ESTABLISHMENT OF A MICRO-BIOREFINERY IN A RURAL COMMUNITY: BENEFICIATION OF FOOD WASTE INTO HIGH VALUE MATERIALS

By

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Master of Science in Chemical Engineering

School of Engineering

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A. ABSTRACT

Farmers are faced with great challenges such as ever rising costs of fertilizers, pesticides, natural disasters, climate change and many more factors that affect the quality and quantities of produce per season. Regardless of these challenges, food is desired with the ever-growing demand.

The population growth also means the exponential increase of organic waste which is estimated to ten million tons annually in South Africa. This organic waste often ends up at landfills, whereas it has valuable nutrients needed to enhance production of fresh food. The spent grain and Spanish reed, food waste and plant waste were used to produce organic compost using the Bokashi process.

This research aims to demonstrate the yield obtained from the application of various kinds of organic compost mixes made using the Bokashi process. The compost was further utilized in growing vegetables such as Chillies, Bell peppers, Swiss Chard, and Tomatoes

It was discovered that compost from spent grain and Spanish reed and 90% Food waste, showed a better yield across the vegetables grown and had highest values of Nitrogen, Phosphorus and Potassium.

The use of organic waste and transforming it into usable compost was found to be a feasible business solution and the compost provided the essential elements needed to produce fresh vegetables. The products were also well acceptable at the market because of high quality.

B. DECLARATION 1

The experimental work described in this dissertation was carried out at Amahlongwa and the Council for Scientific and Industrial Research, Biorefinery Industry Development Facility (BIDF). The result was registered with the University of KwaZulu-Natal, Howard College, within the School of Engineering under the supervision of Prof. B.B. Sithole and Dr. B. Okole from February 2021 until August 2022.

This study represents original work done by the author and has not otherwise been submitted for any degree or diploma to any tertiary education. Where referencing has been made of the work of others, it is duly acknowledged in the text.

Signed by: Miss Mchunu T.

[redacted] ____________________Date ____________________________

As the student's supervisors, we have approved this dissertation for final submission.

Signed by: Prof. B.B. Sithole

______________________________Date ______________________________

Signed by: Dr. B. Okole

________________________________Date _______________________________

C. DECLARATION 2

I, Mchunu Thandiwe, student no. 218088273, declare that:

a) The research reported in this dissertation, except where otherwise indicated, is my original research.
b) This dissertation has not been submitted for any degree or examination at any other university.
c) This dissertation does not contain other person's data, pictures, graphs, or additional information unless expