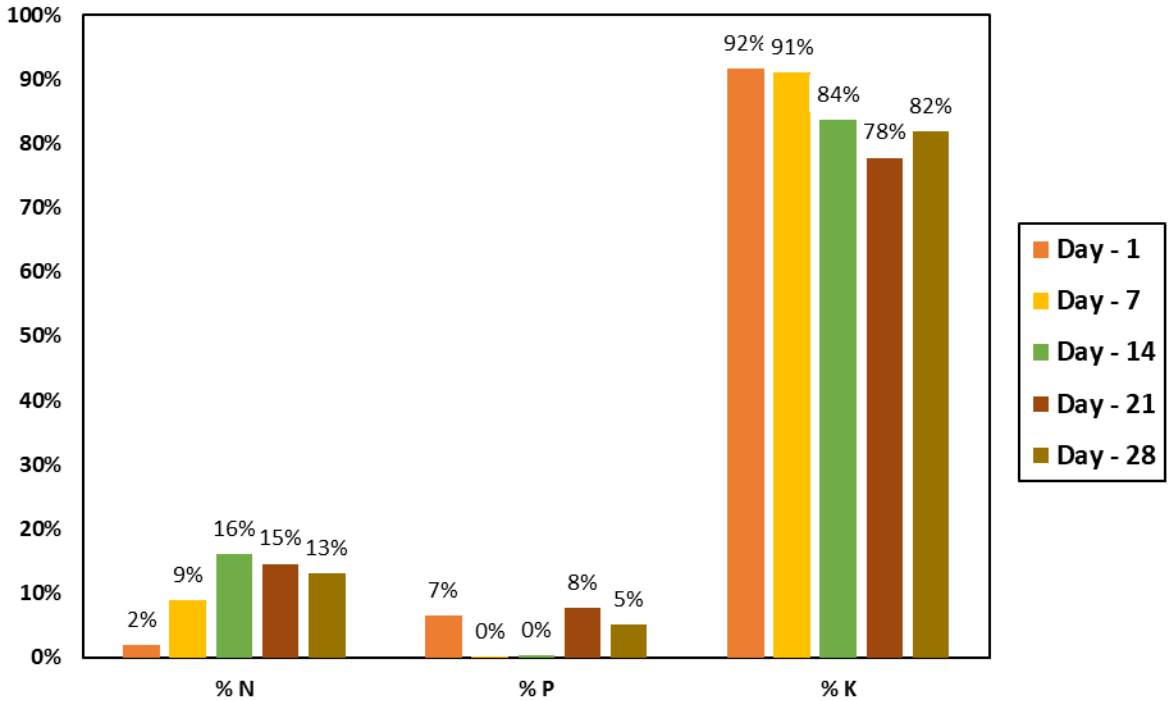



Figure 4-24 Percent distribution of N-P-K for Mango waste (Peel, flesh, and seeds(Rotten))

### 4.1.9 Mango waste (Peel and seeds)

#### 4.1.9.1 Physical condition

The degradation of mango peel and the seed was different from the degradation of the rotten mango (Figure 4-25). The peel of the fruit did not become as dark as it was for the 3-day rotten fruit

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-25 Degradation of Mango waste (Peel and seeds)

#### 4.1.9.2 pH

Similar to the rotten mango waste, the pH of the mango peel and seed was near 4 as shown in **Figure 4-26**. The waste was found to be acidic throughout the 28 days.

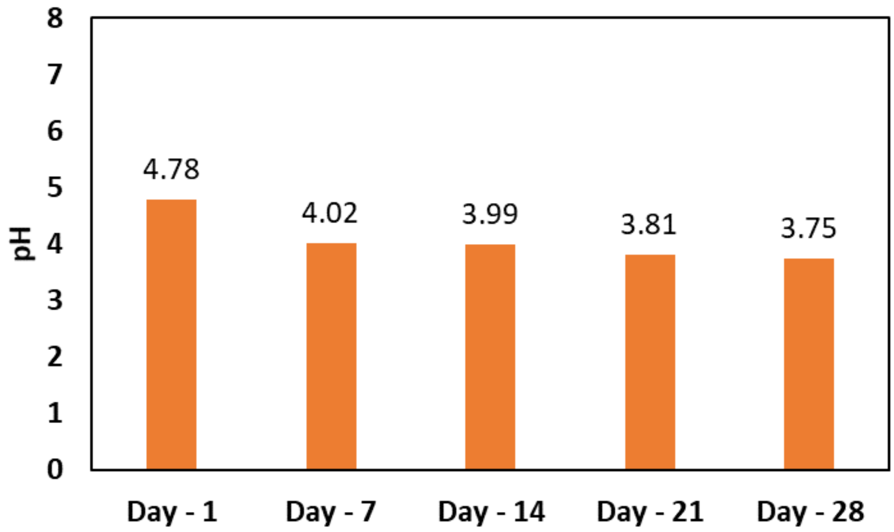



Figure 4-26 Weekly variations of pH of Mango waste (Peel and seeds)

#### 4.1.9.3 N-P-K content

The % N-P-K for the two samples of mango waste was almost similar (Figure 4-27).

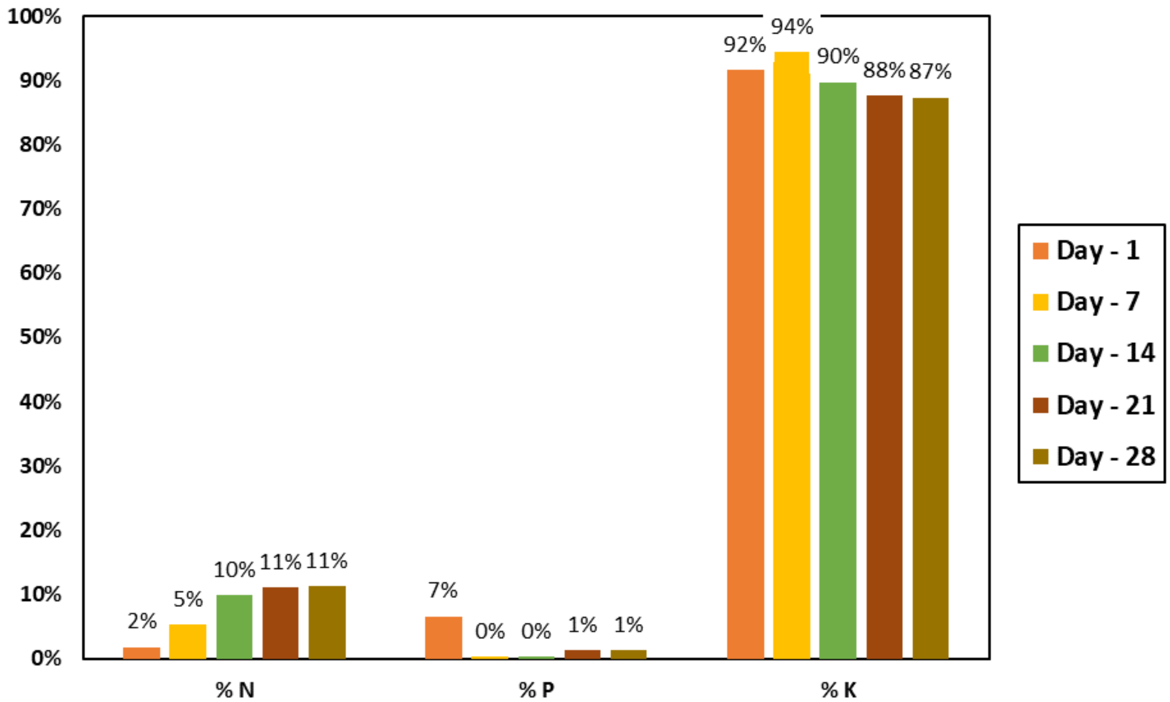



Figure 4-27 Percent distribution of N-P-K for Mango waste (Peel and seeds)

#### 4.1.10 Orange waste (Peel and seeds)

##### 4.1.10.1 Physical condition

The orange peel and seed waste were dry (Figure 4-28). So, 500 mL of water was added to it to accelerate leachate generation from the waste. The waste had a very low moisture content, which resulted in the production of less leachate. The bright orange color of the waste changed to brown color after 28 days.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-28 Degradation of Orange waste (Peel and seeds)

#### 4.1.10.2 pH

The weekly variation of pH for orange waste is shown in Figure 4-29. The waste was acidic on day - 1. Gradually the pH raised and on the 28$^{th}$ day reached 6.8. From the existing data, it was found that the pH for orange lies between 3.3 to 4.19 (PickYourOwn.org, 2020).

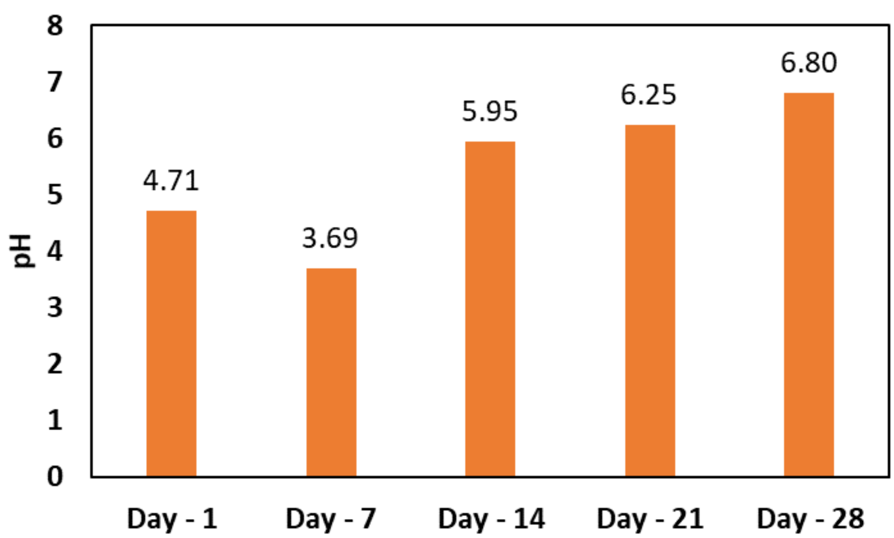



Figure 4-29 Weekly variations of pH of Orange waste (Peel and seeds)

#### 4.1.10.3 N-P-K content

The % N-P-K variation for the orange waste (Figure 4-30) was different from the previous fruits. The amount of Nitrogen was seen to rise over time, whereas the amount of potassium was reduced. A small amount of phosphorus is present, which did not vary much over time. For orange, it was reported that %P and % K for orange waste was 8.19% and 70.06%.

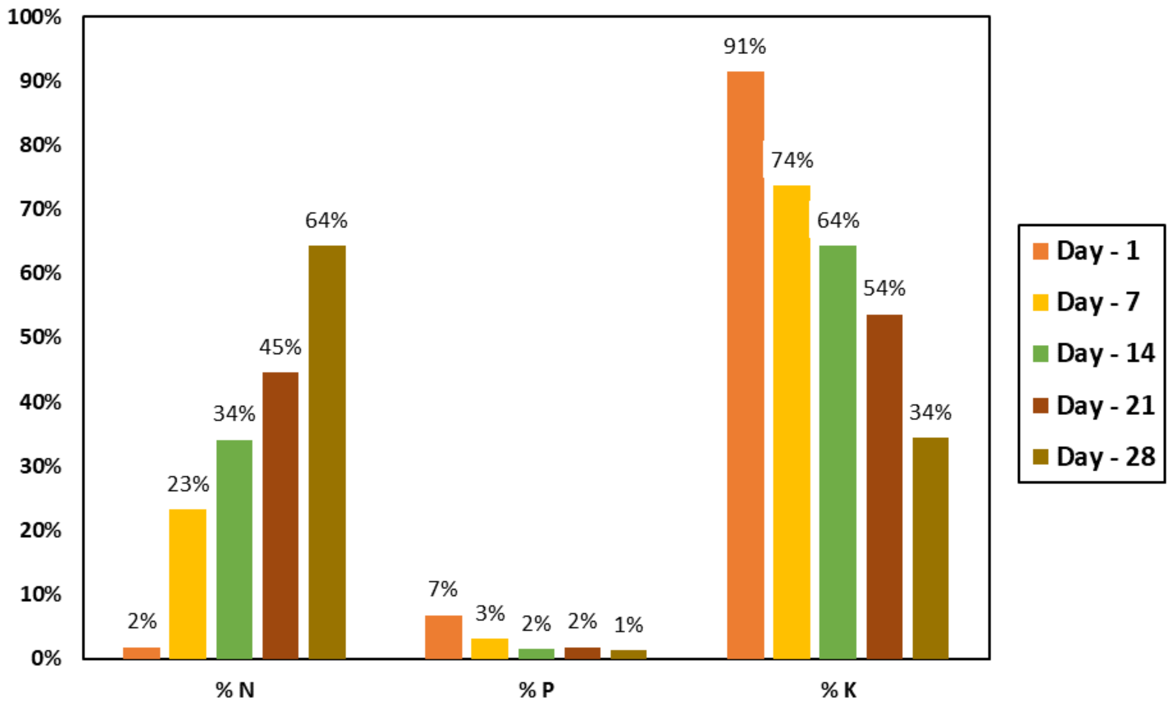



Figure 4-30 Percent distribution of N-P-K for Orange waste (Peel and seeds)

### 4.1.11 Pineapple waste (Leaves, Peel and Core)

#### 4.1.11.1 Physical condition

In case of pineapple waste, it was found that the waste lost its moisture over time and became drier. Some fungus appeared on the waste. The bright yellow color of the waste changed to pale yellow after 28 days (Figure 4-31).

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-31 Degradation of Pineapple waste (Leaves, peel, and core)

#### 4.1.11.2 pH

An increasing trend was seen in the weekly variation of pH for pineapple waste (Figure 4-32). The value went from 3.8 on the day - 1 to 6.18 on day - 28. The acidity of the waste reduced in this period From the existing data, the pH for pineapple was found to be between 3.2 to 4 (PickYourOwn.org, 2020).

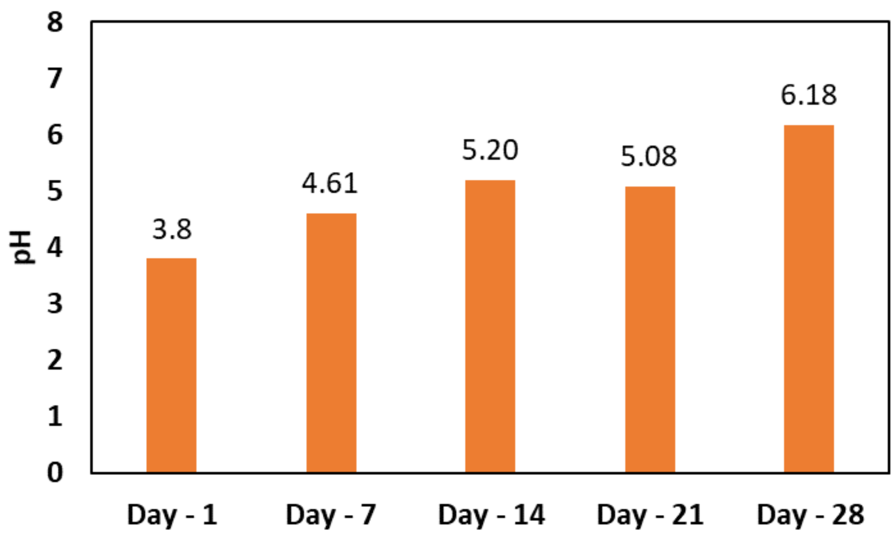



Figure 4-32 Weekly variations of pH of Pineapple waste (Leaves, peel, and core)

#### 4.1.11.3 N-P-K content

% K of the pineapple was high compared to % N and % P (Figure 4-33). On the 28$^{th}$ day, % N increased by a small amount. In pineapple, the amount of Potassium was found to be higher than the other two elements from the existing data (*Mineral Content of Fruit and Vegetables*, 2020).

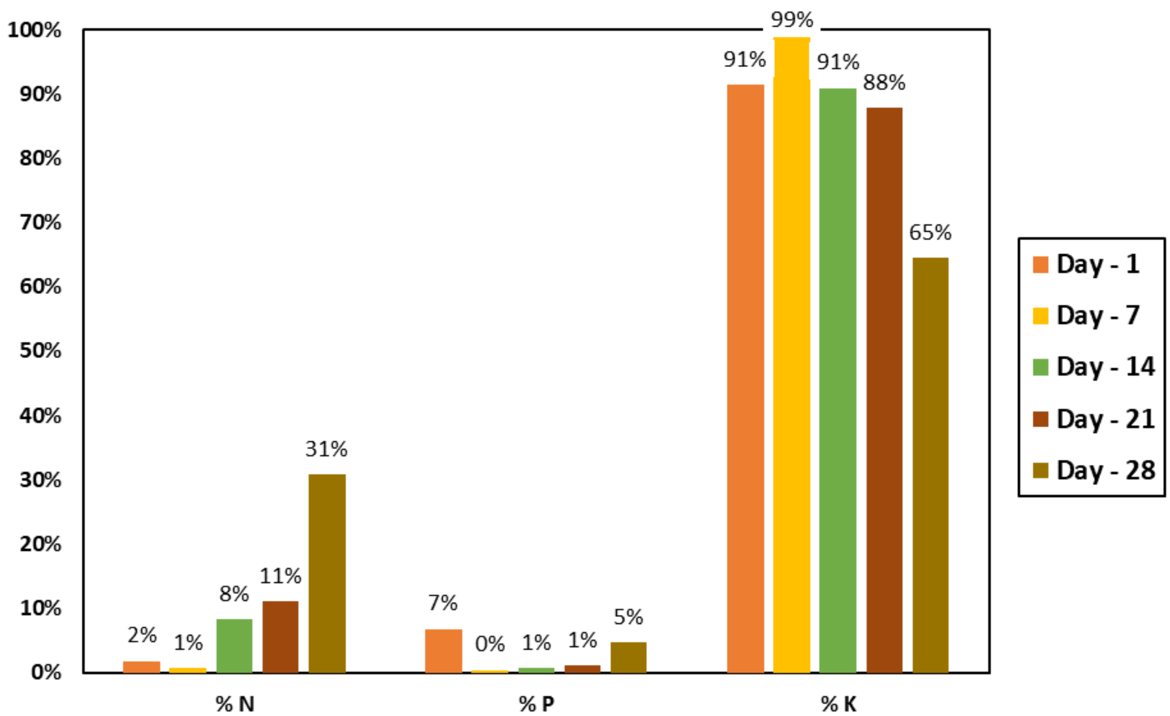



Figure 4-33 Percent distribution of N-P-K for Pineapple waste (Leaves, Peel and Core)

### 4.1.12 Rambutan waste (Peel and seeds)

#### 4.1.12.1 Physical condition

The rambutan waste is shown in Figure 4-34. The waste was dry and so 500 mL of water was added to it to accelerate leachate generation. The color of the peel did not change that much. Some fungus was seen to grow on the surface.


Figure 4-34 Degradation of Rambutan waste (Peel and seeds)

#### 4.1.12.2 pH

From the **existing data, it was found that the pH of rambutan is 4.9 (PickYourOwn.org, 2020). Figure 4-35 shows the weekly variation** of rambutan waste. The value of pH was near 6.

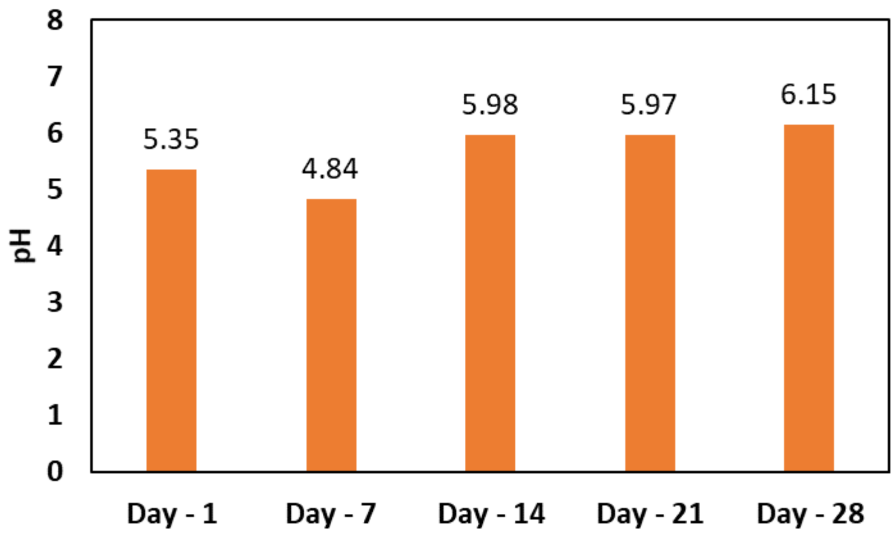



Figure 4-35 Weekly variations of pH of Rambutan waste (Peel and seeds)

#### 4.1.12.3 N-P-K content

The % N-P-K for rambutan waste is shown in Figure 4-36. It is different from the trend seen in the other fruits. The amount of Nitrogen is much more than Phosphorus and Potassium. This is the only sample that had a significant amount of nitrogen in it. Such data was not found in the literature.

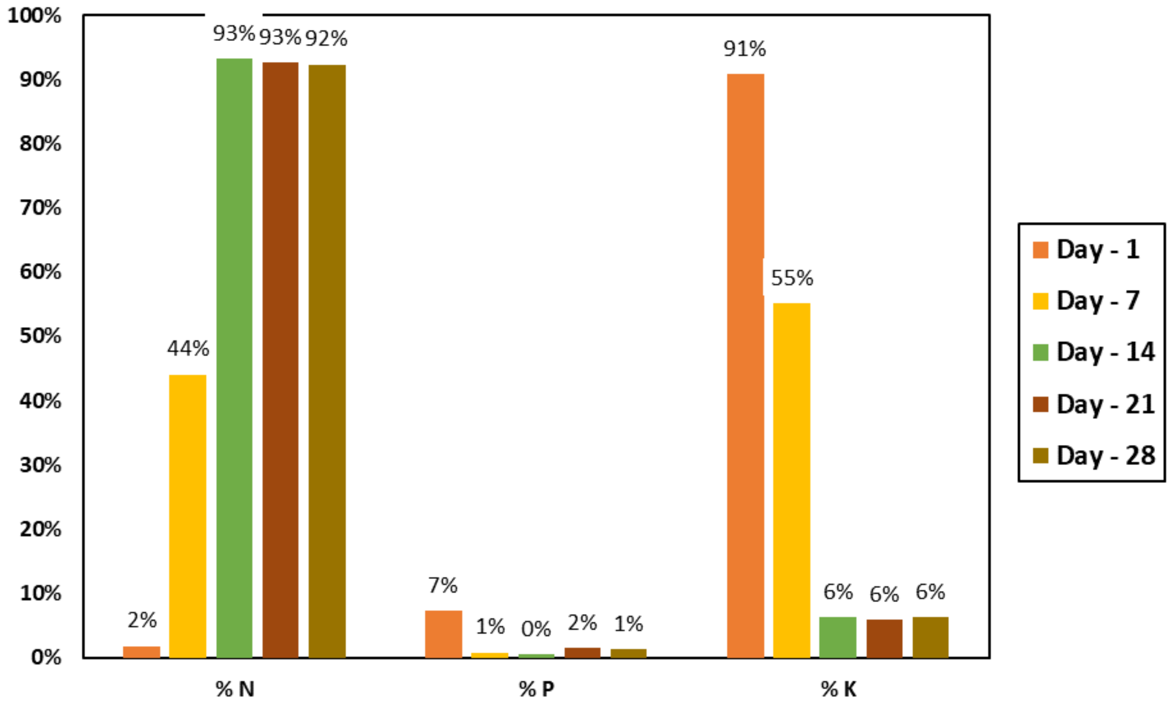



Figure 4-36 Percent distribution of N-P-K for Rambutan waste (Peel and seeds)

### 4.1.13 Watermelon waste (Peel and seeds)

#### 4.1.13.1 Physical condition

After 28 days the condition of the watermelon waste was different from the day - 01. The waste lost most of its moisture and become dry. Also, from the 1st day, white fungus started to appear on the waste. The fungus covers the waste fully within 28 days of observation.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-37 Degradation of Watermelon waste (Peel and seeds)

#### 4.1.13.2 pH

The pH of the pineapple increased over the 28 days. On day - 01 the waste was very acidic (Figure 4-38). The value increased to 7.14 gradually. The pH of watermelon was reported to be within 5.16 - 5.6 (PickYourOwn.org, 2020).

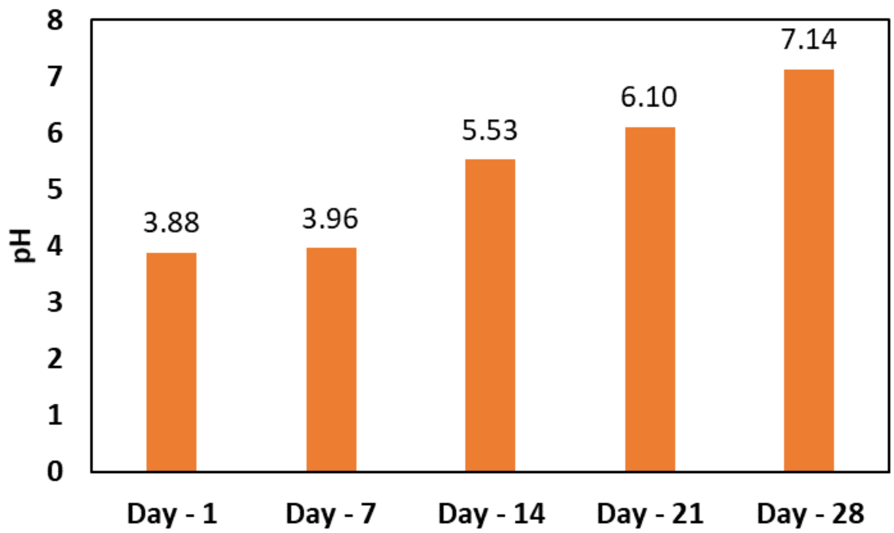



Figure 4-38 Weekly variations of pH of Watermelon waste (Peel and seeds)

#### 4.1.13.3 N-P-K content

It was found the % N of the waste increased and the % K decreased over the weeks. Despite decreasing, the amount of potassium was higher compared to nitrogen. From existing data, the %P and %K was 12.64% and 76.81% (*Mineral Content of Fruit and Vegetables*, 2020).

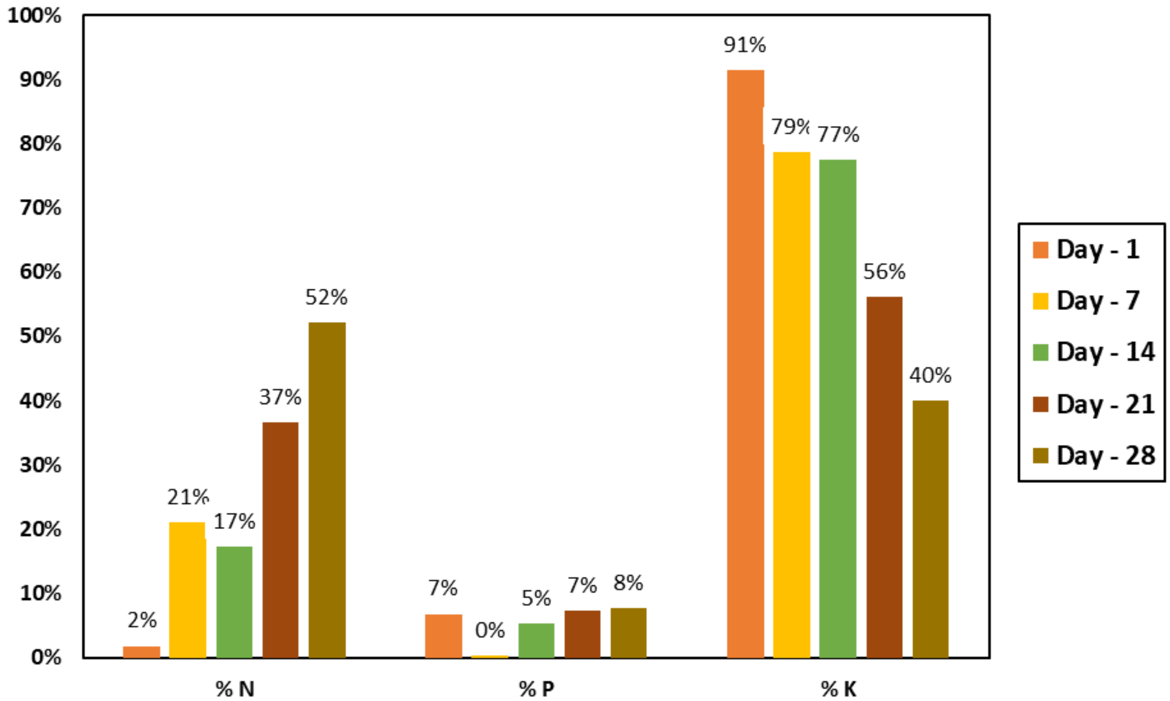



Figure 4-39 Percent distribution of N-P-K for Watermelon waste (Peel and seeds)

## 4.2 pH of Fruit Wastes

From the existing data, it was found that all the fruits used in the study had a pH between 3 - 5, except Cantaloupe and Jackfruit (PickYourOwn.org, 2020). The pH for these two can reach up to 6. It implies that the fruits are acidic. From the current study, it can be inferred that the pH for most of the fruit wastes tends to increase over time. The weekly variation of pH of the fruit waste is shown in Figure 4-40. Only the pH for Mango decreased over time. On the 28$^{th}$ day, the pH for three fruit wastes (Cantaloupe, Durian – Flesh and seeds, and watermelon) was found to exceed 7. pH of other fruits remained below 7. The soil is classified based on pH in Table 4-1. Since most fruit wastes have a pH less than it can be mixed with soil with high pH to reduce the pH. The optimum pH level for Bangladesh soil for agricultural purposes is 6 – 7. Most of the nutrients are easily absorbed in this range (Farid et al., 2005).

Table 4-1 Classification of Soils based on Soil pH Values

| pH | Soil reaction class |
|---|---|
| <4.5 | Very strongly acidic |
| 4.6-5.5 | Strongly acidic |
| 5.6-6.5 | Slightly acid |
| 6.6-7.3 | Neutral |
| 7.4-8.4 | Slightly alkaline |
| 8.5-9.0 | Strongly alkaline |
| >9.0 | Very strongly alkaline |

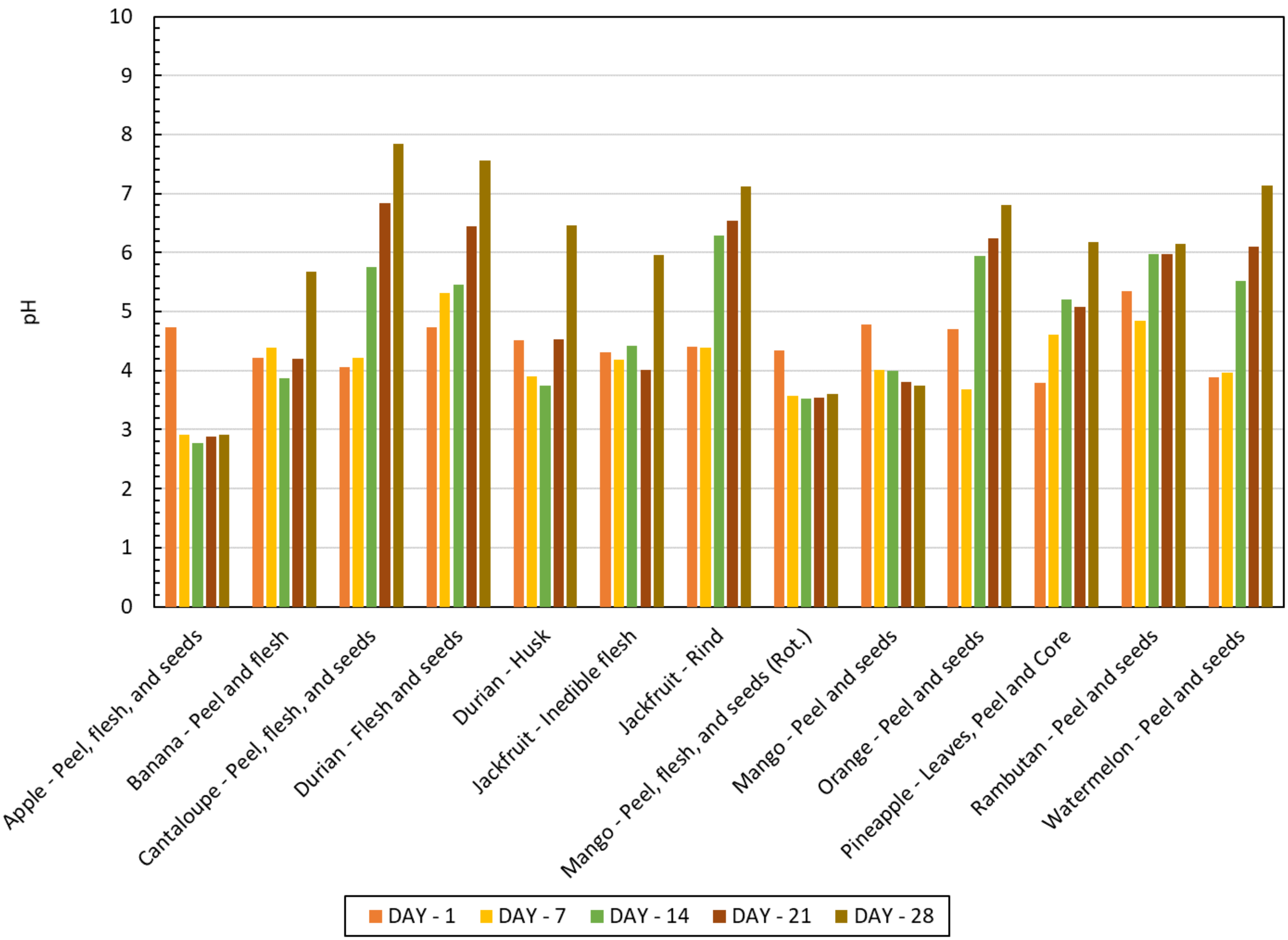



Figure 4-40 Weekly variations of pH of fruit waste

## 4.3 Nitrate content Fruit Waste

The combined data for all fruit wastes over 28 days is shown in Figure 4-41. It is observed that except for Rambutan all other fruits have a lower level of Nitrate. The nitrate levels for watermelon increased as the days passed. Existing mineral content data of fruit and vegetables (*Mineral Content of Fruit and Vegetables*, 2020) show that the amount of Nitrogen in the fruits is negligible. So, the experimental data support the existing data, except for Rambutan and Watermelon

## 4.4 Phosphate content Fruit Waste

The combined data for all fruit wastes over 28 days is shown in Figure 4-42. From the study, it was found that the waste from Banana, Mango Durian, and watermelon had a maximum of 7 %, 11 %, 8 %, and 8 % phosphorus. The existing data on the mineral content shows that Apple, Banana, Mango, Orange, and Watermelon have 6.52%, 6.40%, 11.97%, 8.19%, and 12.64% phosphorus, respectively. From the experiment, less amount of phosphate was found for Apple and Orange (< 4%). For the rest of the mentioned fruits, the experimental mineral content is close to the existing data.

## 4.5 Potassium content Fruit Waste

The combined data for all fruit wastes over 28 days is shown in Figure 4-43. The existing data shows that the fruits have a very high potassium content, almost over 70 % for most of the fruits. The experimental data is similar to the existing data set. For most of the fruits, the potassium level is over or close to 80 %. There are two exceptions. the first is Rambutan, which has very low potassium content compared to other fruits (as low as 6%). For watermelon, the phosphorus content seems to decrease over time.

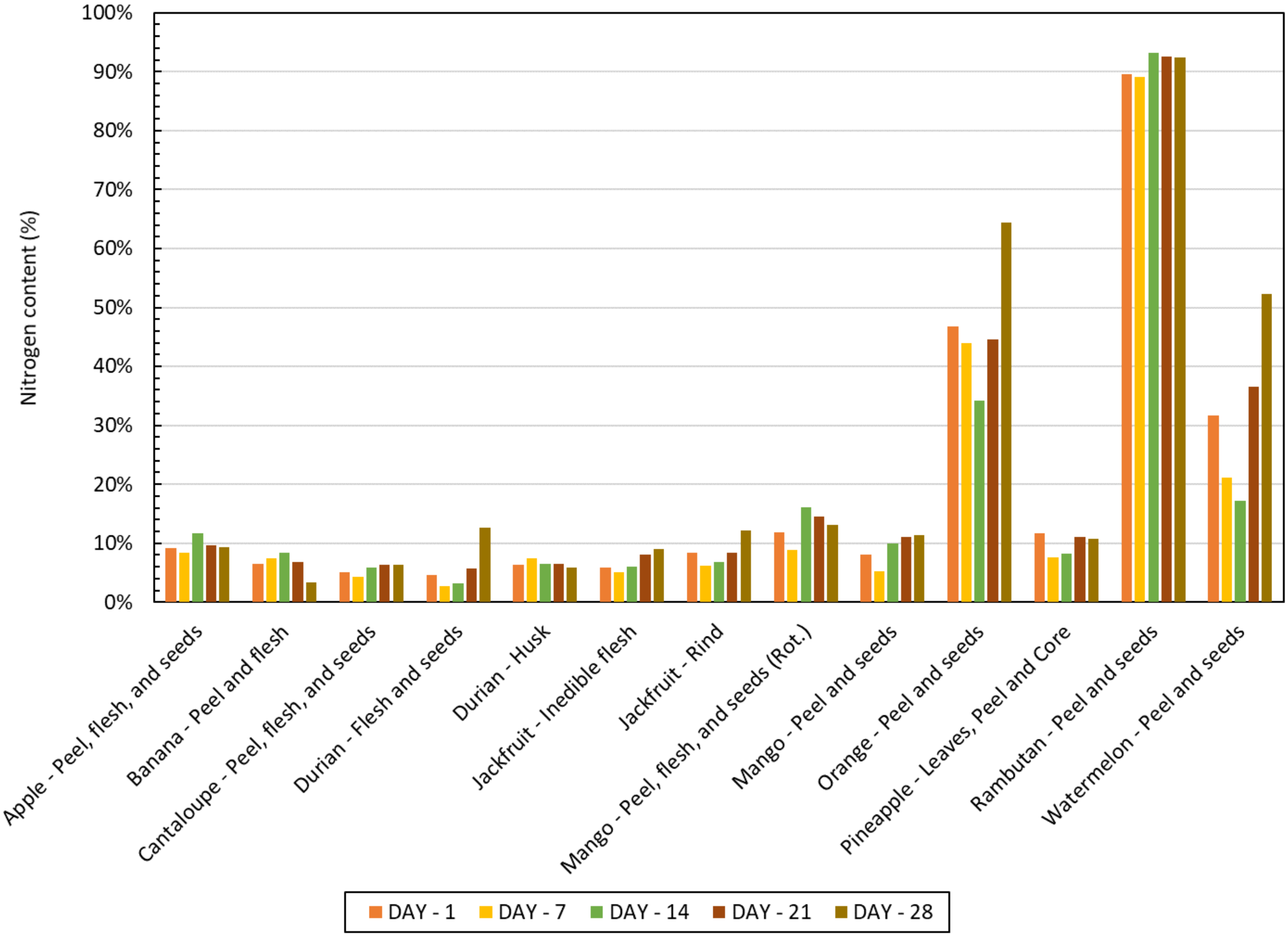



Figure 4-41 Weekly variations of the Nitrate content of the Fruit waste

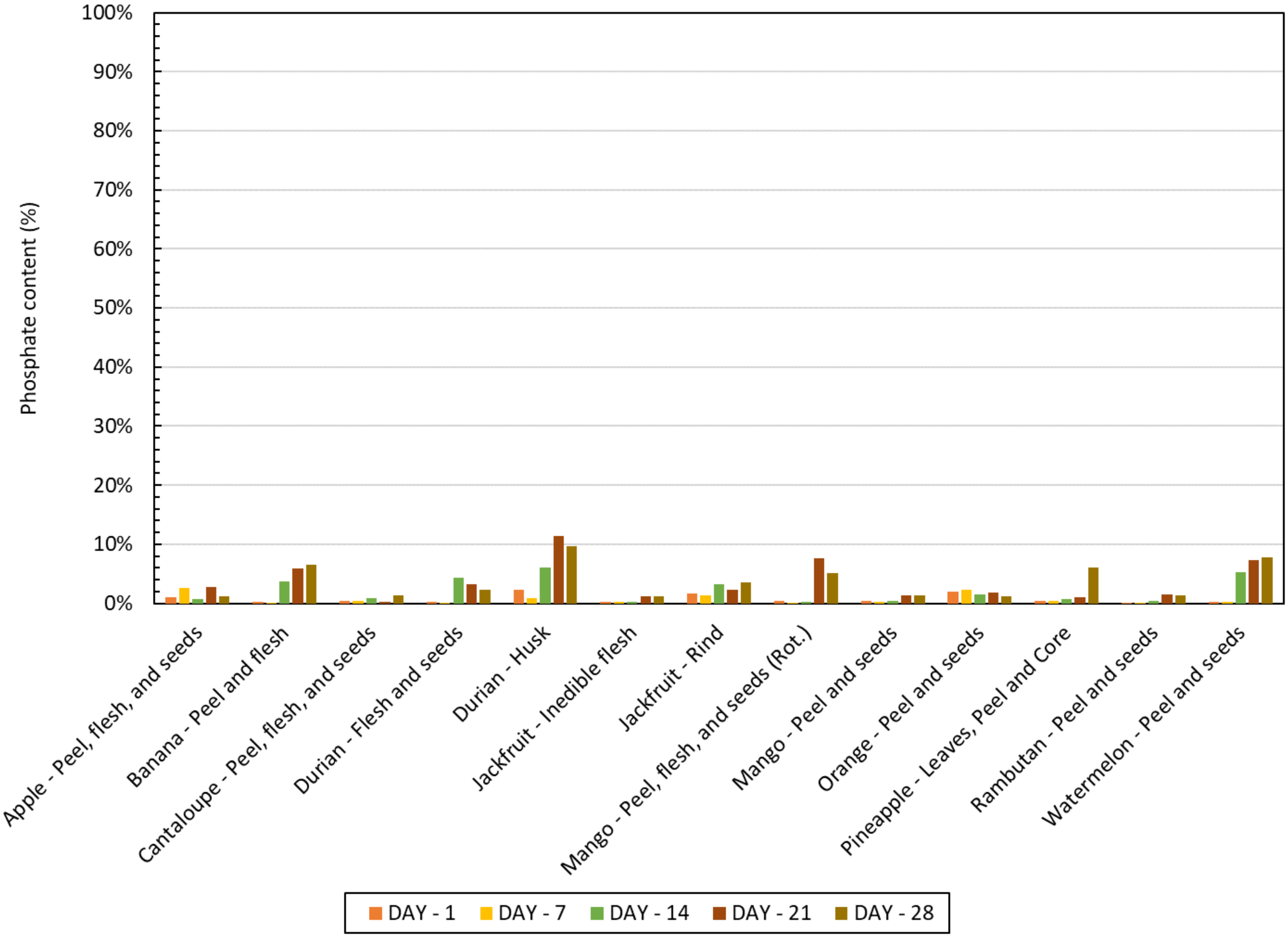



Figure 4-42 Weekly variations of the Phosphate content of the Fruit waste

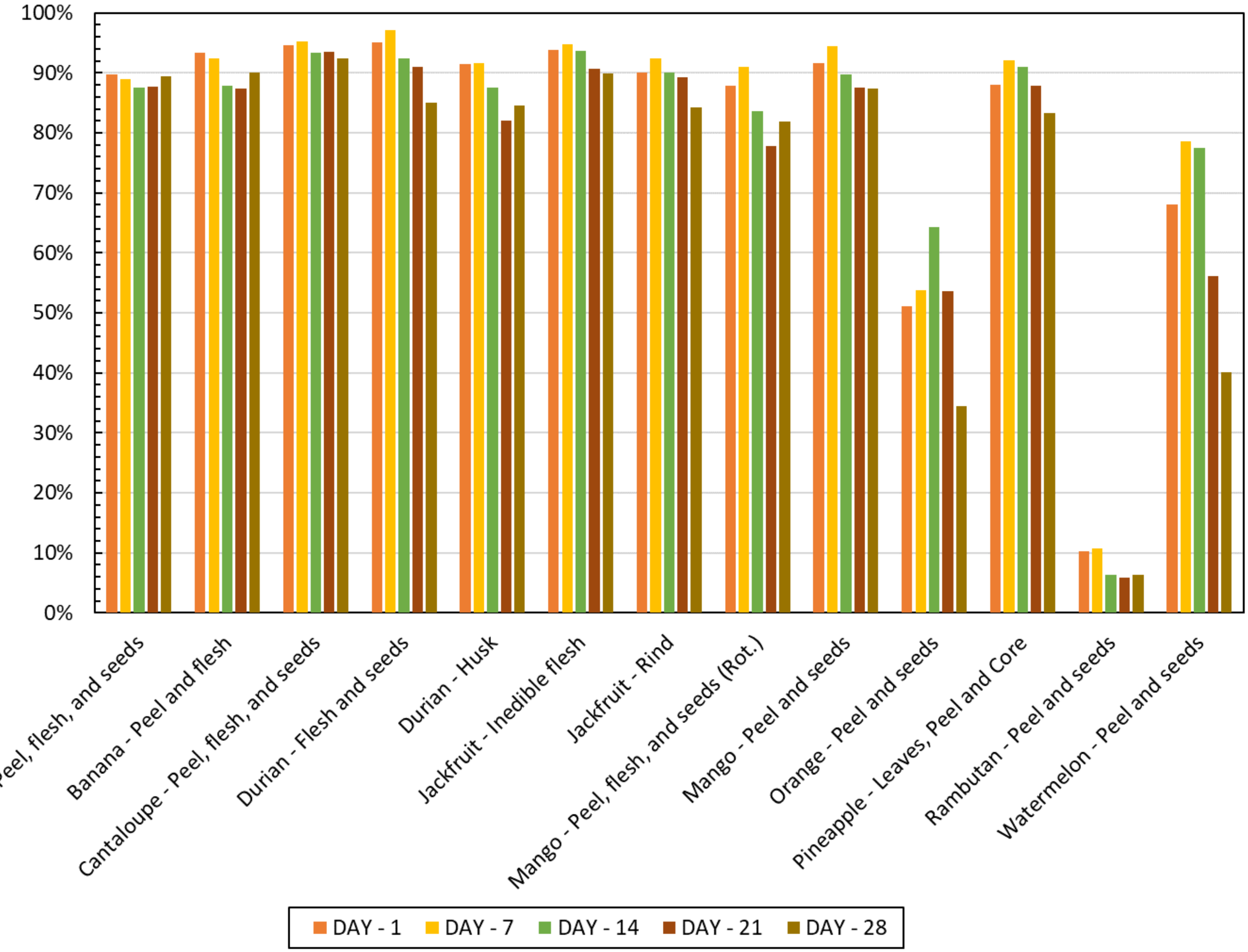



Figure 4-43 Weekly variations of the Potassium content of the Fruit waste

### 4.6 Physical condition and chemical properties of Vegetable Wastes

The physical condition and chemical properties of the vegetable wastes were monitored weekly.

#### 4.6.1 Ash gourd waste (Whole)

##### 4.6.1.1 Physical condition

The ash gourd was cut into small pieces and kept in the bucket for 28 days. Since the waste was dry, 500 mL of distilled water was added to initiate leachate production. Within the first 7 days, some white fibers appeared on the waste (Figure 4-45). Afterward, when the bucket was opened after 14 and 21 days, the white fungus turned black and covered the whole waste. On the last day (28$^{th}$ day) the sample became stiffer due to slow loss of moisture and turned yellowish.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-44 Physical changes of ash gourd waste (whole) observed weekly

Figure 4-45 Development of white fibrous fungus on ash gourd waste

#### 4.6.1.2 pH

The present data suggest that the pH of ash gourd remains between 5.8 - 6.0 (McGlynn, 1992). The weekly pH variation of the ash gourd waste is shown in Figure 4-46. The initial pH is within the mentioned range. Slowly the waste decomposes and the pH increases. On the 28$^{th}$ day, the pH was found to be 7.92.

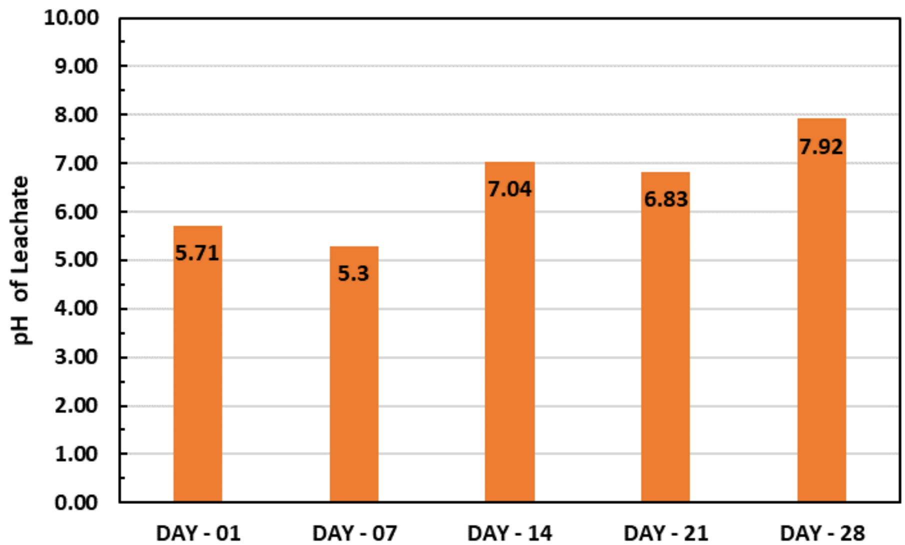



Figure 4-46 Weekly variations of pH of ash gourd waste (whole)

#### 4.6.1.3 N-P-K Content

According to the existing data, the percentage of nitrate (%N), phosphate (%P), and potassium (%K) are 27.6%, 5.8%, and 66.7% respectively (*Mineral Content of Fruit and Vegetables*, 2020). The weekly variation of the N-P-K content of the ash gourd waste of the current study is presented in Figure 4-47. The percentage of potassium is much higher (close to 80%) than the other two in the leachate. The potassium content is observed to decrease slightly over time.

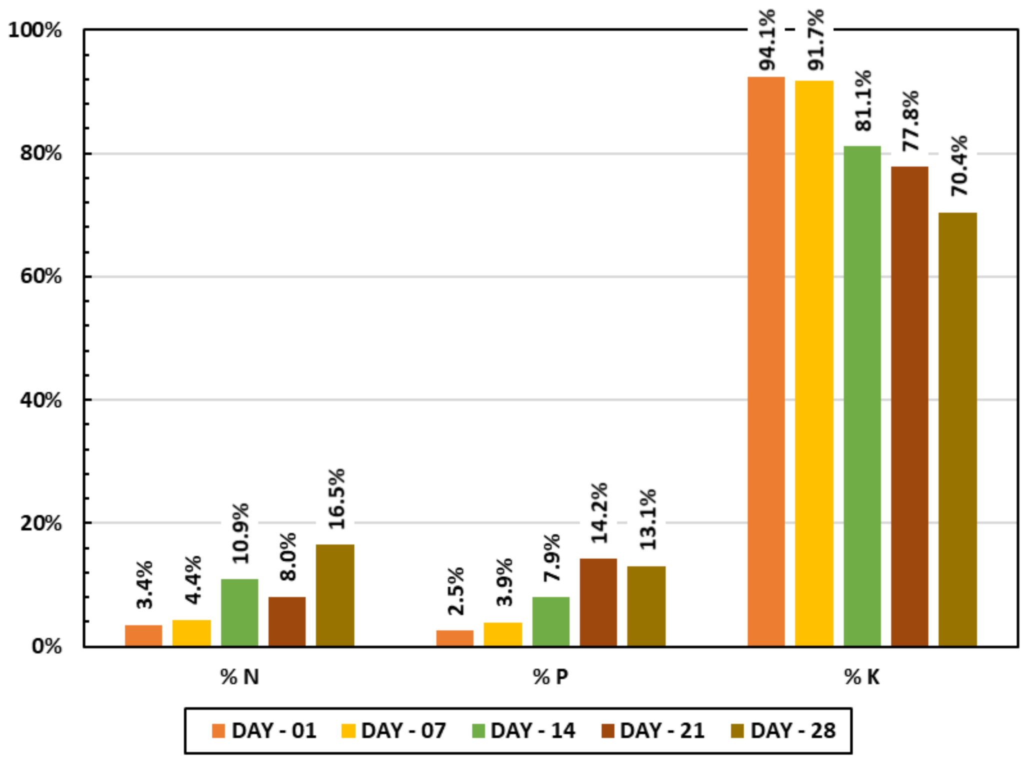



Figure 4-47 Percent distribution of N-P-K for ash gourd (whole) waste

### 4.6.2 Bitter melon waste (whole)

#### 4.6.2.1 Physical condition

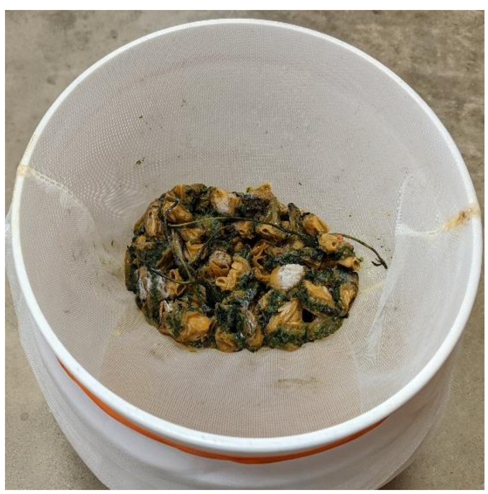
The weekly physical changes of the bitter melon waste are given in Figure 4-48. Over the span of 28 days, the sample lost moisture slowly and shrunk. The bright color of the fresh sample gradually darkened. A lump of white fungus was also developed on the sample.

Day – 01

Day – 07

Day – 14

Day – 21



Day - 28

Figure 4-48 Physical changes of ash Bitter melon (whole) waste observed weekly

#### 4.6.2.2 pH

Figure 4-49 shows the change of pH of the biller melon waste. The pH value increases over time. The existing databank suggested that the pH of the fresh bitter melon lies between 6.0 - 6.2 (McGlynn, 1992). In the current study initially, the leachate was found to be acidic (pH < 7.0) and finally it turned to be basic (pH > 7.0).

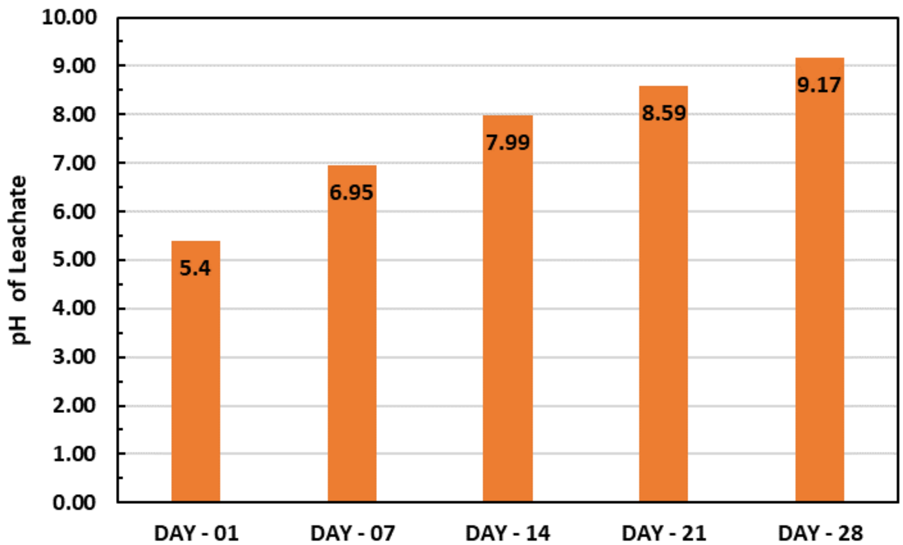



Figure 4-49 Weekly variations of pH of bitter melon (whole) waste

#### 4.6.2.3 N-P-K Content

From the existing data, the percentage of nitrate (%N), phosphate (%P), and potassium (%K) are 23.4%, 7.3%, and 69.3% respectively (*Mineral Content of Fruit and Vegetables*, 2020). The percentage N-P-K content of the leachate produced from the sample is shown in Figure 4-50. The percentage of potassium is much higher than the other two minerals. The maximum nitrate content obtained (27.8% ) from the experiment shows slight variation from the reported data (23.4 %).

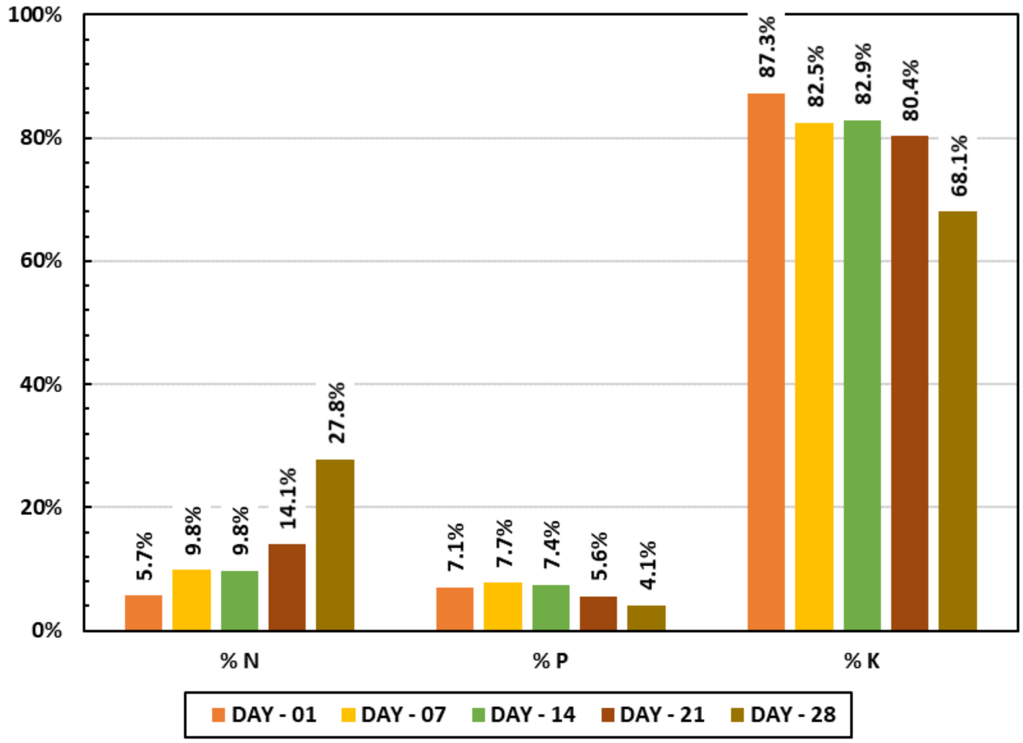



Figure 4-50 Percent distribution of N-P-K of bitter melon (whole) waste

### 4.6.3 Broccoli and Cauliflower (Whole)

#### 4.6.3.1 Physical condition

Equal masses of broccoli and cauliflower wastes were mixed well to prepare this sample as shown in Figure 4-51. During the experiment period, the color of the vegetables faded slowly. The volume of the sample reduced due to the loss of water. Also, white fungus started to appear on the waste. After 28 days some fluid accumulation was seen on the sample.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-51 Physical changes of broccoli and cauliflower (whole) waste observed weekly

#### 4.6.3.2 pH

From the existing data, it is found that the pH of the broccoli and cauliflower ranges from 5.6 - 6.0 (McGlynn, 1992). For the waste sample, the weekly variation of pH of the leachate is shown in Figure 4-52. The initial value of the pH obtained from the sample matches with the previously reported value. But over time the pH value rises and reaches 8.78, which indicates that the leachate becomes basic.

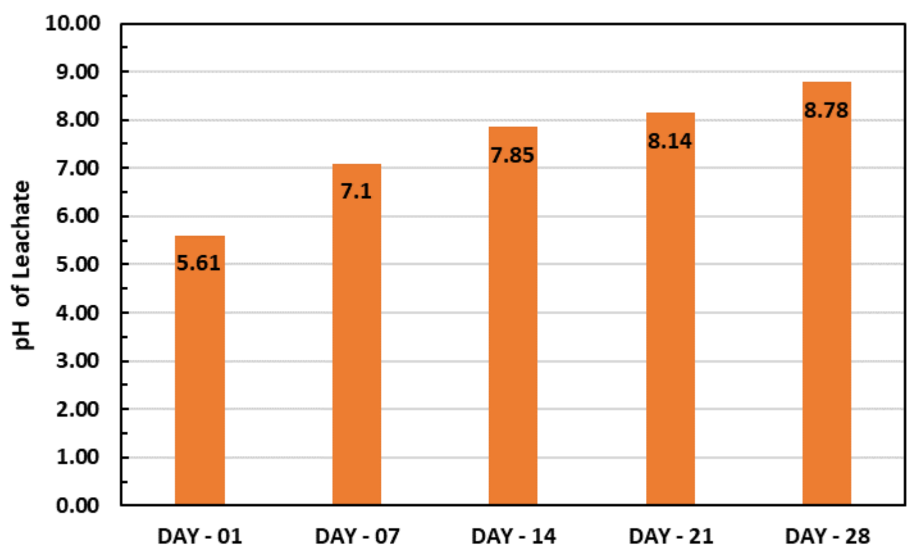



Figure 4-52 Weekly variations of pH of broccoli and cauliflower (whole) waste

#### 4.6.3.3 N-P-K Content

From the existing data, the percentage of nitrate (%N), phosphate (%P), and potassium (%K) in fresh broccoli are 42.5%, 9.9%, and 47.6%, and in cauliflower are 39.5%, 8.0%, and 52.5% respectively (*Mineral Content of Fruit and Vegetables*, 2020). In the combined sample it can be expected that the percentage of nitrate must be greater. The percentage N-P-K content of the leachate produced from the sample is shown in Figure 4-53. The percentage of potassium was higher than the other two for the 1st two weeks. Eventually, the percentage of nitrate increased and approached 50 %, which was expected from the existing data. On the contrary, the percentage of potassium demonstrates a large variance from the existing data. The experimental data was in the range of 50 - 80 % over the 28 days, whereas for both the vegetables the maximum percentage of potassium was 42.4 %.

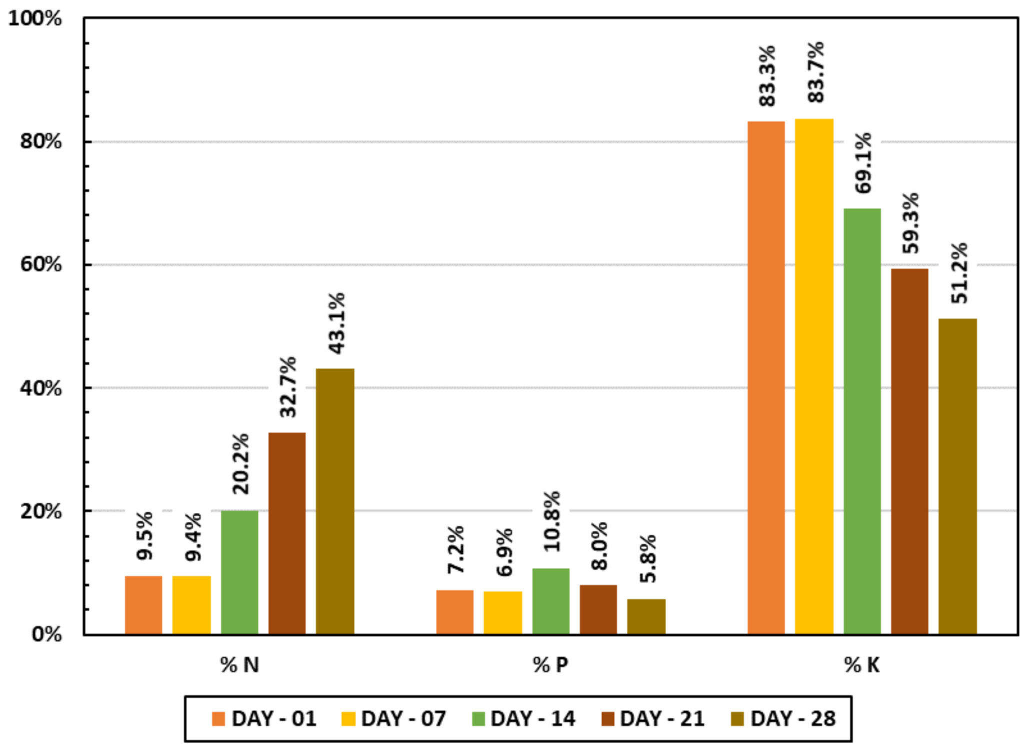



Figure 4-53 Percent distribution of N-P-K of broccoli and cauliflower (whole) waste

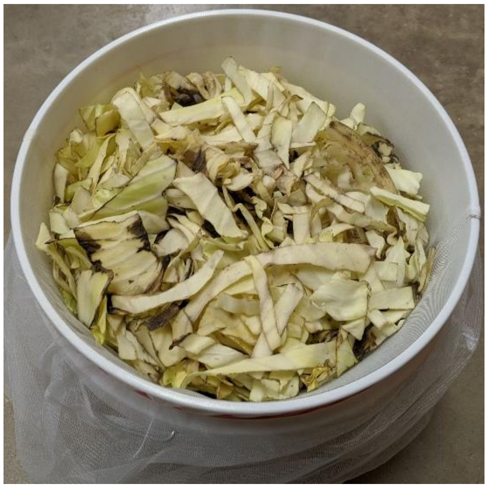
### 4.6.4 Cabbage (Whole)

#### 4.6.4.1 Physical condition

The physical deterioration of the cabbage waste is presented in Figure 4-54. The waste was cut into smaller strips to ensure uniform decomposition. For the first two weeks, the waste retained most of its initial appearance. A slight hint of shrinkage was observed after 14 days, along with few black spots on the surface. At the end of the experiment period, the black spots became more common and covered most of the waste. The volume of the waste was also reduced due to further moisture loss.

Day – 01

Day – 07



Day – 14

Day – 21

Day - 28

Figure 4-54 Physical changes of cabbage (whole) waste observed weekly

#### 4.6.4.2 pH

The results of the pH tests of the cabbage waste sample are illustrated in Figure 4-55. The pH value increases over time and turns slightly basic after 28 days. The existing databank exhibits that the pH of cabbage ranges between 5.4 - 6.9 (McGlynn, 1992). Data in the current study remains close to this range.

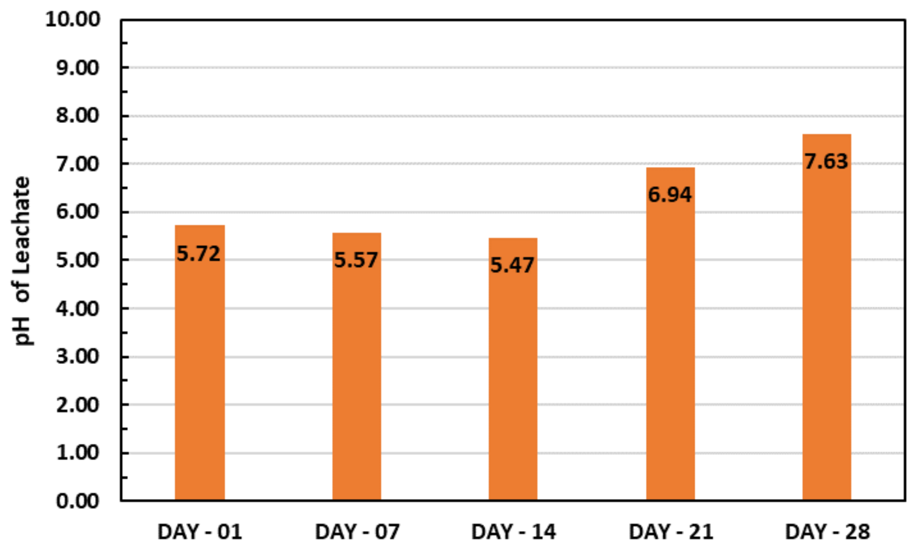



Figure 4-55 Weekly variations of pH of cabbage (whole) waste

#### 4.6.4.3 N-P-K Content

Figure 4-56 demonstrates the experimental results of the percentage N-P-K content of the cabbage waste sample. The percent content of potassium is significantly higher than nitrate and phosphorus (maximum of 90.9 %). This is a deviation of the existing data, where it is reported that the percent content of nitrate, phosphate, and potassium are 26.7%, 8.1%, and 65.1% respectively. The nitrate content of the sample (27.0 % on Day - 28) becomes almost identical to the existing value (26.7%) after 28 days. The phosphorus percentage is almost similar.

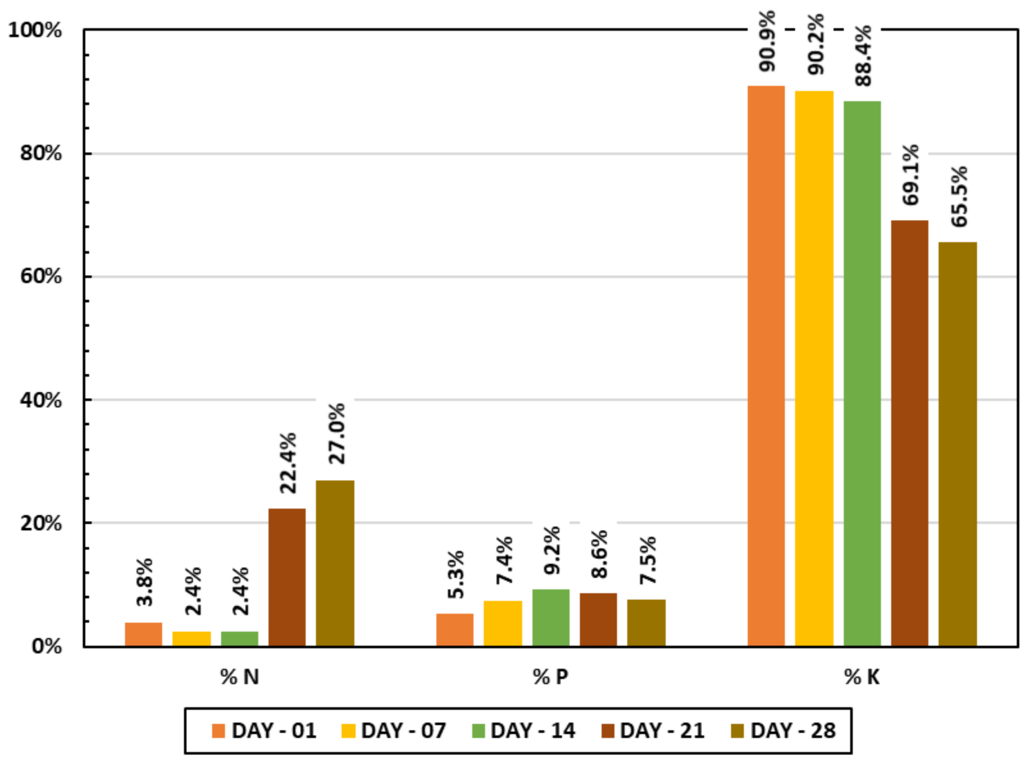



Figure 4-56 Percent distribution of N-P-K for cabbage (whole) waste

### 4.6.5 Carrot (whole)

#### 4.6.5.1 Physical condition

From Figure 4-57 it is seen that, from the beginning of the experimental period, black spots start to appear on the carrot waste. Due to the loss of moisture, the sample became stiffer. On day - 28 formation of white fungus is observed on the sample and most of the sample turned black.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-57 Physical changes of carrot (whole) waste observed weekly

#### 4.6.5.2 pH

Figure 4-58 depicts the increment of pH of the carrot waste. The range of pH observed from the existing data is 4.9 - 5.2. The numbers obtained in the current study go beyond this range and finally after 28 days the leachate becomes basic in nature (pH > 7).

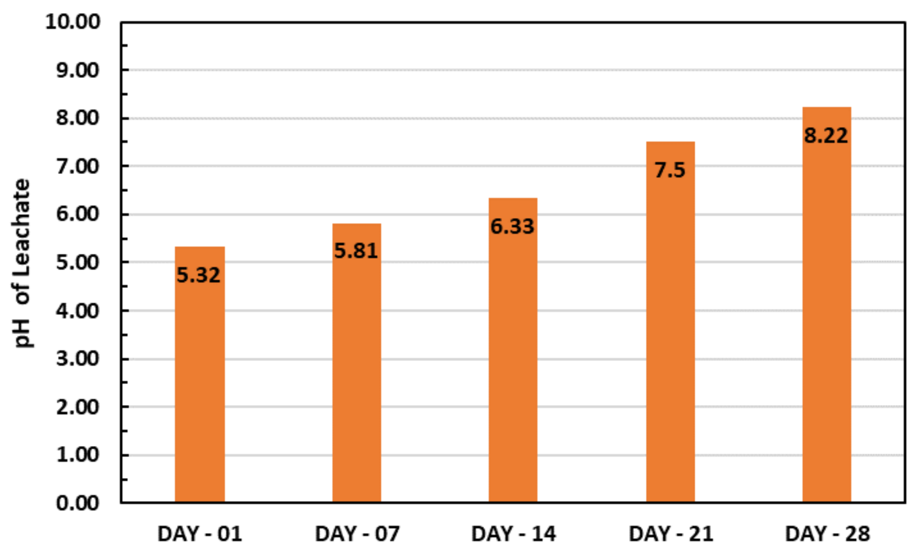



Figure 4-58 Weekly variations of pH of carrot (whole) waste

#### 4.6.5.3 N-P-K Content

For fresh carrots, the percentage N-P-K content is found to be 20.8%, 7.8%, and 71.4% respectively. The numbers shown in Figure 4-59 have a slight variation from the reported data but follow the limit on average. If ranked from maximum to minimum in both cases it is seen that potassium comes first, followed by nitrate and phosphate.

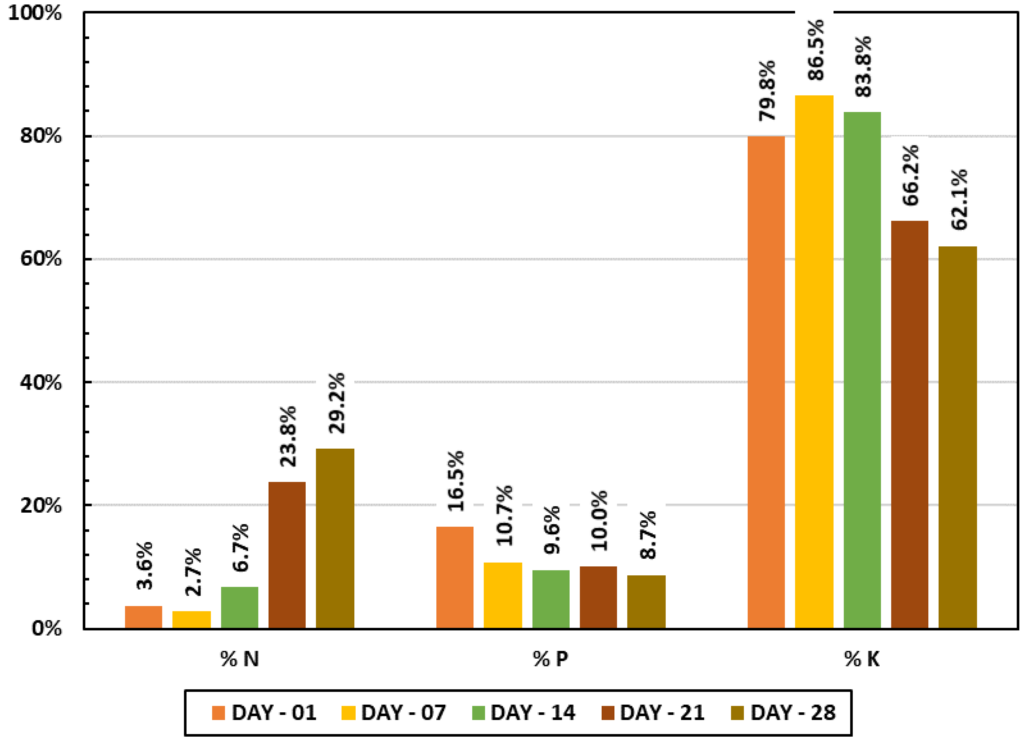



Figure 4-59 Percent distribution of N-P-K of carrot (whole) waste

### 4.6.6 Cucumber (Whole)

#### 4.6.6.1 Physical condition

After keeping the cucumber waste for 7 days in the leachate collection buckets, white fibrous fungus started growing on it (Figure 4-60). Comparing the images from day - 1 and day - 28, a massive difference in the moisture content of the sample can be seen. The volume of the sample was reduced to 22 % of the initial amount. With time the sample got covered with white fungus.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-60 Physical changes of cucumber (whole) waste observed weekly

#### 4.6.6.2 pH

The pH of fresh cucumber ranges from 5.1 - 5.7. Figure 4-61 shows that the initial pH of the cucumber leachate was below this range and within 28 days the value got up to 8.94. The leachate started as an acidic solution and turned into a basic one when left to degrade.

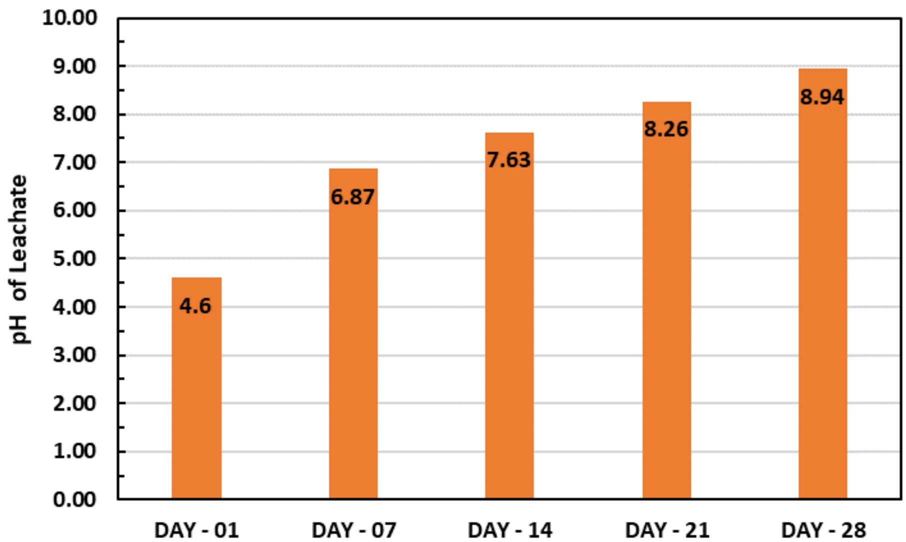



Figure 4-61 Weekly variations of pH of cucumber (whole) waste

#### 4.6.6.3 N-P-K Content

In Figure 4-62 the percent N-P-K content of the cucumber waste is shown. The numbers obtained from the existing data are 27.9% N, 6.8% P and 65.2% K. Though the experimental numbers do not match exactly with the previous one, the distribution of the data is identical, the percentage of potassium is the highest among the minerals.

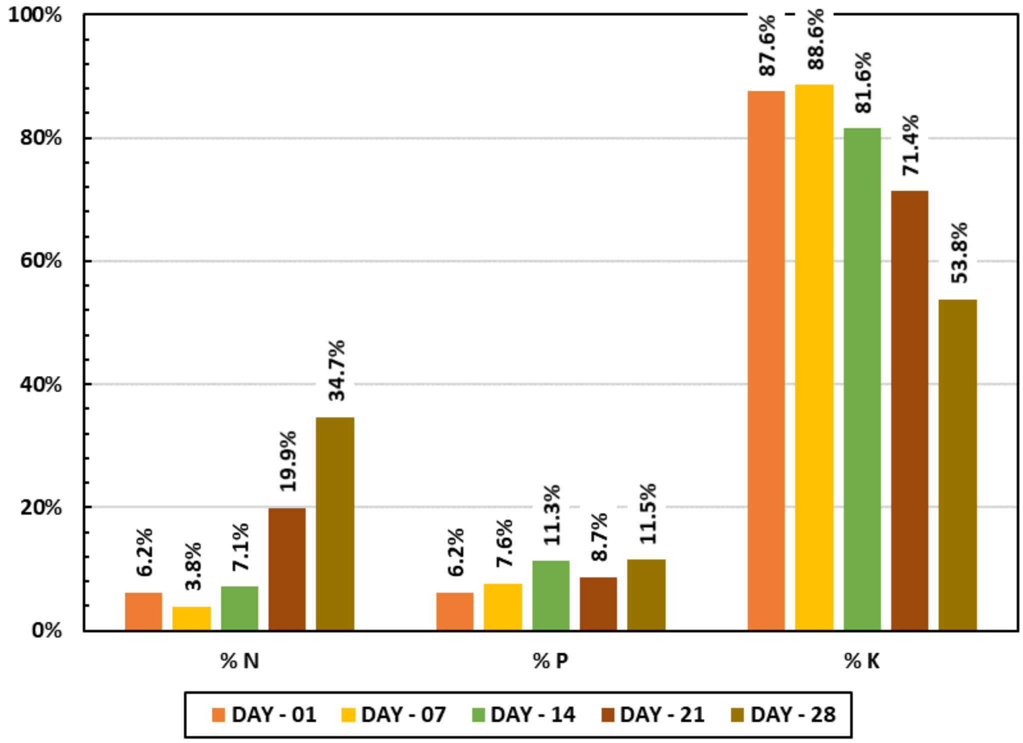



Figure 4-62 Percent distribution of N-P-K of cucumber (whole) waste

### 4.6.7 Eggplant (whole)

#### 4.6.7.1 Physical condition

The eggplant waste was covered with white fibrous fungus within the 1st 7 days of the study (Figure 4-63) and remained like that although the experiment period. On the final day, some black liquid was seen to accumulate on top of the sample. For the fungus covering, the degradation of the sample could not be observed properly, but comparing the images from day 1 and day 28, it can be inferred that there was a significant loss of water from the sample, both as leachate and water vapor.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-63 Physical changes of eggplant (whole) waste observed weekly

#### 4.6.7.2 pH

The pH range for fresh eggplant is 4.5 - 5.3. Figure 4-64 shows that the leachate from the eggplant also followed a similar trend of increasing with the number of days passed. The initial pH on the day - 1 was a fraction higher than the specified range. The value increased with time and the leachate turned basic.

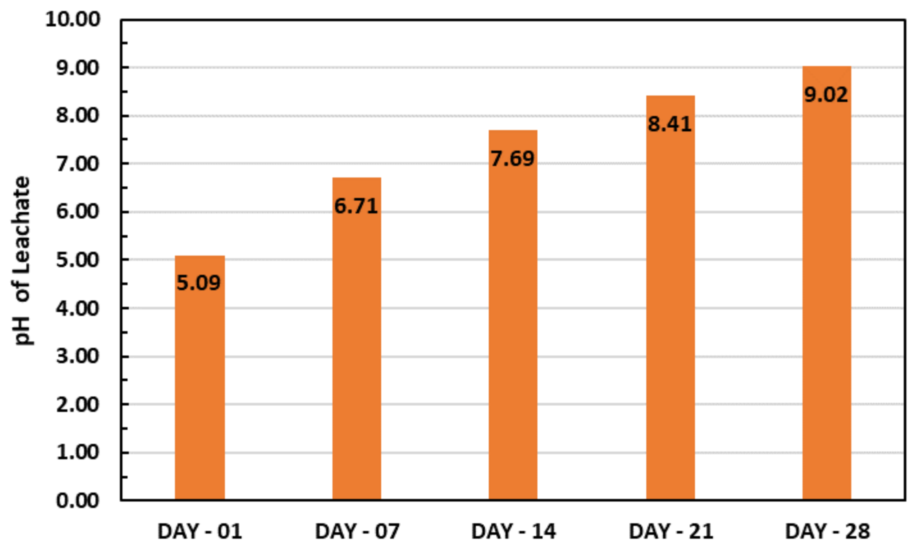



Figure 4-64 Weekly variations of pH of eggplant (whole) waste

#### 4.6.7.3 N-P-K Content

In Figure 4-65, an increasing trend in the percentage nitrate content is noticed, whereas an opposite trend is seen for potassium. Previous data indicate that the percentage nitrate, phosphate, and potassium content for eggplant are 27.9%, 6.8%, and 65.2% respectively. The average of the %N and % K values, shown in Figure 4-65 lies close to the previous data. The gradual increase and decrease of the data can be attributed to the quick formation of the fungus, which may be responsible for causing some chemical changes in the sample.

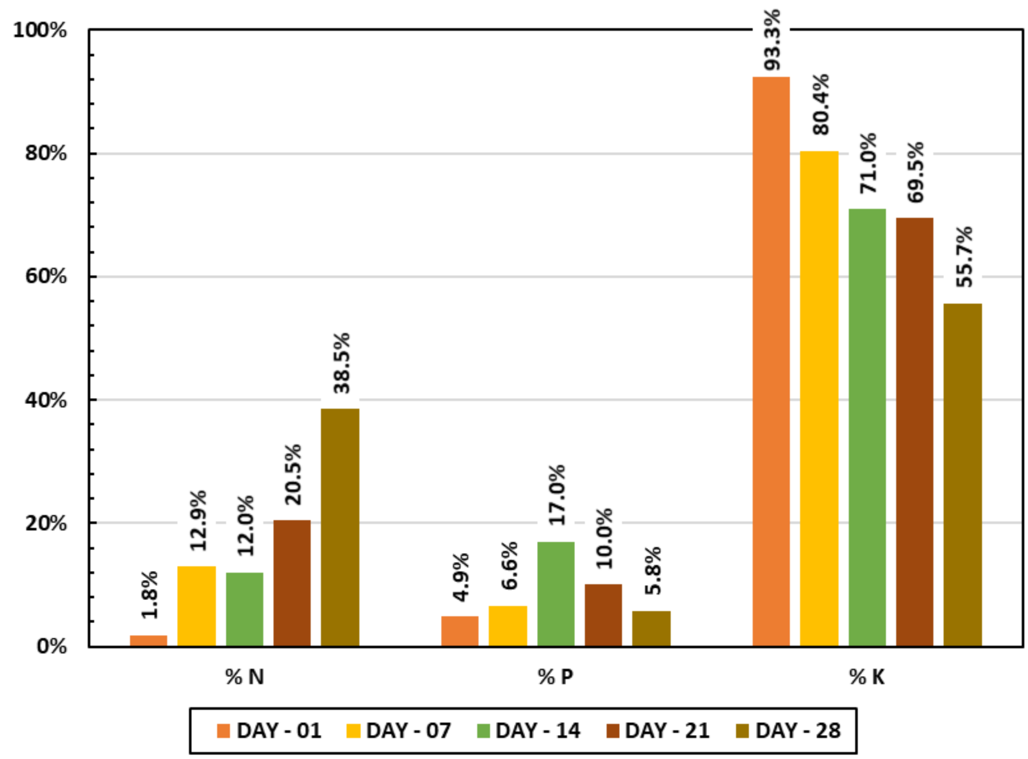



Figure 4-65 Percent distribution of N-P-K of eggplant (whole) waste

### 4.6.8 Green Beans (whole)

#### 4.6.8.1 Physical condition

After 7 days it was observed that the green beans in the leachate collection buckets started to turn darker. Some lumps of white fungus were noticed on the surface (Figure 4-66). On the 21st and 28th day the individual pieces of the beans could not be differentiated. The whole thing took the shape of a sticky mass. In the process, the sample lost water and was reduced in volume.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-66 Physical changes of green beans (whole) waste observed weekly

#### 4.6.8.2 pH

Figure 4-67 demonstrates the variation of pH of leachate from green beans over the 28 days. The pH range of fresh eggplant is 5.7 - 6.2. Massive variation in pH of the leachate is observed at the end of 28 days. The pH of the leachate increased.

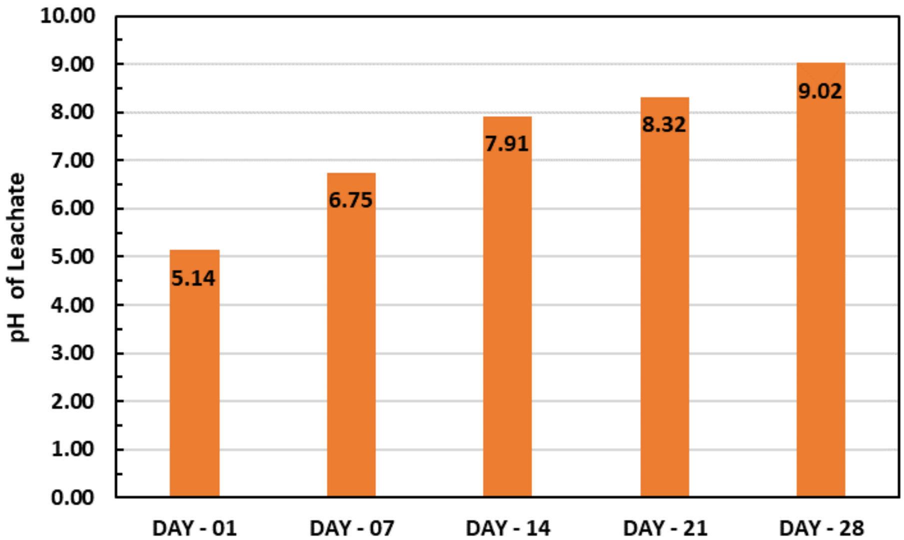



Figure 4-67 Weekly variations of pH of green beans (whole) waste

#### 4.6.8.3 N-P-K Content

Figure 4-68 shows the variation of percentage nitrate, phosphate and potassium content of green beans waste. Like eggplants, an increasing trend in nitrate content and decreasing trend in potassium content is seen. From the previous data, it is found the percent N-P-K content of green beans are 42.4%, 8.8%, and 48.8%, which contrasts with the experimental data. The experimental data suggests that the potassium percentage should be higher than nitrate and phosphate, whereas from the previous data it is found that the gap between percentages of nitrate and phosphate is small. The experimental percent content of phosphate is near the previously reported data.

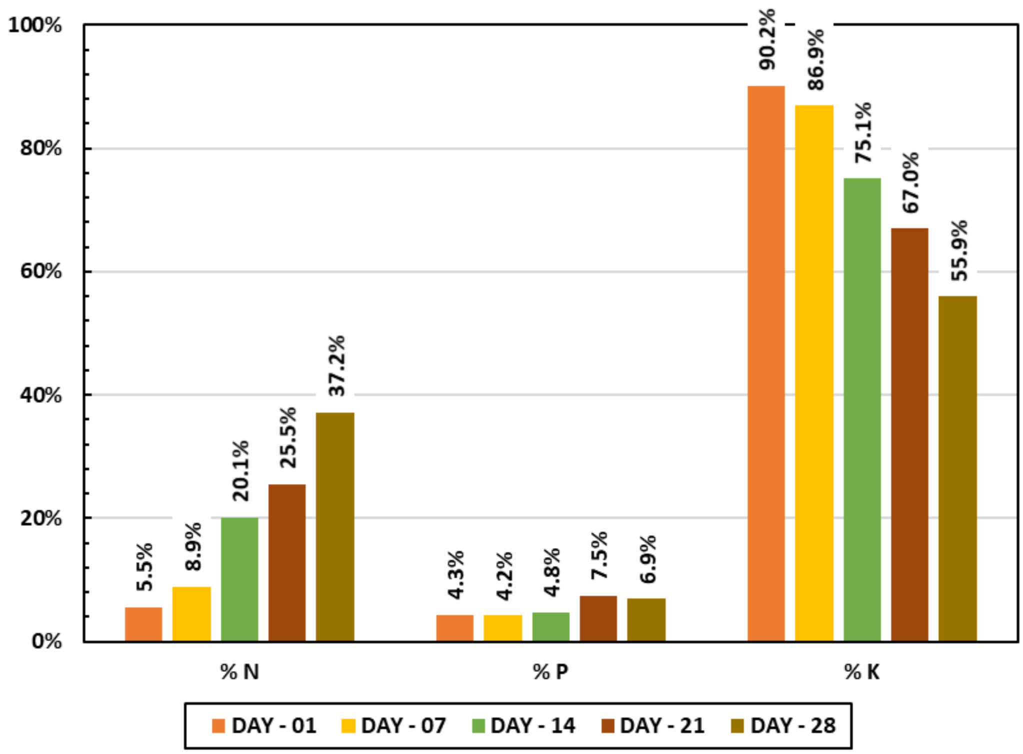



Figure 4-68 Percent distribution of N-P-K of green beans (whole) waste

### 4.6.9 Green Papaya (Whole)

#### 4.6.9.1 Physical condition

Figure 4-69 shows the gradual changes in the papaya waste. A covering of white fungus forms on the papaya waste with day - 7. The fungus propagated and covered the whole sample. The sample lost moisture over time.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-69 Physical changes of green papaya (whole) observed weekly

#### 4.6.9.2 pH

The pH range for fresh papaya was found to be 5.2 - 5.7. Figure 4-70 shows the pH variation of the leachate obtained from the experiment. The numbers obtained from the experiment increase over time, finally leading to basic leachate at the end of 28 days.

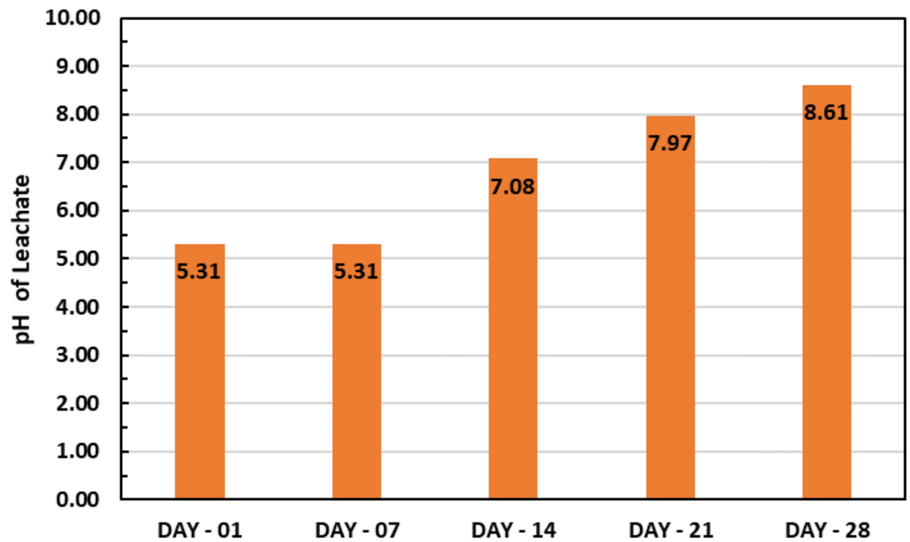



Figure 4-70 Weekly variations of pH of green papaya (whole) waste

#### 4.6.9.3 N-P-K Content

An upward and downward trend is observed in the nitrate and potassium content of the leachate (Figure 4-71). From the existing data, it is determined that the percentage nitrate, phosphate, and potassium content of fresh raw papaya are 46.6%, 3.7%, and 49.7% respectively. The experimental data for the nitrate and potassium content are not in agreement with the existing data. The phosphate content of the leachate is also higher than the reported value.

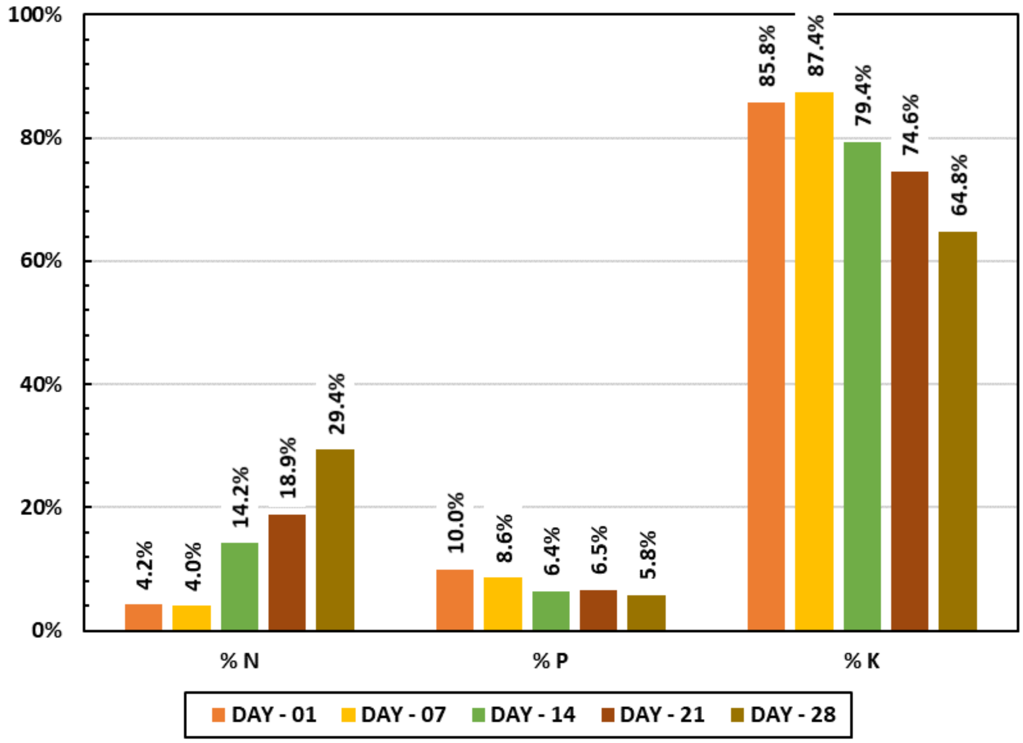



Figure 4-71 Percent distribution of N-P-K of green papaya (whole) waste

### 4.6.10 Lemons (whole)

#### 4.6.10.1 Physical condition

The lemon samples started to lose their moisture from day 1. By day 7 the sample shrunk noticeably (Figure 4-72). After 7 more days there was the formation of white fungus started, which eventually covered the whole sample by day 28. The bright yellow of the lemons turned pale within 28 days.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-72 Physical changes of lemons (whole) waste observed weekly

#### 4.6.10.2 pH

Due to the presence of citric acid, the lemons are acidic in nature and their pH ranges from 2.2 - 2.4. Despite that, the gradual decomposition of the sample takes the pH up to 6.84 as shown in Figure 4-73, which is not as high as other vegetables.

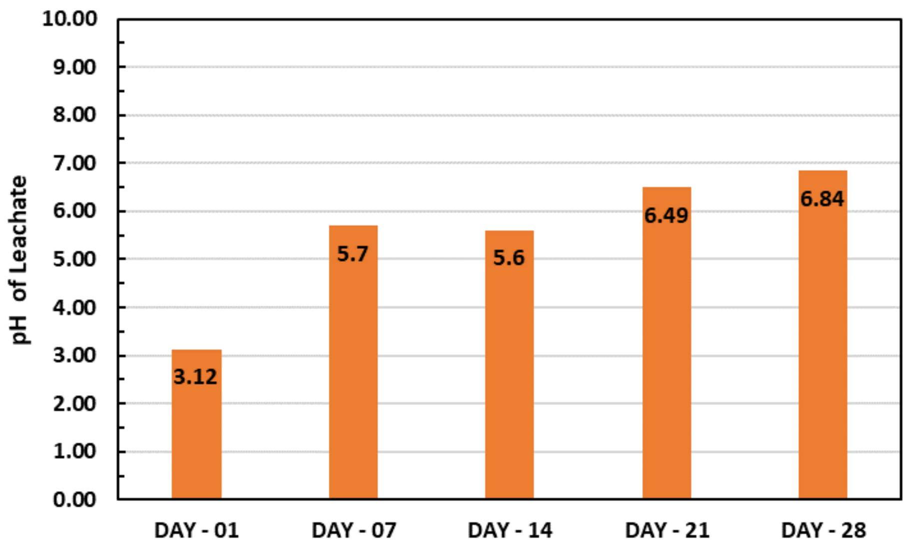



Figure 4-73 Weekly variations of pH of lemons (whole) waste

#### 4.6.10.3 N-P-K Content

The leachate from the lemon waste had negligible phosphate in it as reported in Figure 4-74. Previous data show that the percentage nitrate, phosphate and potassium content in fresh lemons are 46.6%, 3.7% and 49.7% respectively. The experimental data in the figure below shows approximately 10 - 11 % variation between the %N and % K.

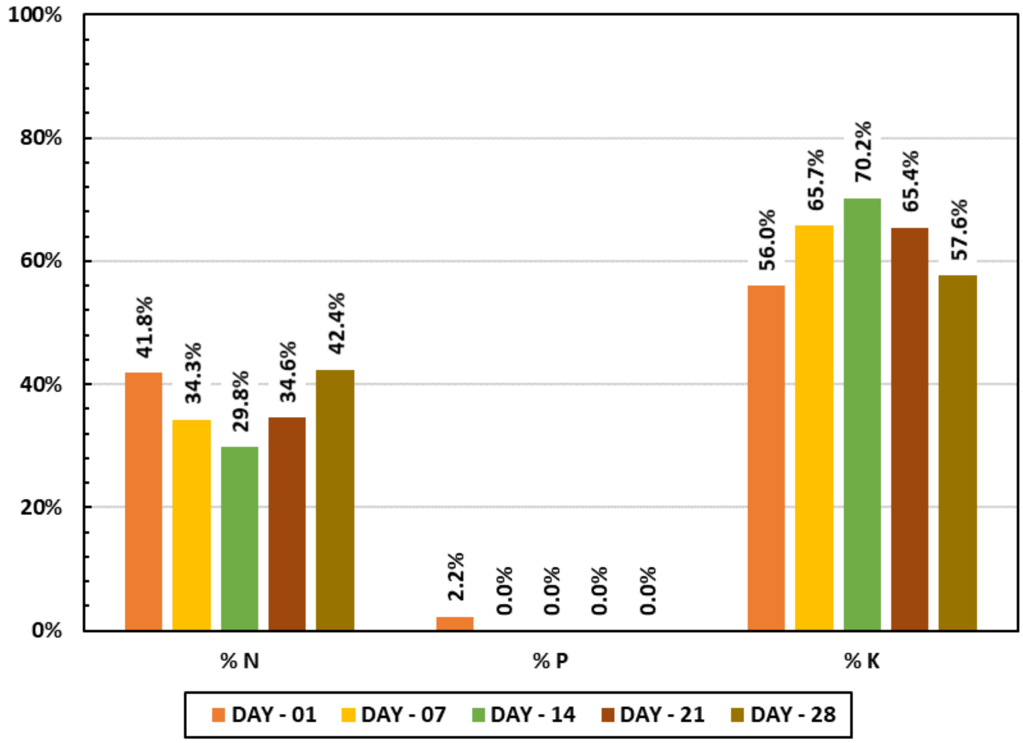



Figure 4-74 Percent distribution of N-P-K of lemons (whole) waste

### 4.6.11 Okra (Whole)

#### 4.6.11.1 Physical condition

After 7 days it was observed that the okra in the leachate collection buckets started to turn darker as shown in Figure 4-75. By day 28 the whole of the sample formed a lump, in which the separate pieces of okra were indistinguishable. There was a loss of moisture.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-75 Physical changes of okra (whole) waste observed weekly

#### 4.6.11.2 pH

Figure 4-76 shows the variation of pH of leachate obtained from okra waste. The pH value for fresh okra ranges between 5.5 - 6.4. The experimental value on day 1 was close to this range, after that, it departed towards higher numbers. The final pH of the leachate was 9.14.

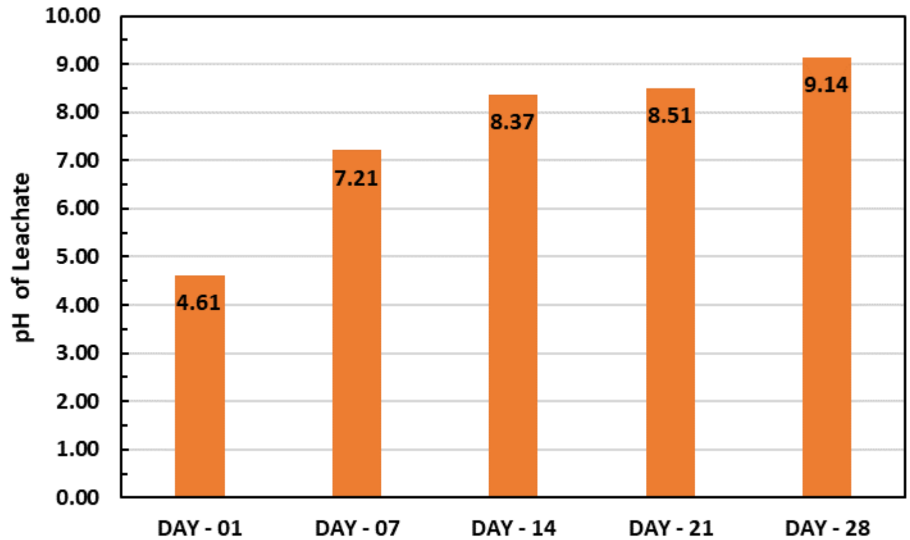



Figure 4-76 Weekly variations of pH of okra (whole) waste

#### 4.6.11.3 N-P-K Content

As reported in the previous literature okra was higher potassium content (% N-P-K - 34.9%, 11.0%, and 54.1% respectively). The numbers in Figure 4-77 show a rising trend in the percent nitrate content and a decreasing trend in percent potassium content.

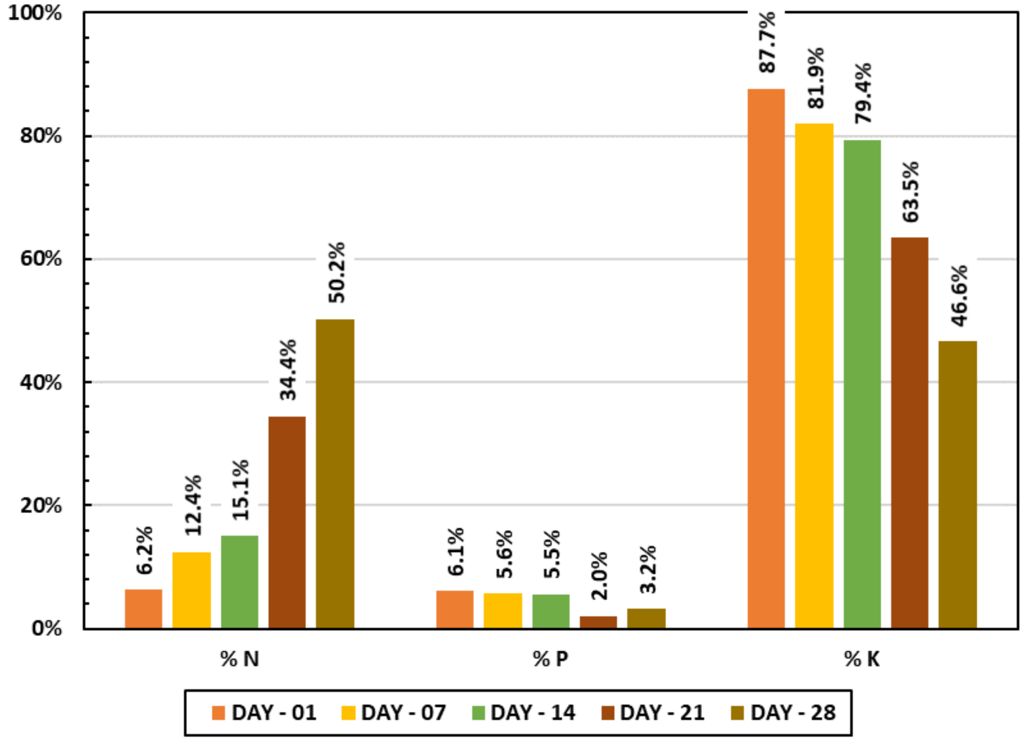



Figure 4-77 Percent distribution of N-P-K of okra (whole) waste

### 4.6.12 Potato (whole)

#### 4.6.12.1 Physical condition

Since the potato is more starch-type food material, the deterioration of it is not that prominent as other vegetables (Figure 4-78). Without the development of black spots and white fungus on the surface, there is no other anomaly in the appearance of potato waste from the day - 1 to day - 28. The volume change is also negligible.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-78 Physical changes of potato (whole) waste observed weekly

#### 4.6.12.2 pH

There is a slim margin between the pH value of the potato reported in the previous data (pH value 6.1) and the experimental data as shown in Figure 4-79. This also indicated that there was a negligible deterioration of the potato waste in 28 days.

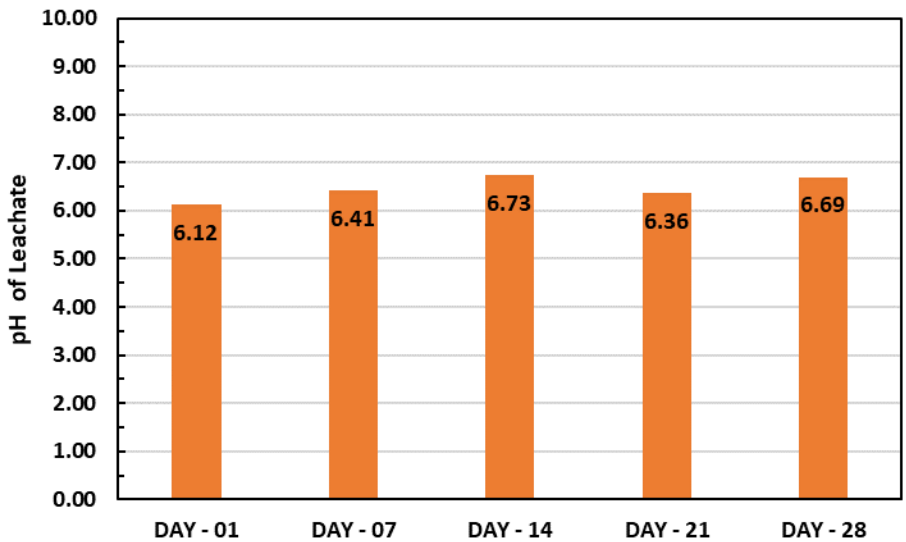



Figure 4-79 Weekly variations of pH of potato (whole) waste

#### 4.6.12.3 N-P-K Content

In potatoes, the percent nitrate, phosphate, and potassium content are as follows, 29.7%, 8.4%, and 61.9%. The range of experimental data in Figure 4-80 has a resemblance to the previously reported values.

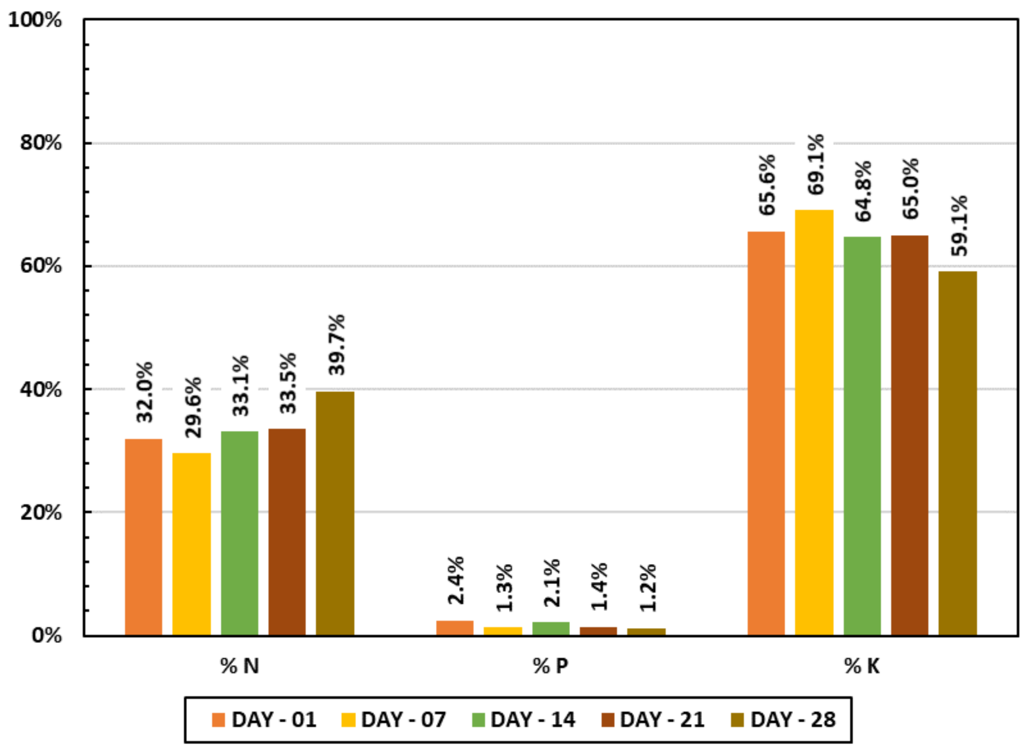



Figure 4-80 Percent distribution of N-P-K of potato (whole) waste

### 4.6.13 Pumpkin (whole)

#### 4.6.13.1 Physical condition

Pumpkin is a juicy vegetable. For that reason, major degradation of the sample can be observed comparing the pictures on day 1 and day 28 (Figure 4-81). The waste got covered with white fungus.


Day – 01


Day – 07


Day – 14


Day – 21


Day - 28

Figure 4-81 Physical changes of pumpkin (whole) waste observed weekly

**4.6.13.2 pH**

The pH range for pumpkin is 4.8 - 5.2. Figure 4-82 shows that the pH exceeded this range by day - 14 of the experiment. The final pH value was found to be 8.16, indicating a basic solution.

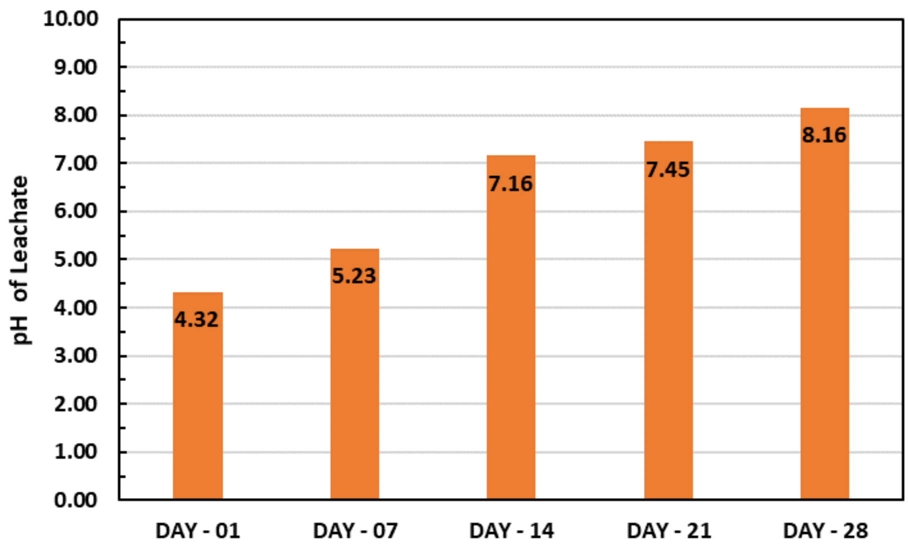



Figure 4-82 Weekly variations of pH of pumpkin (whole) waste

**4.6.13.3 N-P-K Content**

The experimental data suggests that the pumpkin leachate is high in potassium as the percentage ranges between 79.6 to 93.7 % (Figure 4-83). It is found from the experimental data that the percentage nitrate, phosphate, and potassium content of pumpkin are 20.7%, 9.1% and 70.2%. The experimental data for the leachate has a resemblance with the existing data.

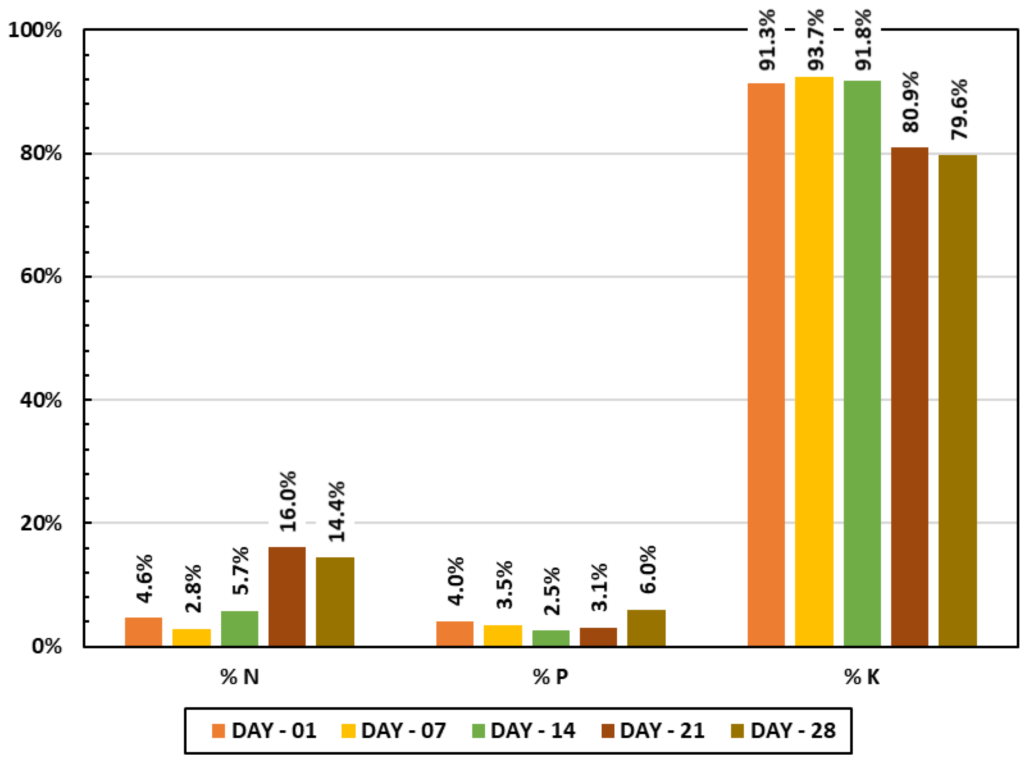



Figure 4-83 Percent distribution of N-P-K of pumpkin (whole) waste

### 4.6.14 Radish (whole)

#### 4.6.14.1 Physical condition

As shown in Figure 4-84, black spots started to develop on the surface of the radish sample within day 7 of the experiment. Eventually, these black spots covered the whole surface of the sample within 28 days. Also, the waste lost some water and shrunk in volume.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-84 Physical changes of radish (whole) waste observed weekly

#### 4.6.14.2 pH

The pH of fresh radish lies between 5.8 - 6.5. Figure 4-85 shows that the pH goes us every 7 days.

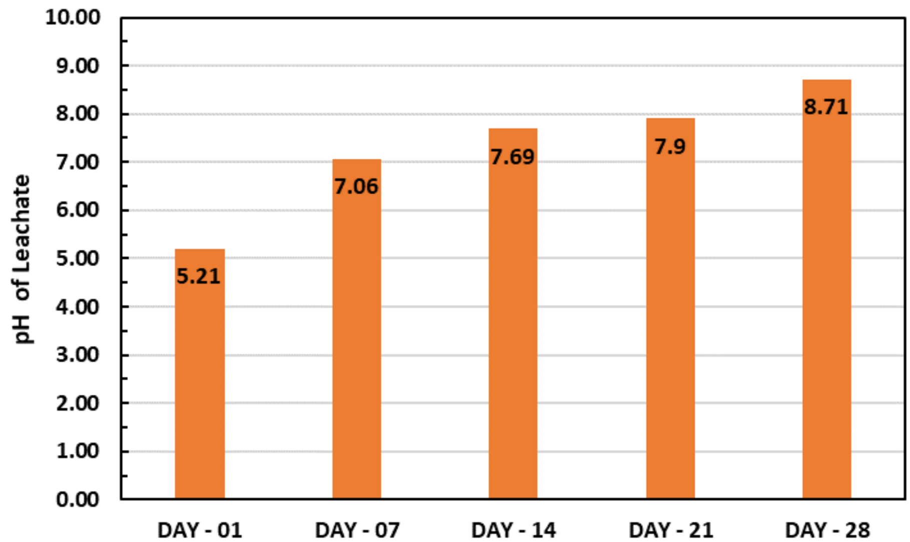



Figure 4-85 Weekly variations of pH of radish (whole) waste

#### 4.6.14.3 N-P-K Content

For radish, it is found from the existing data that the percentage nitrate, phosphate, and potassium content are 21.2%, 6.2%, and 72.6% respectively. The average of the experimental value matches with these values, also indicating the higher percentage of potassium in radish.

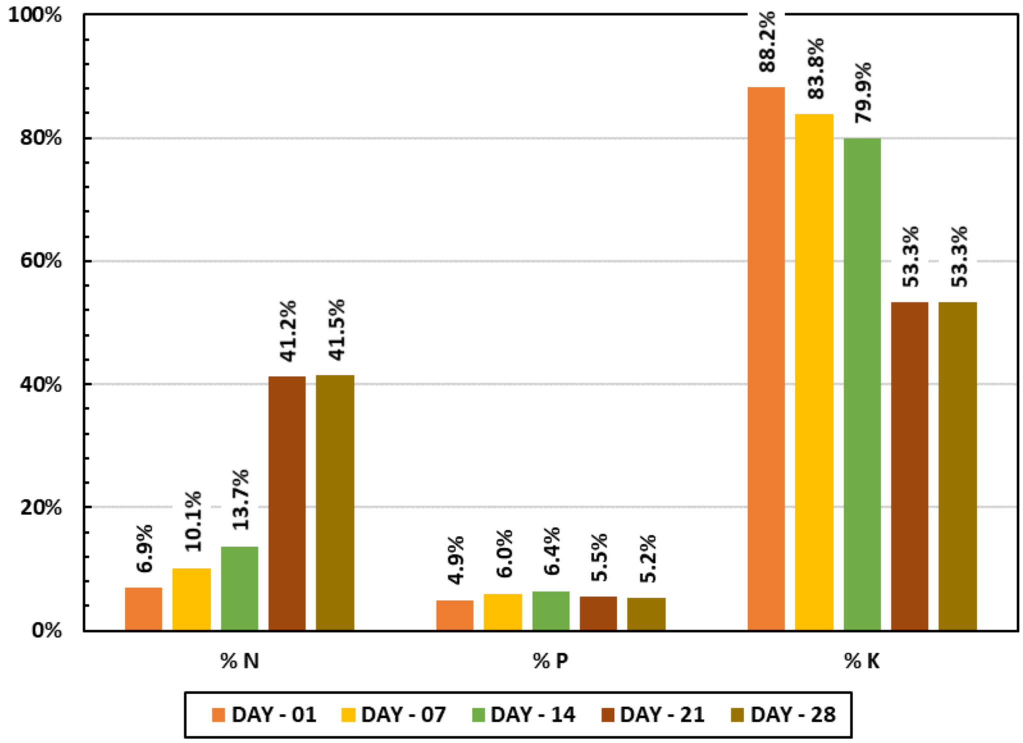



Figure 4-86 Percent distribution of N-P-K of radish (whole) waste

### 4.6.15 Spinach and Cilantro (whole)

#### 4.6.15.1 Physical condition

The sample was prepared by mixing an equal mass of spinach and cilantro. Figure 4-87 shows the gradual degradation of the waste mix. The waste takes on a dark green color after just 7 days. Within the next few weeks the shredded pieces of spinach and cilantro form into a dense wet sticky mass.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-87 Physical changes of spinach and cilantro (whole) waste observed weekly

#### 4.6.15.2 pH

Figure 4-88 shows that the starting pH for the sample was 7.06, this indicates a slightly acidic solution. The pH for spinach was found to range from 5.5 - 6.8. The pH for this mixture also increased within the 28 days experimental period.

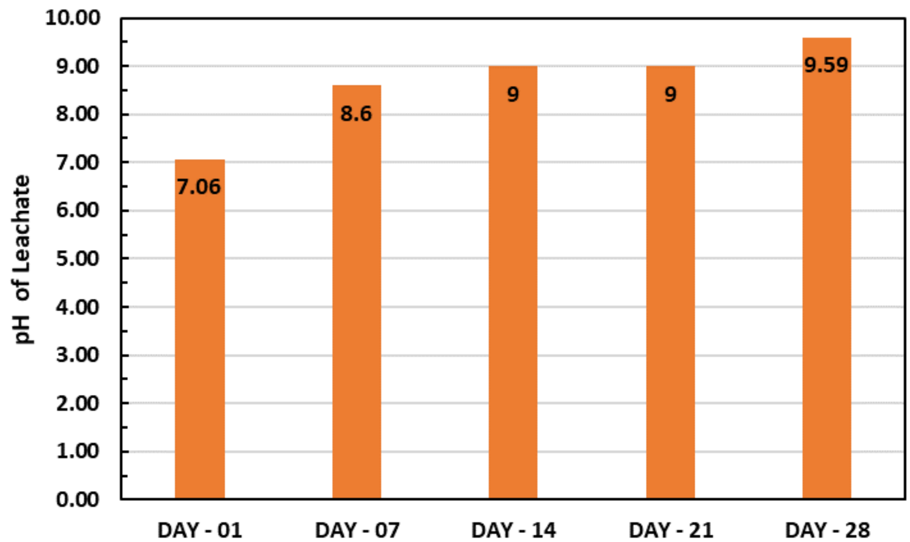



Figure 4-88 Weekly variations of pH of spinach and cilantro (whole) waste

#### 4.6.15.3 N-P-K Content

Spinach and cilantro have similar percentage of nitrate, phosphate and potassium content (for spinach - 27.2%, 6.1% and 66.6% and for cilantro - 32.0%, 5.5% and 62.5%). The mix of the two leafy vegetables is also expected to have similar values. The numbers are shown in Figure 4-89 support the assumption.

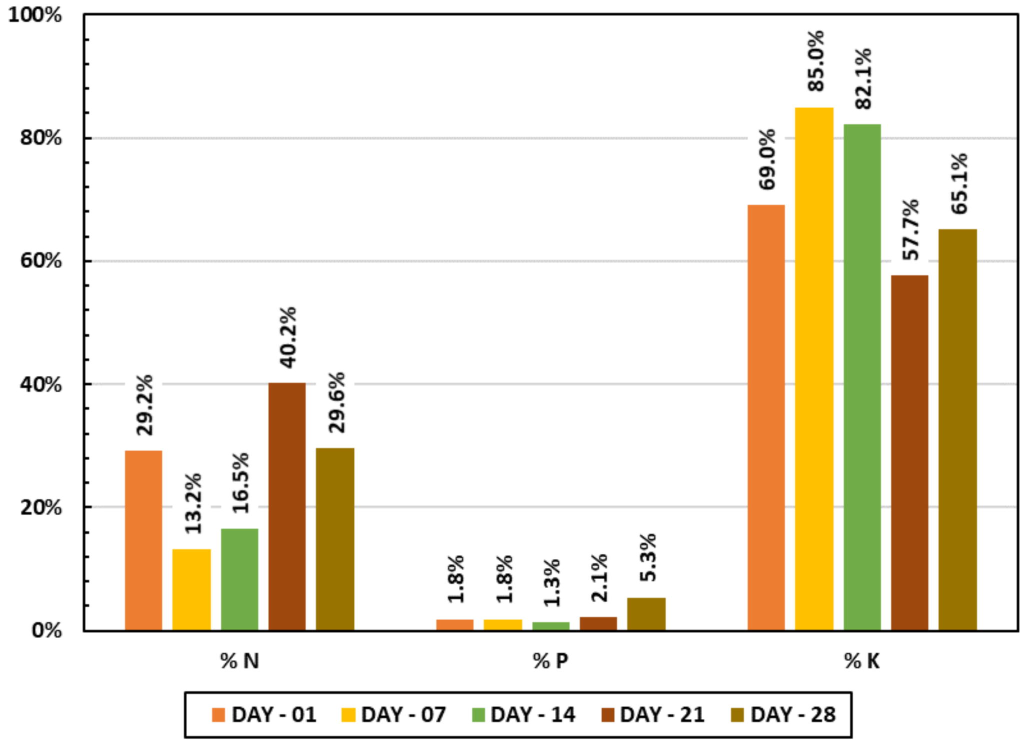



Figure 4-89 Percent distribution of N-P-K of spinach and cilantro (whole) waste

### 4.6.16 Tomato (whole)

#### 4.6.16.1 Physical condition

Like pumpkin, tomato is a juicy vegetable. It loses a huge amount of moisture as depicted in Figure 4-90. From day 1 there is the development of white fungus on the tomato waste. Gradually the waste lost water and by day - 28 only peel of tomato is seen on the strainer.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-90 Physical changes of tomato (whole) waste observed weekly

#### 4.6.16.2 pH

Tomato has low pH (4.2 - 4.9) indicating that it's acidic. Figure 4-91 shows that the leachate was also acidic initially. As it degraded the pH of the leachate increased and on the 28th day it reached 9.01. So, within a span of 28 days the leachate became basic.

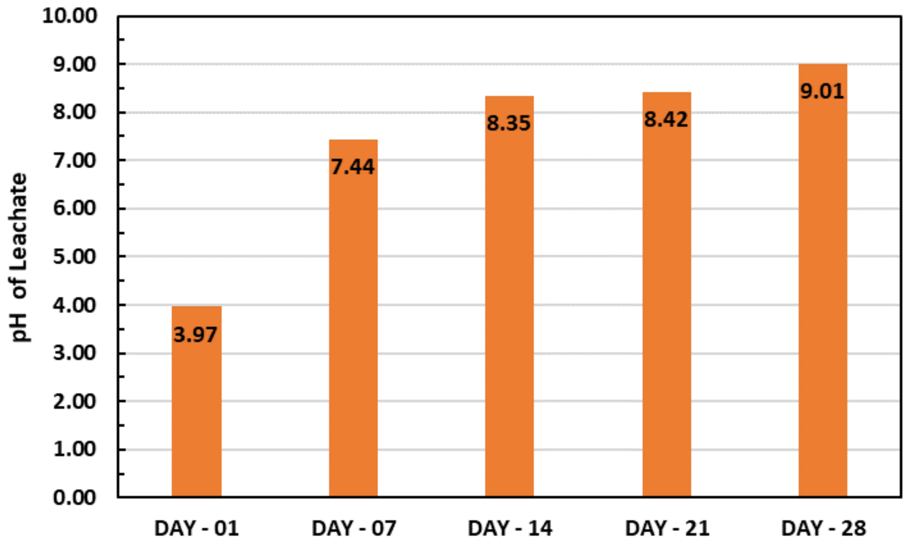



Figure 4-91 Weekly variations of pH of tomato (whole) waste

#### 4.6.16.3 N-P-K Content

The percentage nitrate, phosphate, and potassium content of fresh tomato are 25.2%, 6.9%, and 67.9% respectively. An increase in the nitrate and phosphate content and decrease in potassium content of the leachate is observed in the experimental data (Figure 4-92).

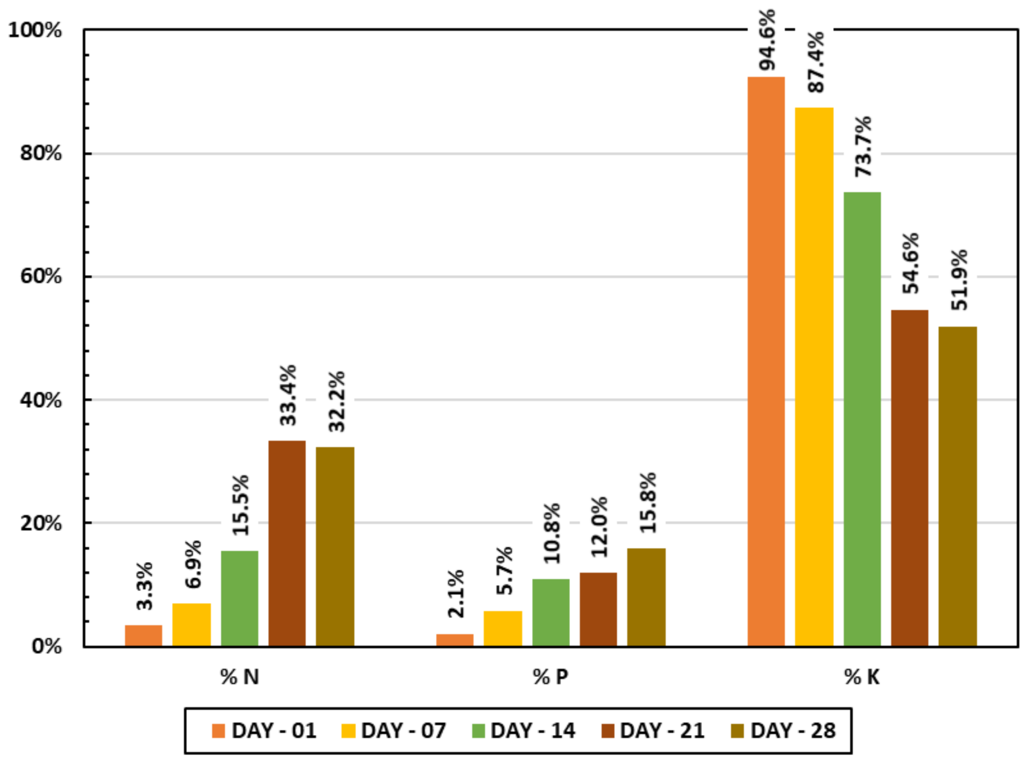



Figure 4-92 Percent distribution of N-P-K of tomato (whole) waste

## 4.7 pH of Vegetable Waste

The pH values for leachates produced from all the vegetable waste samples are summarized in Figure 4-93. As the decomposition goes on the pH of the leachate increases for all the vegetables. Only the pH of the potato remained almost unchanged. From this experimental data, it can be inferred that the leachate from vegetable wastes can be used for increasing the pH value of soil. In the regions where the crop growth is arrested due to the excessive acidity of the soil, vegetable waste leachate can be applied thereto raise the pH of the soil.

## 4.8 Nitrate content of Vegetable Waste

Figure 4-94 shows that similar to the leachate from fruit wastes, the leachate from the vegetable wastes lack nitrate. Though the percentage of nitrate was observed to increase after 28 days, the concentration obtained might not be beneficial for crop production given the time constraints.

## 4.9 Phosphate content of Vegetable Waste

The leachates from the vegetables were very poor in phosphate content. As illustrated in Figure 4-95, the phosphate content of the leachates is not appreciable compared to nitrate or potassium. In all cases, the percentage is between 5 - 15% or even lower. For this reason, the use of leachate from the vegetable waste might not be sufficient to fill up the phosphate deficiency of cultivatable lands.

## 4.10 Potassium content of Vegetable Waste

The numbers in Figure 4-43 indicated that the leachate from the fruit waste can be used as a source of potassium for the soil. In the case of vegetable waste leachate, though the percentage of potassium is not that high (Figure 4-96), it can also be used as a source of potassium.

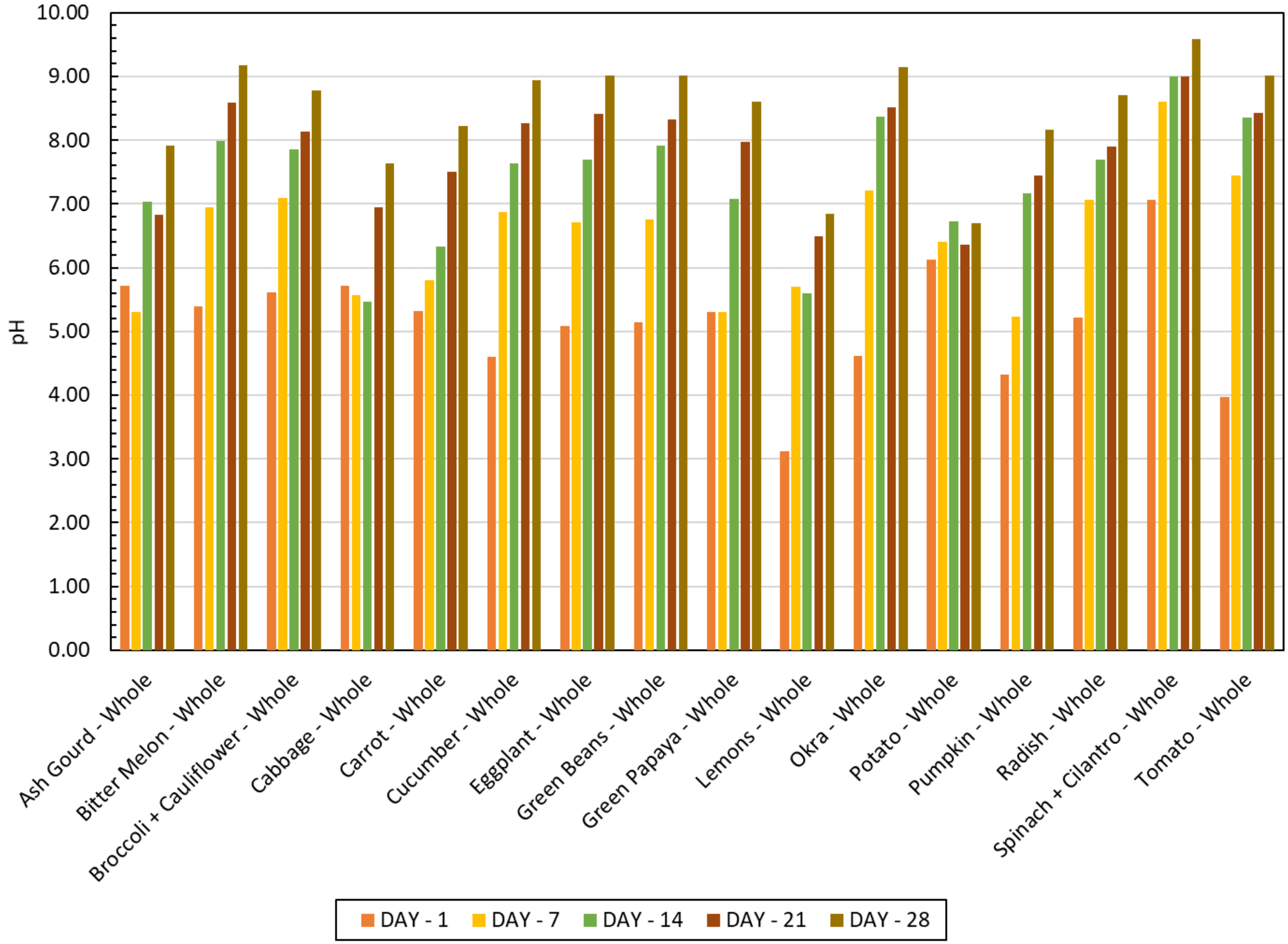



Figure 4-93 Weekly variations of the pH of vegetable waste

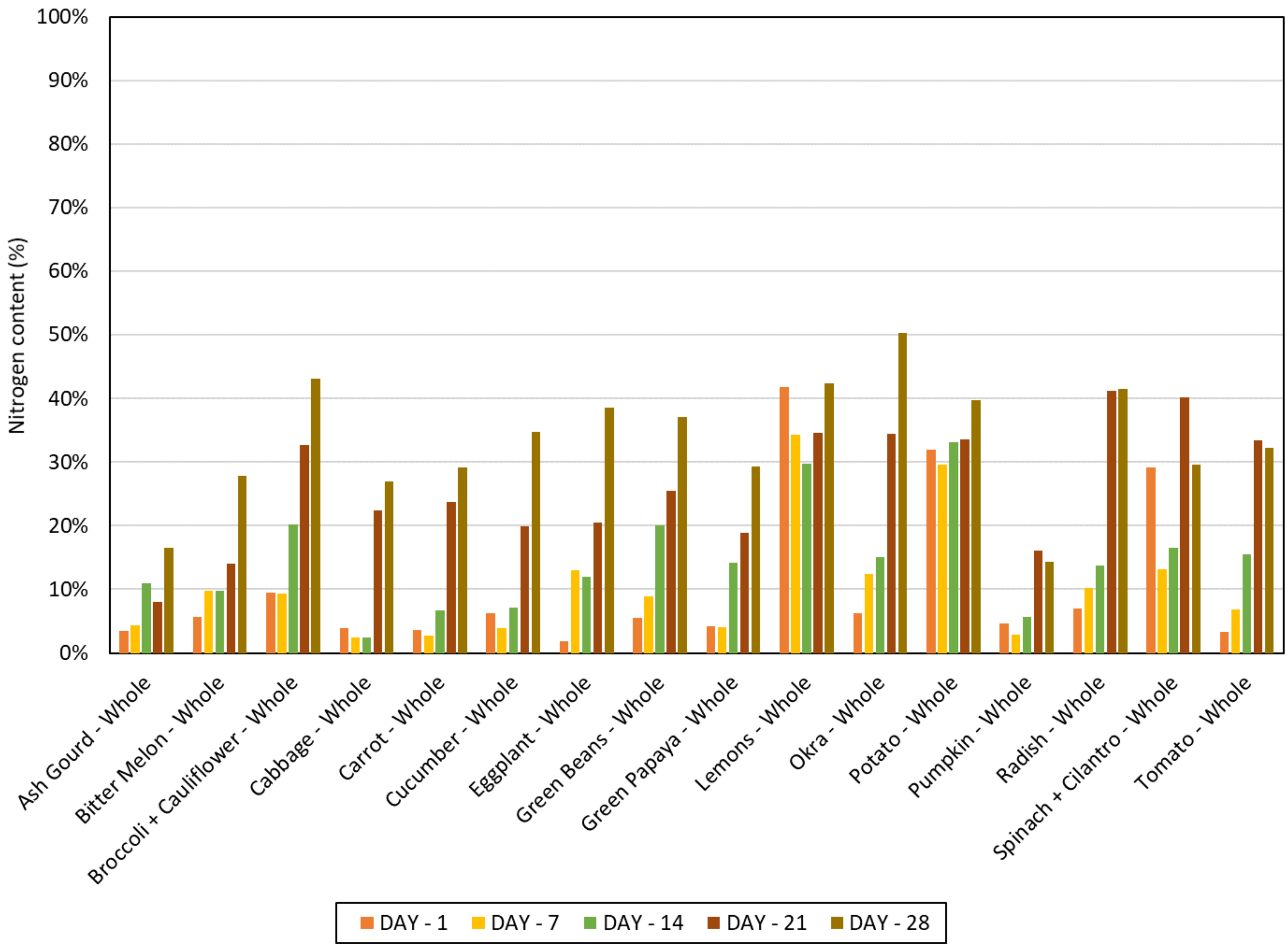



Figure 4-94 Weekly variation of the nitrate content (%) of vegetable wastes

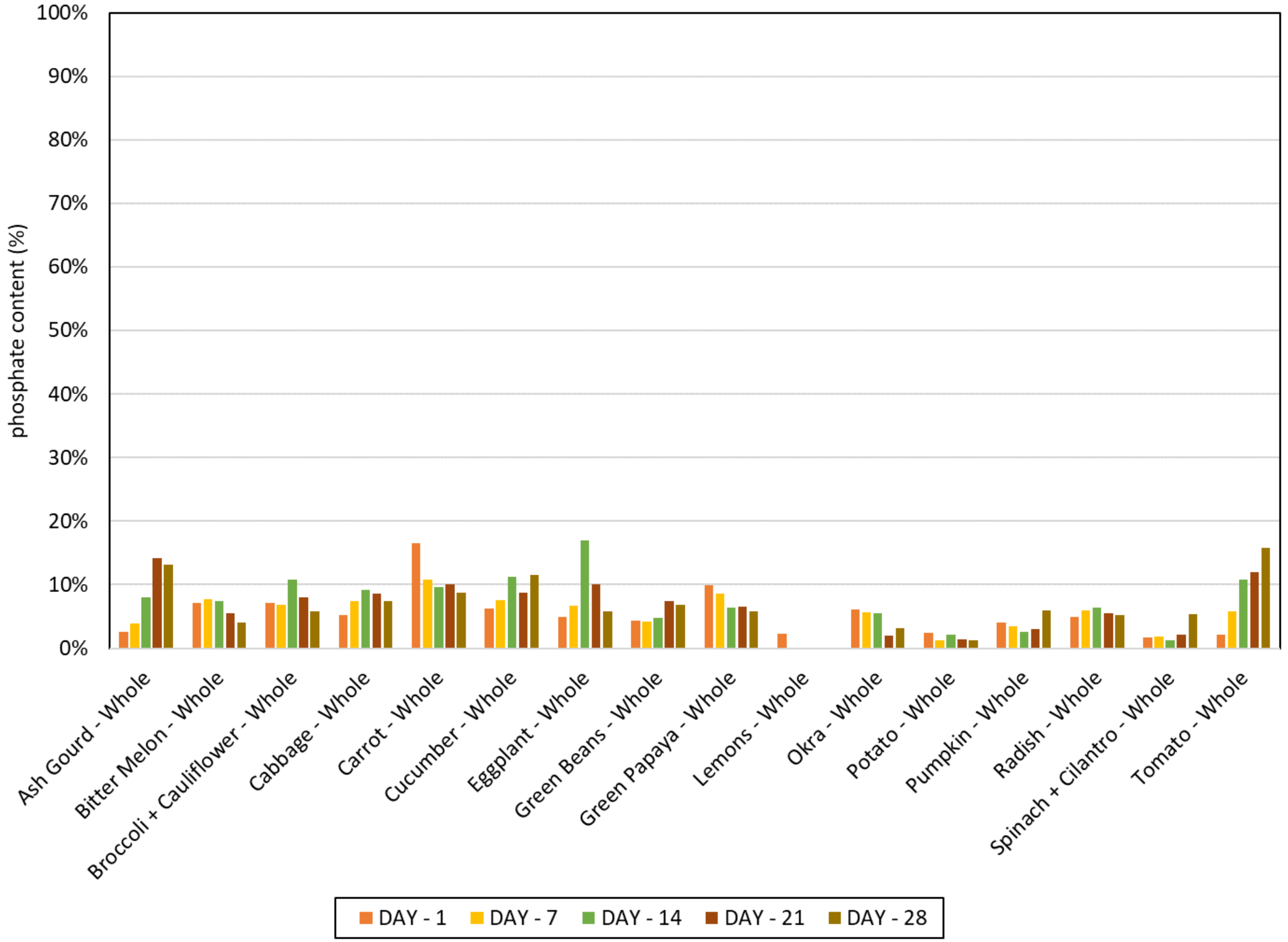



Figure 4-95 Weekly variations of the phosphate content (%) of vegetable waste

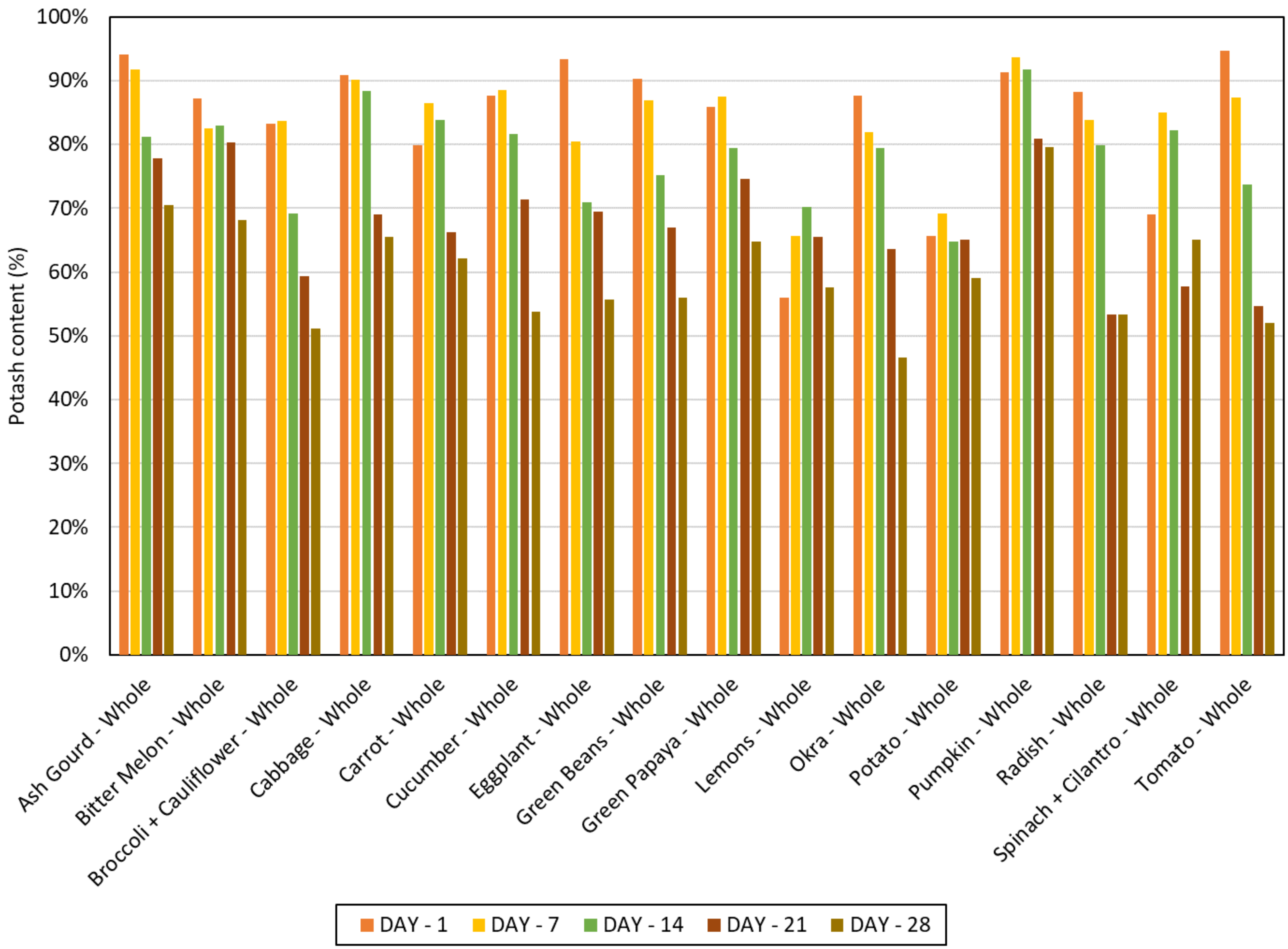



Figure 4-96 Weekly variations of the potassium content (%) of vegetable wastes

### 4.11 Physical condition and chemical properties of Waste Mixtures

The physical condition and chemical properties of the waste mixtures were monitored weekly.

#### 4.11.1 Mixtures of Fruit peels

##### 4.11.1.1 Physical condition

Peels from all the fruits used in the experiment were mixed to prepare the sample ( Figure 4-97). The mixture lost water gradually and white fungus developed on it.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-97 Physical changes of a mixture of fruit peel wastes observed weekly

#### 4.11.1.2 pH

As shown in Figure 4-98, the pH of the leachate from the fruit peel mixture remained below 5, thus indicating acidic nature.

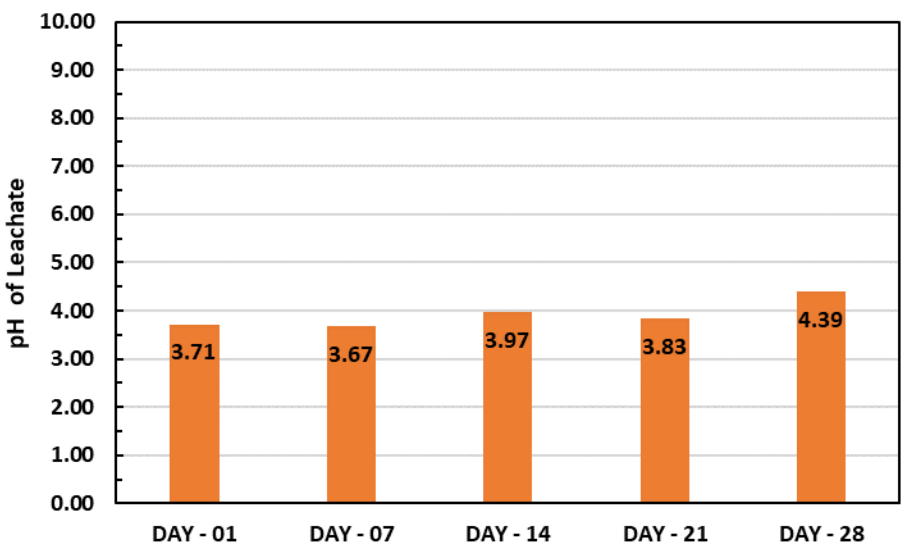



Figure 4-98 Weekly variation of pH of the leachate of a mixture of fruit peel wastes

#### 4.11.1.3 N-P-K Content

The percentage of potassium was greater in the individual fruit wastes. A similar distribution of N-P-K is seen for the leachate of the mixture of the fruit peels (Figure 4-99)

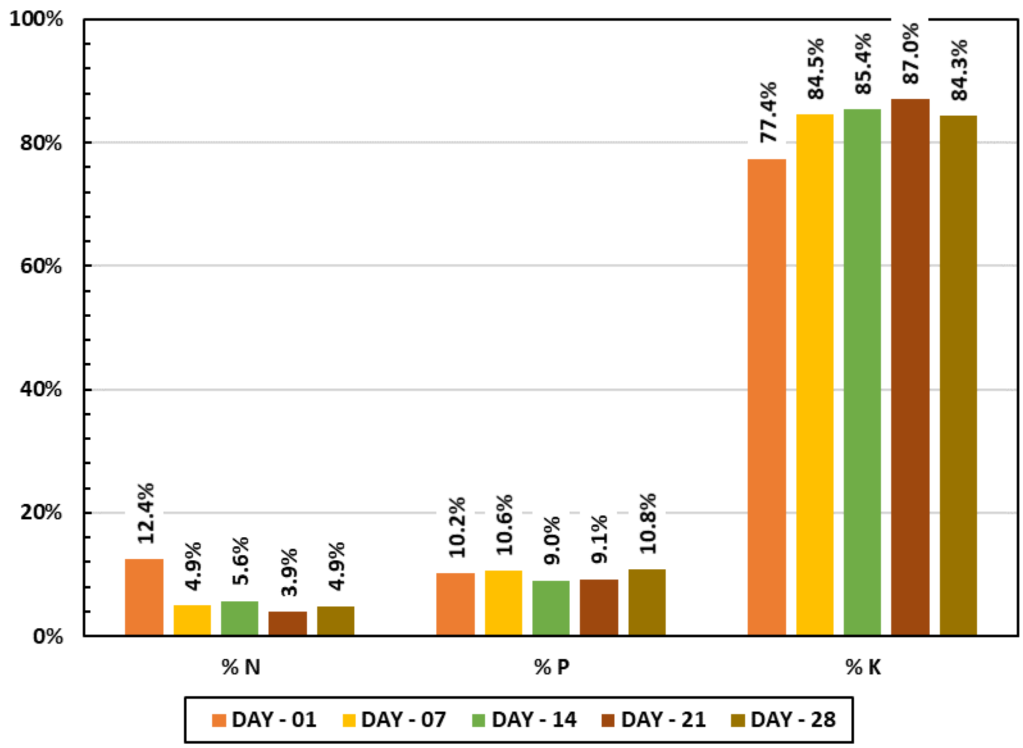
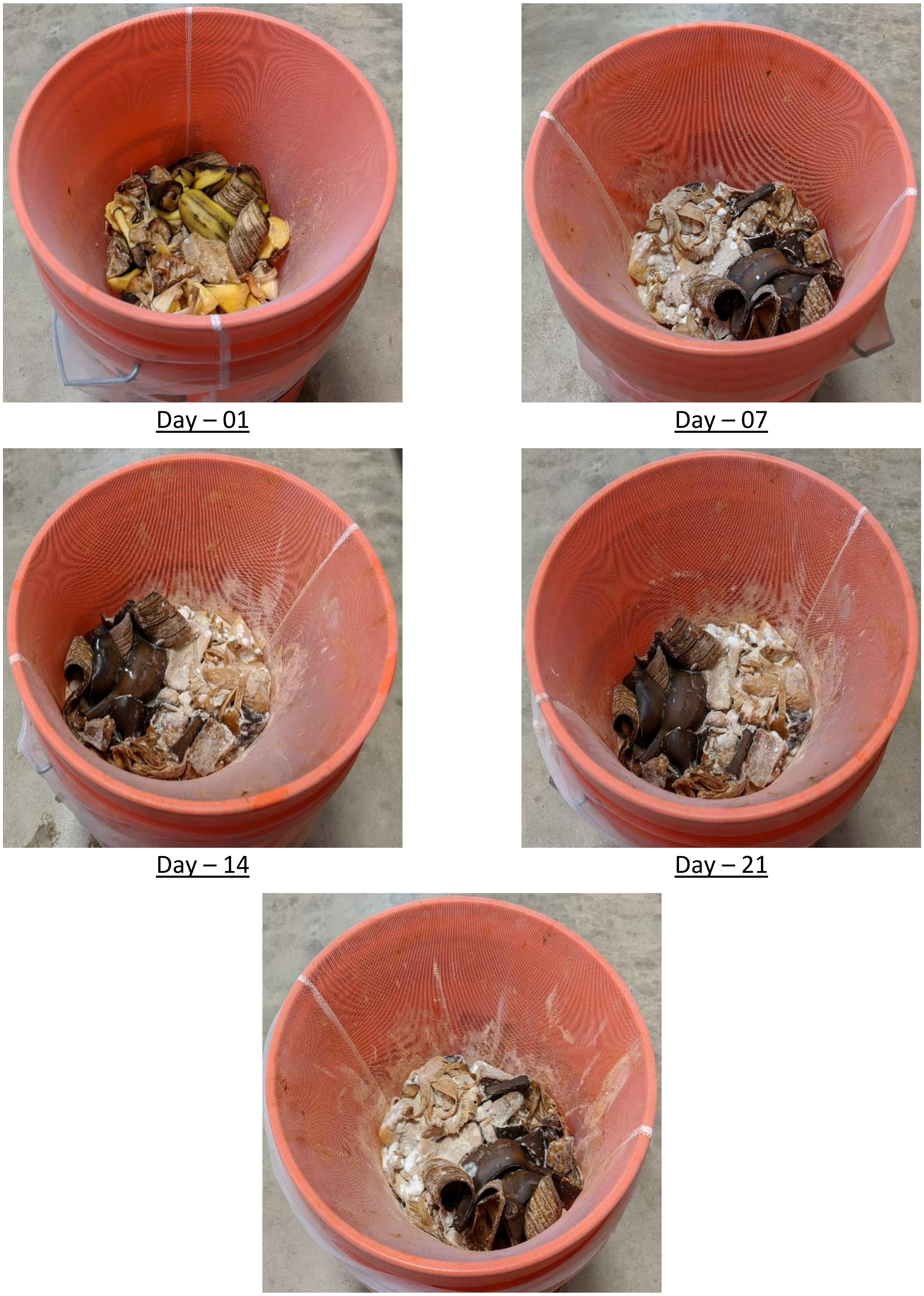



Figure 4-99 Percent distribution of a mixture of fruit peel wastes

### 4.11.2 Mixtures of Fruits Leftovers

#### 4.11.2.1 Physical condition

Leftovers or parts of all the fruits used in the experiment were mixed to prepare the sample ( Figure 4-100). The mixture lost water gradually and white fungus developed on it.



Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-100 Physical changes of a mixture of fruit leftover wastes observed weekly

#### 4.11.2.2 pH

As shown in Figure 4-101, the pH of the leachate from the fruit leftovers mixture remained below 5, thus indicating acidic nature.

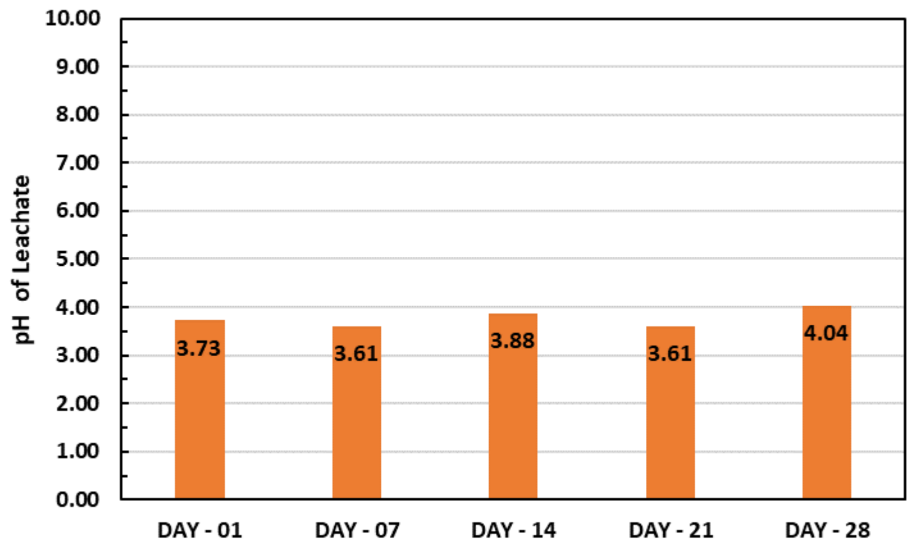



Figure 4-101 Weekly variations of the mixture of fruit leftover wastes

#### 4.11.2.3 N-P-K Content

The percentage of potassium was greater in the individual fruit wastes. A similar distribution of N-P-K is seen for the leachate of the mixture of the fruit leftovers (Figure 4-102)

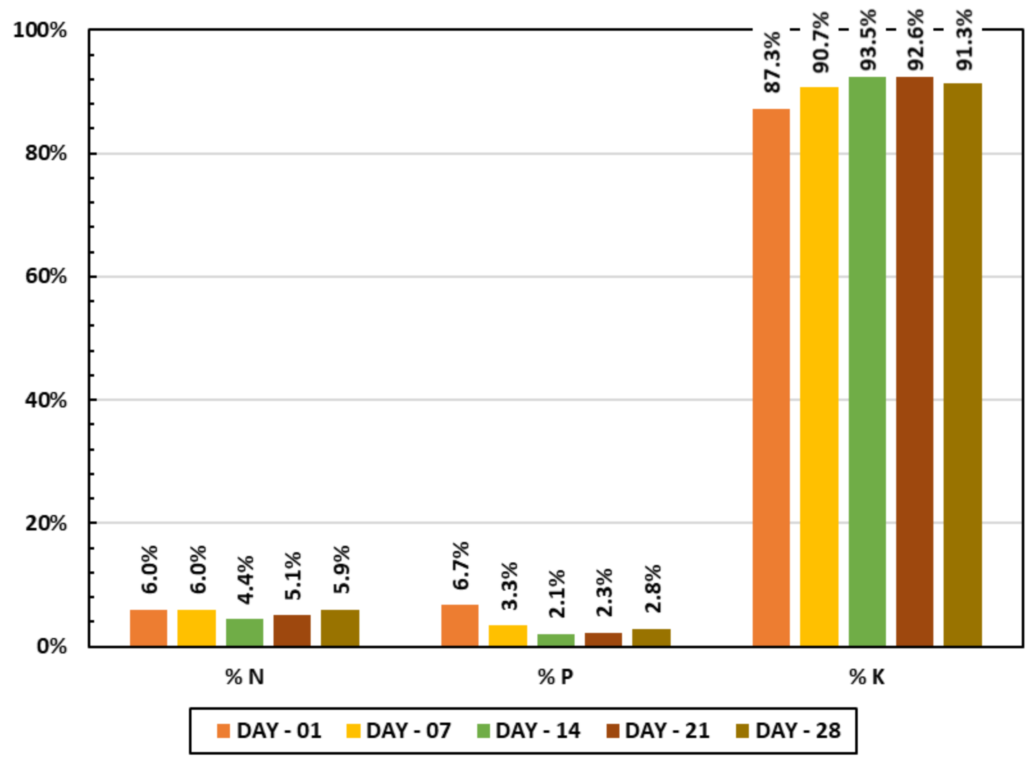



Figure 4-102 Percent distribution of N-P-K of the mixture of fruit leftover wastes

### 4.11.3 Mixture of Vegetable wastes

#### 4.11.3.1 Physical condition

Equal masses of all the vegetables used in the experiment were mixed and two sets of samples were prepared. The degradation of both the samples was identical (Figure 4-103Figure 4-104). The samples lost water and a form of white fungus covered it gradually.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-103 Physical changes of the mixture of vegetable wastes - Sample - 1 observed weekly

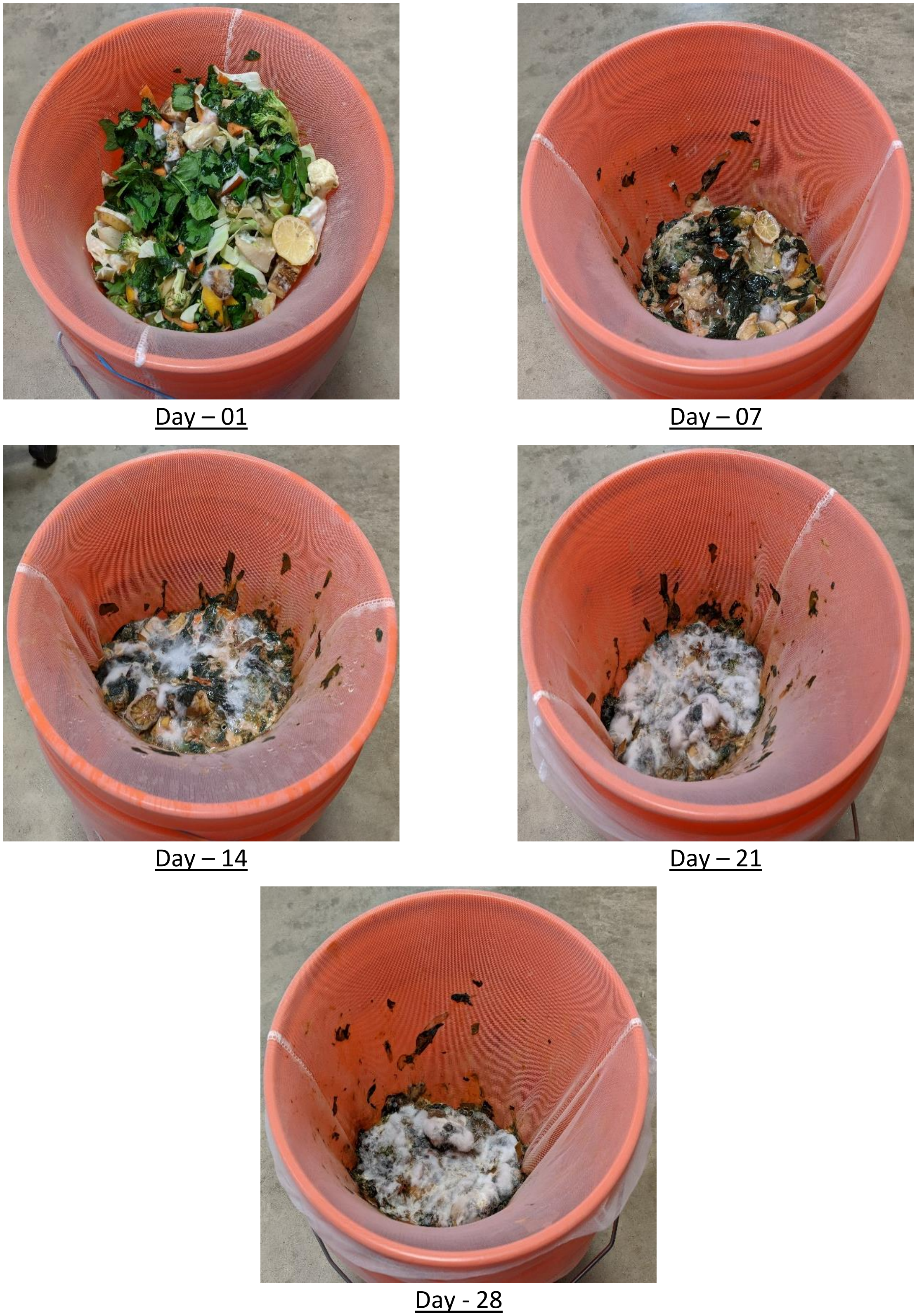



Figure 4-104 Physical changes of the mixture of vegetable wastes - sample - 2 observed weekly

#### 4.11.3.2 pH

The leachates generated from both the mixed vegetable samples demonstrated a similar pattern of increase of pH. (Figure 4-105 and Figure 4-106). From the previous sections, we have seen that in the case of individual vegetables the pH increased. So, this increase in the pH of the leachate was expected.

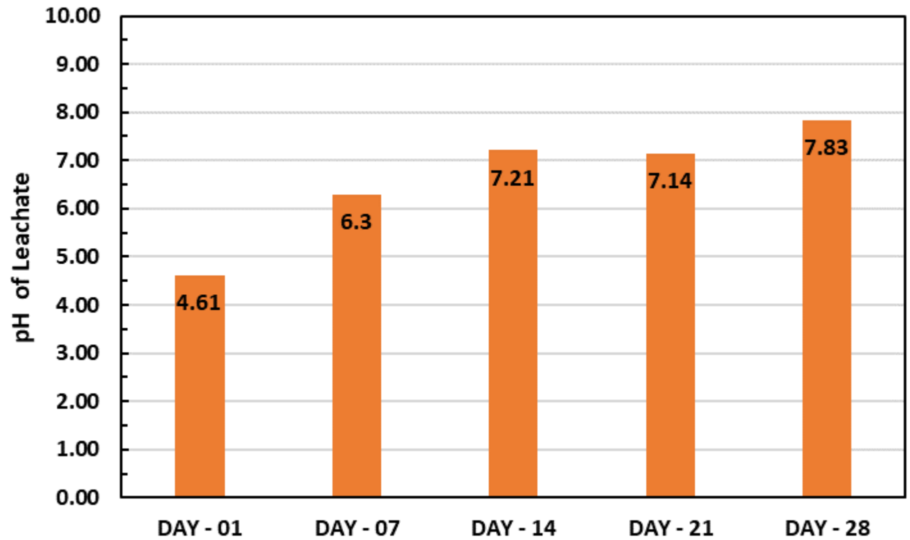



Figure 4-105 Weekly change of pH of leachate from the mixture of vegetable wastes - sample - 1

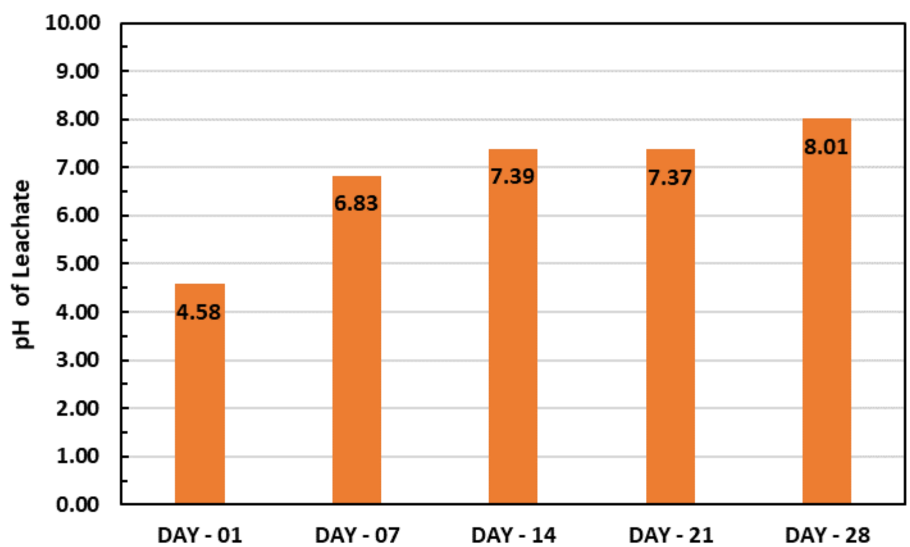



Figure 4-106 Weekly change of pH of leachate from the mixture of vegetable wastes - sample - 2

#### 4.11.3.3 N-P-K Content

The samples had similar N-P-K content (%) (Figure 4-107 and Figure 4-108). The percentage of potassium in the vegetable waste leachate was higher. The same thing is seen here.

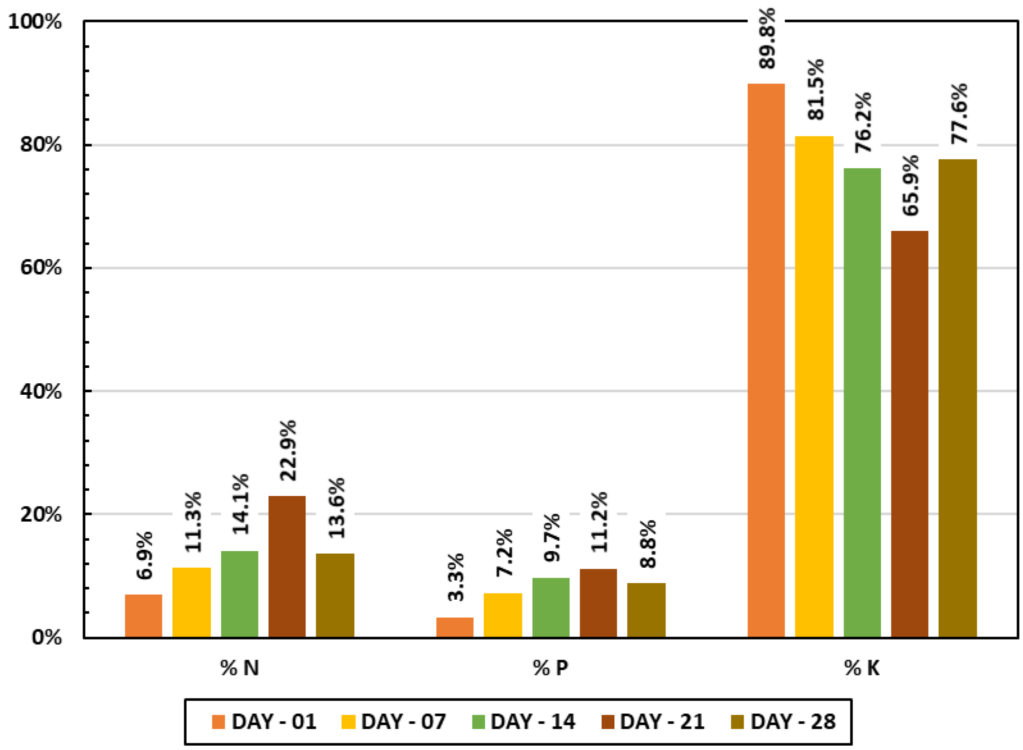



Figure 4-107 Mixture of vegetable wastes - Sample - 1

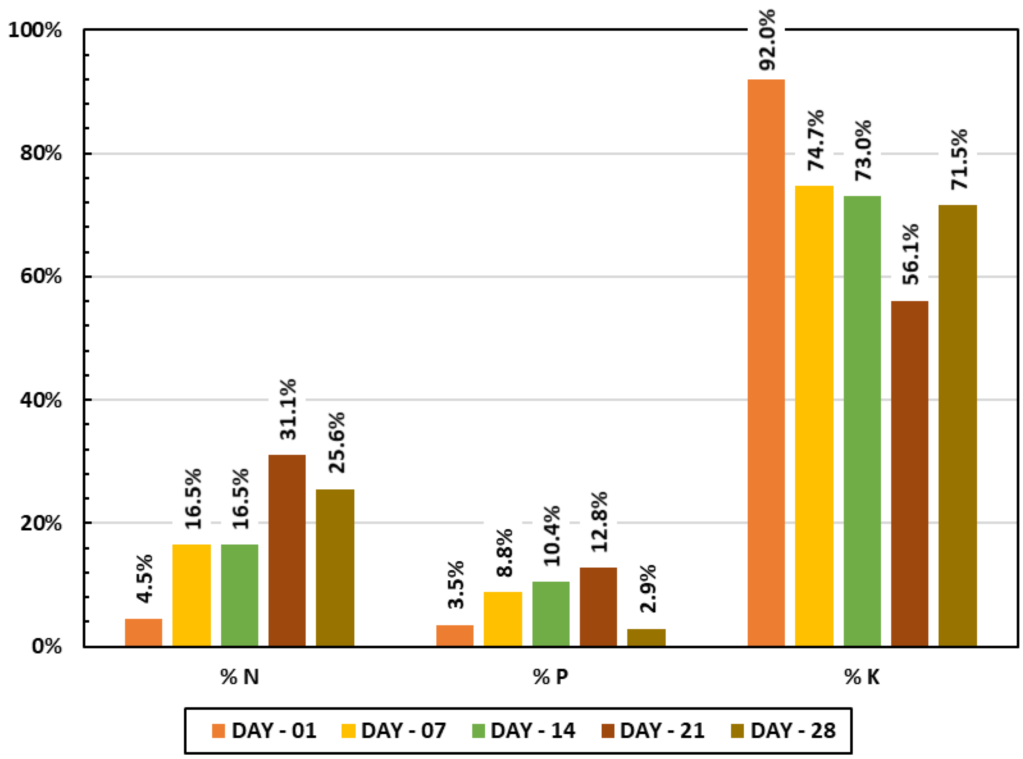



Figure 4-108 Mixture of vegetable wastes - Sample - 2

### 4.11.4 Mixture of Fruit and Vegetable wastes

#### 4.11.4.1 Physical condition

Equal portions of fruit and vegetable wastes were mixed to prepare this sample.

Day – 01

Day – 07

Day – 14

Day – 21

Day - 28

Figure 4-109 Physical changes of the mixture of fruit and vegetable wastes observed weekly.

#### 4.11.4.2 pH

As seen from the previous sections the leachate from the fruit waste had a pH value less than 5, whereas the leachate from the vegetable waste had a pH value almost near 9. Now, when these two types are mixed the pH value should remain somewhere in between. This is seen in the figure below.

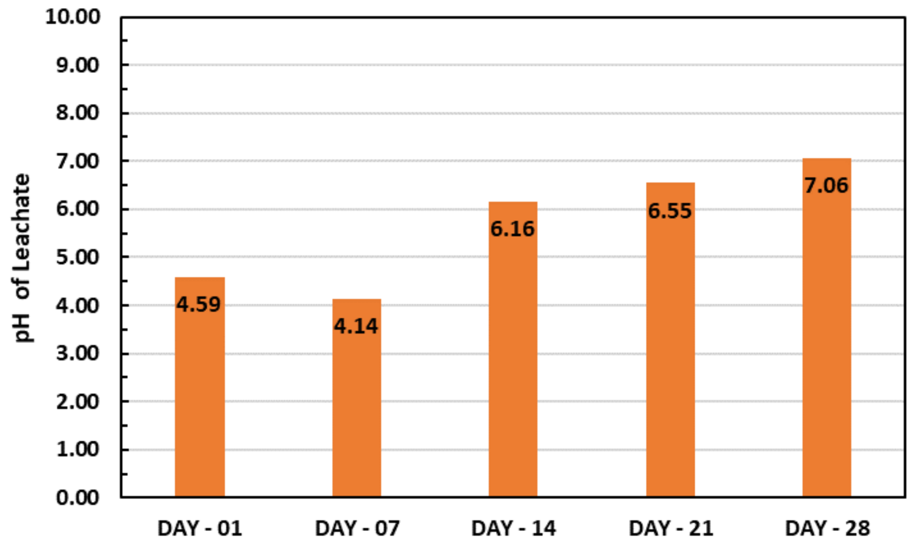



Figure 4-110 weekly variations of pH of leachate from the mixture of fruit and vegetable wastes

#### 4.11.4.3 N-P-K Content

Both the fruit waste and vegetable leachate had a higher percentage of potassium content. Naturally, the same proportion is displayed in their mixture. The mixture is rich in potassium.

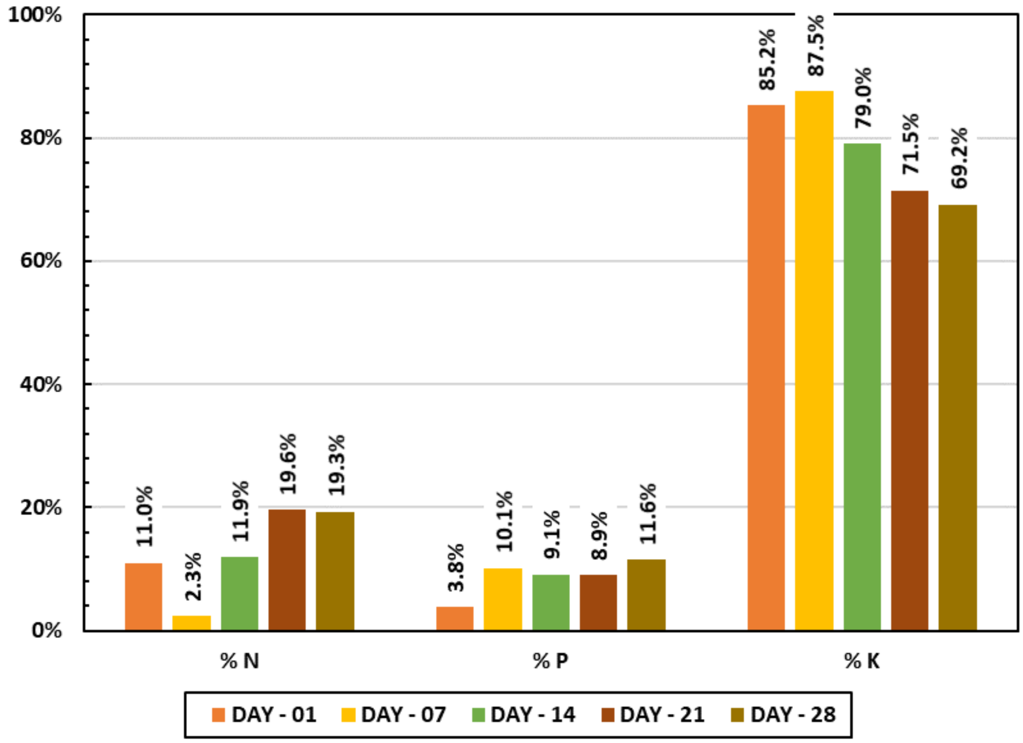



Figure 4-111 Weekly variation of N-P-K content of leachate from the mixture of fruit and vegetable waste

### 4.12 Using the Liquid Fertilizer from Food waste

From the above analysis, it is observed that compared to Nitrogen and Phosphate (Phosphorus), the concentration of Potash (Potassium) is higher in fruit waste, vegetable waste, and their mixture. For this reason, instead of all three major nutrients, Nitrogen, Phosphate, and Potash, it will be beneficial to concentrate on the potash content of the leachate obtained from the waste. If a soil sample has other nutrient deficiencies, it can be fulfilled by using chemical fertilizers.

A simple equation is proposed below to determine the amount of solid waste (in tons) required to fulfill the nutrient demand of large cultivatable land.

$$M_{sw} = \frac{X_f\ A_f}{X_w\ (LG)} f_u \qquad (1)$$

where,

$M_{sw}$ = total mass of the solid waste (tons or kg)

$X_f$ = concentration of nutrient (N/P/K) required in the field (in kilogram/hectare)

$X_w$ = concentration of nutrient (N/P/K) present in the waste (in ppm or milligram/L)

$A_f$ = area of the field (hectare or square feet)

$LG$ = volume of leachate obtained from waste (%)

= 20 % (for fruit waste)

= 10 % (for vegetable waste)

= 13 % (for mixed waste)

$f_u$ = 1000, if area is in hectares and mass of waste is in ton

= 9.3, if area is in square feet (sft) and mass of waste is in kg

To demonstrate the use of equations (1) two charts have been developed (Figure 4-112 and Figure 4-113) for rice (*Oryza sativa L.*) and rose (*Rosa centiflora*) respectively.

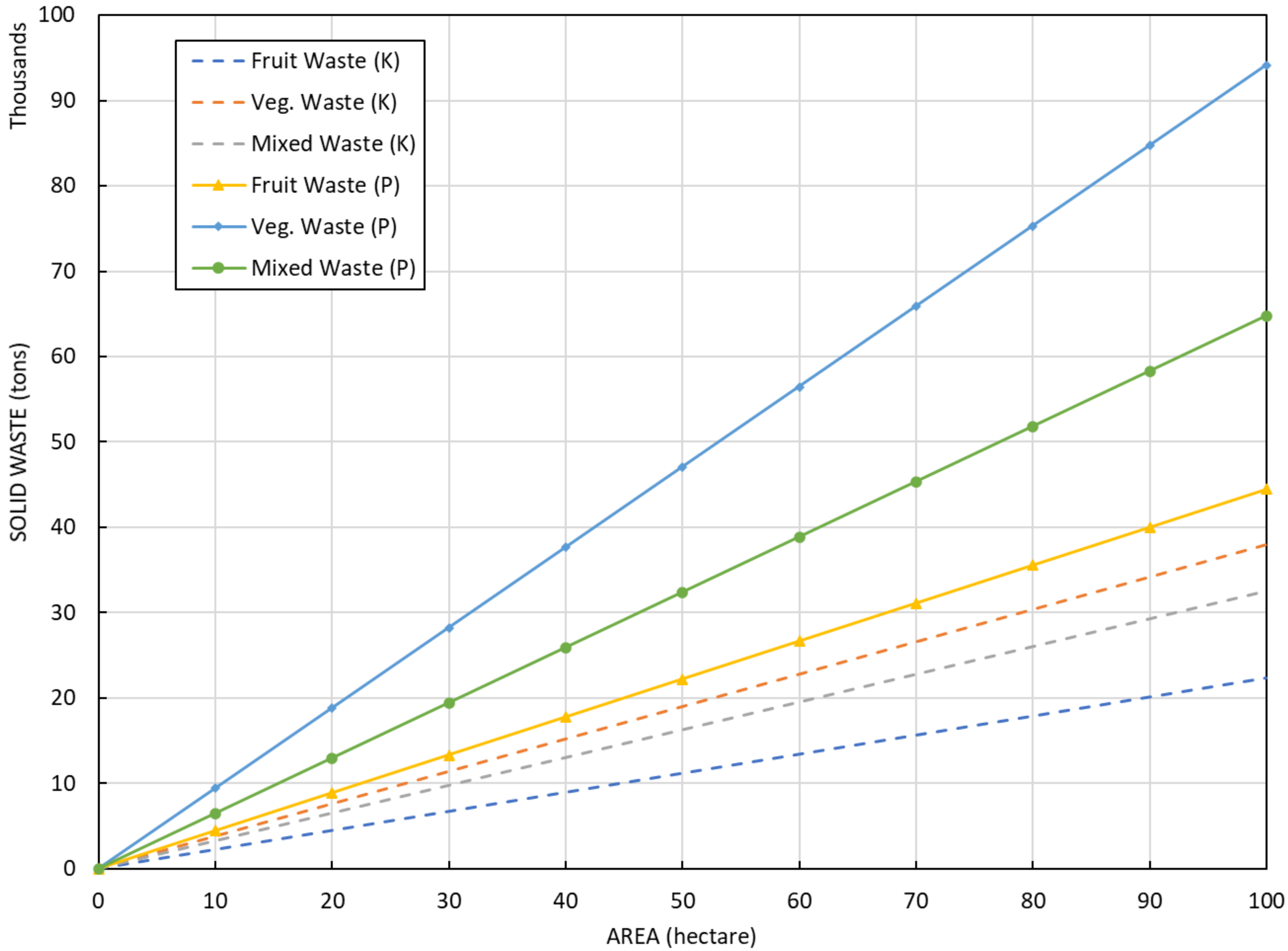



Figure 4-112 Mass of waste required (tons) for rice cultivation for area (hectare) of land

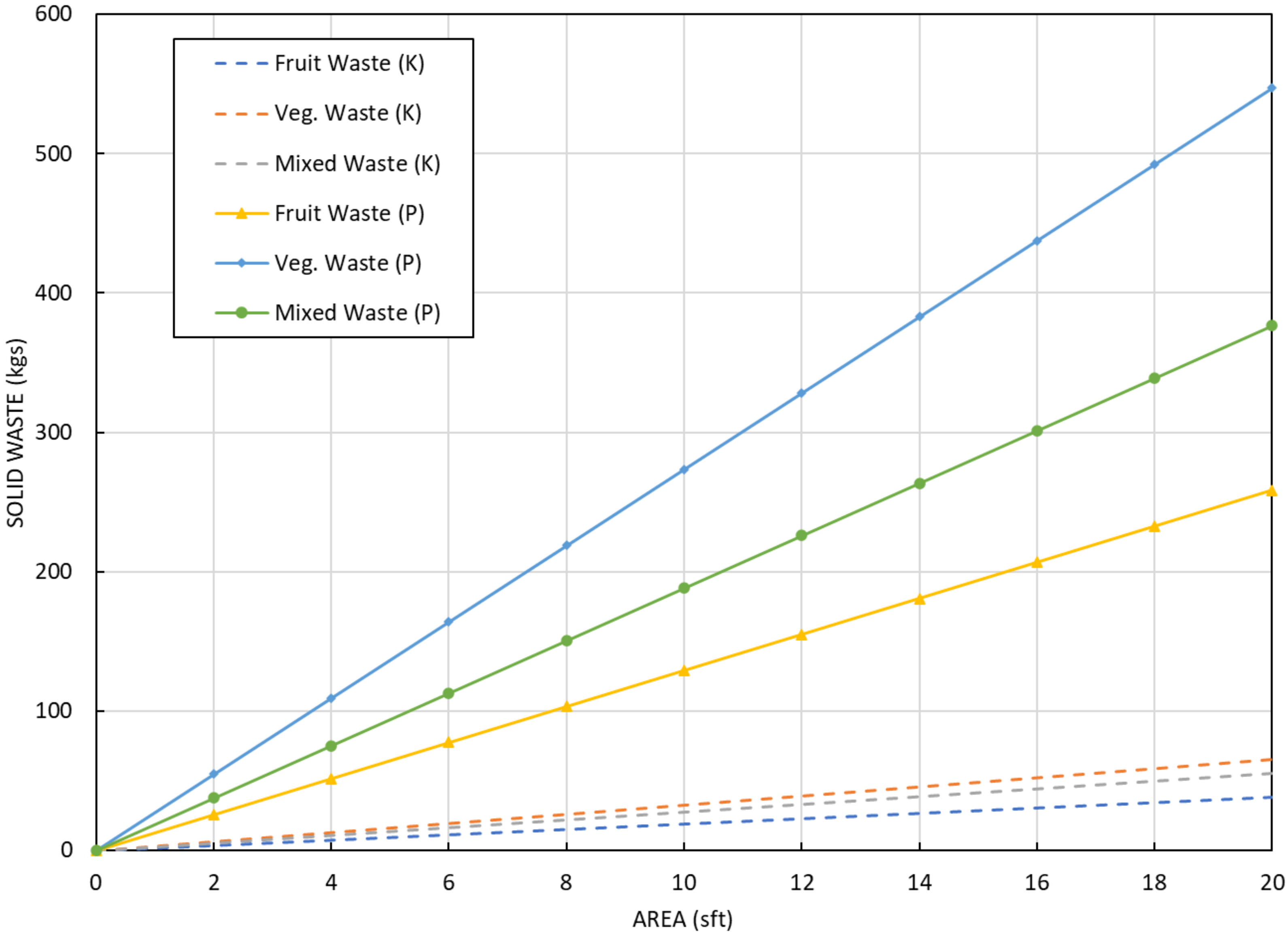



Figure 4-113 Mass of waste required (kg) for rose cultivation for area (sft) of land

For rice (*Oryza sativa L.*) cultivation in a field with "medium" nutrient content soil of Bangladesh, the required N-P-K ratio is 120 - 16 - 76. If the area of the field is 30 hectares and if mixed fruit and vegetable waste is used (with a leachate generation rate of 13%) then from Figure 4-114, it can be found that approximately 9750 ton and 19450 ton of mixed waste will be required to fulfill the K and P demand, respectively.

For a small backyard rose (*Rosa centiflora*) garden with "medium" nutrient content soil of Bangladesh, the required N-P-K ratio is 70 - 150- 70. If the area of the garden is 10 square feet and if mixed fruit and vegetable waste is used (with leachate generation rate of 13%) then from Figure 4-115, it can be found that approximately 190 kg and 30 kg of mixed waste will be required to fulfill the K and P demand, respectively.

The above two examples show that to fulfill the phosphate requirement of the soil, a higher amount of waste is required than that for potash. For this reason, it is expected that these equations will be more feasible for calculating the waste that is required to satisfy the potash demand of the soil for a particular crop.

It is important to mention that the leachate generation rate used to develop the charts is determined after 28 days of observation. For different crops and nutrient content of the waste similar equation can be to develop charts.

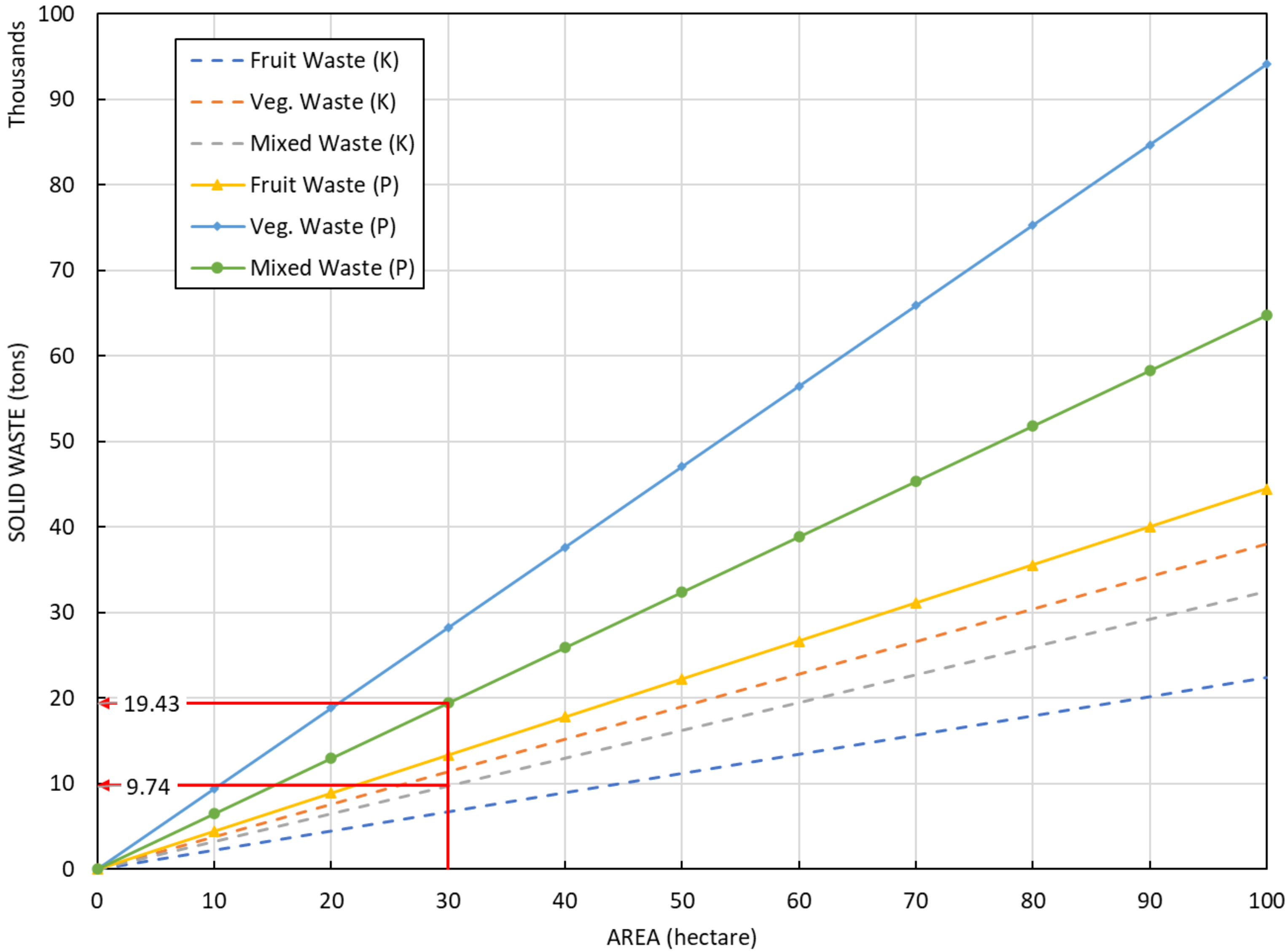



Figure 4-114 Mass of waste required (tons) for rice cultivation for a certain area (hectare) of land (with example)

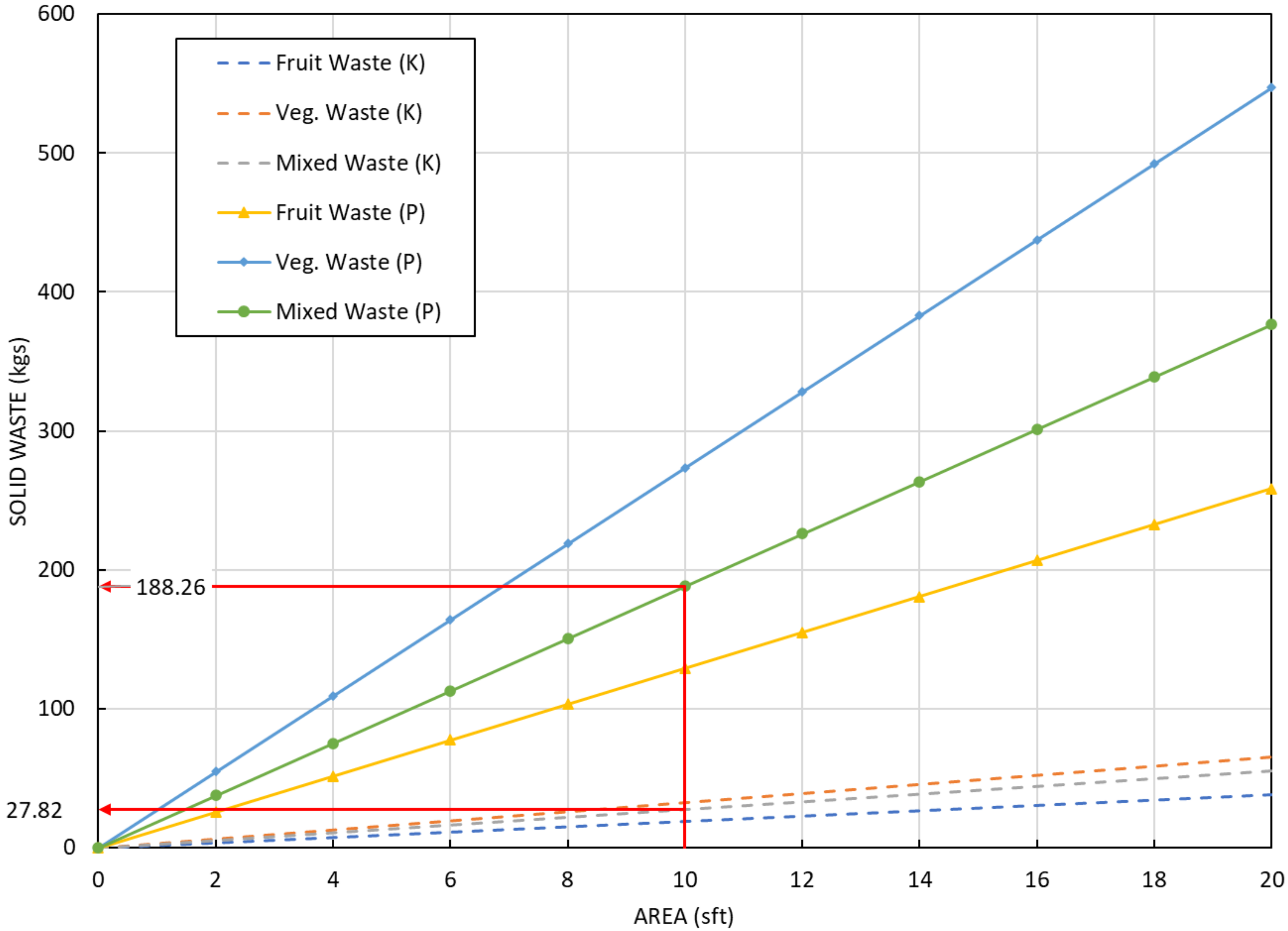



Figure 4-115 Mass of waste required (kg) for rose cultivation for a certain area (sft) of land (with example)

In the experiment, no external force was applied to the waste to extract the liquid. The leachate in the buckets was solely collected by gravity. Table 4-2 lists the percentage of Total Solid (TS) and Volatile Solid (VS) from different substrate sources as presented in the literature. From the Table 4-2, we can observe that the total solid content (%) for fruit wastes is 15 - 20 %. which implies that 80 - 85% of the waste is liquid. Comparing it with the data obtained from the experiment it can be easily understood that more liquid can be extracted from the waste. In practical cases, some form of external pressure can be applied to the waste leading to more liquid generation from it, which will drastically reduce the total mass of the solid waste required for meeting the demand of a large field.

Table 4-2 Total Solids (TS) and Volatile Solids (VS) in biowaste (Vögeli et al., 2014)

| **Substrate** | **Total Solid, TS (% of raw waste)** | **Volatile Solid, VS (% of Total Solid)** |
|---|---|---|
| Spent fruits | 25 - 45 | 90 - 95 |
| Vegetable wastes | 5 - 20 | 76 - 90 |
| Market wastes | 8 - 20 | 75 - 90 |
| Leftovers (canteen) | 9 - 37 | 75 - 98 |
| Overstored food | 14 - 18 | 81 - 97 |
| Fruit wastes | 15 - 20 | 75 - 85 |
| Biowaste | 25 - 40 | 50 - 70 |
| Kitchen waste | 9 - 37 | 50 - 70 |
| Market waste | 28 - 45 | 50 - 80 |

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Summary and Conclusion

The chemical characteristics of several fruit and vegetable wastes were studied to use the leachate generated from it as a potential source of nutrients for the soil. The chemical properties were pH, nitrate, phosphate, and potassium content (%) of the leachate. From the experimental study the following conclusions can be drawn:

- The leachate from the fruit wastes is acidic in nature, whereas the leachate from the vegetable wastes was basic. So, an optimum mixture of the two types of waste can be made to fulfill the specific pH demand of the soil.
- Nitrogen, phosphorus, and potassium are the most significant minerals required for the proper growth of crops. The leachates from the fruit wastes and vegetables are rich in potassium, but they lack nitrate and phosphorus content. For this reason, the soil, where potassium deficiency is a problem or for the crops which require more potassium for better growth like soybean, sweet corn, the mixture of fruit waste and vegetable waste leachate can be used to provide the necessary minerals.

- The extraction process of the leachate is important for getting good quality liquid. In the experiment, the leachate collection in a closed bucket ensured that no impurities are introduced into the leachate.
- From the experiment, it is evident that the chemical properties of the leachate changes with time, even if it is kept in a closed container. For this reason, the leachate generated should be used immediately or as soon as possible.

## 5.2 Recommendations

During the investigation, several additional topics for further study were identified. Some of which were:

- Meat and fish were excluded from the experimental study. This can be incorporated in future studies with the view to providing nitrate and phosphate from liquid fertilizers produced from the food wastes.
- Besides the parameters tested, electroconductivity, C/N ratio, and other mineral content of the liquid can be tested to get a better idea about the chemical characteristics.
- Some sort of mechanical force can be applied to extract ore liquid from the waste, which will drastically reduce the mass of the waste required to produce a certain volume of leachate.

## APPENDIX A

Area, yield rate, and production of fruits in Bangladesh for fiscal years 2015-16, 2016-17, and 2017-18 (Bangladesh Bureau of Statistics (BBS), 2018)

| | 2015 - 16 | | | 2016 - 17 | | | 2017 - 18 | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** |
| Banana | 117 | 6811 | 798 | 120 | 6715 | 807 | 121 | 6676 | 810 |
| Pineapple | 33 | 5991 | 7200 | 35 | 5970 | 212 | 35 | 5914 | 208 |
| Melon/Bangi | 10 | 4846 | 49 | 9 | 4494 | 41 | 9 | 4512 | 41 |
| Watermelon | 27 | 9144 | 250 | 29 | 8646 | 254 | 29 | 7833 | 227 |
| **Total Temporary Fruits** | **187** | **6936** | **1297** | **193** | **6808** | **1314** | **194** | **6628** | **1286** |
| Mango | 93 | 82 | 1162 | 103 | 92 | 1288 | 110 | 76 | 1166 |
| Jack Fruit | 27 | 128 | 1031 | 35 | 1022 | 1050 | 25 | 121 | 1076 |
| Ripe Papaya | 10 | 24 | 130 | 4 | 25 | 135 | 8 | 25 | 132 |
| Litchi | 6 | 59 | 78 | 7 | 65 | 90 | 41 | 66 | 94 |
| Guava | 8 | 23 | 214 | 12 | 22 | 229 | 11 | 23 | 242 |
| Bel | 5 | 35 | 86 | 7 | 36 | 90 | 4 | 48 | 114 |
| Orange | 1 | 23 | 3 | 1 | 24 | 3 | 221 | 25 | 3 |
| Pomelo | 0.81 | 35 | 66 | 1 | 35 | 66 | 1 | 37 | 68 |

| | 2015 - 16 | | | 2016 - 17 | | | 2017 - 18 | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** |
| Lime & Lemon | 5 | 18 | 65 | 6 | 18 | 69 | 4 | 12 | 67 |
| Tetul | 0.08 | 42 | 11 | 0.022 | 39 | 11 | 15 | 44 | 12 |
| Jamrul | 0.01 | 35 | 10 | 0.008 | 34 | 10 | 0.008 | 34 | 11 |
| Khirai | 13 | 4 | 44 | 14 | 4 | 50 | 14 | 356 | 47 |
| Other Fruits | 0.01 | 27 | 15 | 0.037 | 26 | 16 | 8 | 21 | 12 |
| Other Citrus Fruits | 0.05 | 78 | 21 | 0.079 | 44 | 23 | 522 | 47 | 22 |
| Green Coconut | 12 | 66 | 423 | 4 | 76 | 471 | 193 | 68 | 445 |
| Wood apple | 0.05 | 52 | 28 | 0.062 | 50 | 29 | 18 | 50 | 28 |
| Black Berry | 0.35 | 45 | 52 | 0.29 | 44 | 52 | 47 | 44 | 50 |
| Kamranga | 0.01 | 41 | 16 | 0.017 | 37 | 14 | 7 | 38 | 15 |
| Jalpai | 0.01 | 45 | 19 | 0.184 | 40 | 18 | 21 | 39 | 18 |
| Amra | 0.01 | 48 | 36 | 0.247 | 50 | 40 | 18 | 53 | 40 |
| **Total Permanent Fruits** | **180** | **2079** | **3510** | **195** | **2062** | **3754** | **1288** | **2843** | **3662** |
| **Total Fruit (Temporary + Permanent)** | **367** | **1349** | **4807** | **388** | **1349** | **5068** | **1482** | **3338** | **4948** |

**APPENDIX B**

Area, yield rate and production of vegetables in Bangladesh for fiscal years 2015-16, 2016-17 and 2017-18 (Bangladesh Bureau of Statistics (BBS), 2018)

| | **2015 - 16** | | | **2016 - 17** | | | **2017 - 18** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** |
| Rabi Brinjal | 78 | 4335 | 310 | 80 | 4334 | 348 | 80 | 4414 | 356 |
| Rabi Pumpkin | 43 | 4365 | 186 | 43 | 4474 | 191 | 42 | 4586 | 191 |
| Cauliflower | 48 | 5623 | 268 | 49 | 5695 | 278 | 48 | 5705 | 274 |
| Cabbage | 44 | 6670 | 296 | 46 | 6822 | 312 | 46 | 7020 | 322 |
| Water gourd | 46 | 4764 | 218 | 47 | 4845 | 226 | 46 | 5044 | 232 |
| Tomato | 67 | 5451 | 368 | 68 | 5686 | 389 | 70 | 5539 | 385 |
| Radish | 65 | 4312 | 281 | 66 | 4273 | 280 | 66 | 4273 | 281 |
| Beans | 50 | 2577 | 129 | 51 | 2665 | 137 | 51 | 2650 | 135 |
| Carrot | 4 | 3590 | 16 | 5 | 3597 | 16 | 5 | 3673 | 19 |
| Spinach | 22 | 2346 | 51 | 22 | 3069 | 66 | 23 | 2431 | 55 |
| Lalsak | 28 | 1839 | 52 | 28 | 1890 | 54 | 29 | 2012 | 59 |
| Lausak | 15 | 1607 | 25 | 15 | 1622 | 25 | 16 | 1754 | 29 |
| Other winter vegetable | 18 | 2244 | 40 | 18 | 2386 | 44 | 19 | 2194 | 41 |

| | 2015 - 16 | | | 2016 - 17 | | | 2017 - 18 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Area (thousand acres) | Yield (kg per acre) | Production (thousand tons) | Area (thousand acres) | Yield (kg per acre) | Production (thousand tons) | Area (thousand acres) | Yield (kg per acre) | Production (thousand tons) |
| **Total Winter Vegetables** | **529** | **4234** | **2239** | **538** | **4393** | **2366** | **540** | **51295** | **2379** |
| Kakrol | 12 | 2308 | 28 | 12 | 2295 | 27 | 12 | 2319 | 29 |
| Pumpkin, Kharif | 28 | 3731 | 105 | 28 | 3733 | 104 | 28 | 4072 | 112 |
| Brinjal, Kharif | 46 | 3574 | 165 | 46 | 3501 | 160 | 46 | 3500 | 160 |
| Patal | 25 | 3422 | 86 | 24 | 3518 | 86 | 24 | 3542 | 85 |
| Lady's Finger | 28 | 1927 | 54 | 28 | 1953 | 55 | 28 | 1984 | 56 |
| Jhinga | 24 | 1926 | 47 | 25 | 1951 | 49 | 25 | 2024 | 50 |
| Karala | 25 | 2204 | 54 | 26 | 2186 | 57 | 26 | 2186 | 58 |
| Green Banana | 26 | 5584 | 148 | 28 | 4548 | 150 | 28 | 5599 | 157 |
| Arum | 56 | 4058 | 228 | 58 | 5164 | 244 | 55 | 4169 | 230 |
| Chalkumra | 24 | 2975 | 72 | 25 | 2993 | 74 | 25 | 3044 | 75 |
| Cucumber | 23 | 2734 | 63 | 23 | 3030 | 71 | 24 | 3764 | 65 |
| Khirai | 13 | 3592 | 46 | 14 | 3597 | 50 | 14 | 3372 | 47 |
| Puisak | 25 | 3116 | 79 | 26 | 3090 | 79 | 26 | 3198 | 82 |
| Chichinga | 18 | 1995 | 37 | 19 | 2023 | 39 | 19 | 2017 | 37 |
| Danta | 27 | 2759 | 75 | 27 | 2710 | 72 | 27 | 2786 | 75 |
| Barbati | 17 | 1527 | 26 | 16 | 1567 | 25 | 16 | 1575 | 26 |

| | 2015 - 16 | | | 2016 - 17 | | | 2017 - 18 | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** | **Area (thousand acres)** | **Yield (kg per acre)** | **Production (thousand tons)** |
| Dundal | 10 | 1871 | 18 | 10 | 1953 | 19 | 10 | 2010 | 20 |
| Kachur lati | 18 | 2600 | 46 | 18 | 2624 | 46 | 17 | 2466 | 42 |
| Shajna | - | - | 27 | - | - | 28 | 1 | - | 31 |
| Green Papaya | 5 | 40 | 202 | 7 | 26 | 223 | 6 | 28 | 257 |
| Other Summer Vegetables | 25 | 1880 | 47 | 27 | 1902 | 52 | 4 | 1883 | 48 |
| **Total Summer Vegetables** | **476** | **3472** | **1653** | **487** | **3511** | **1710** | **468** | **3722** | **1742** |
| **Total Vegetables (Winter & Summer)** | **1005** | **7706** | **3892** | **1025** | **7904** | **4076** | **1008** | **55017** | **4121** |

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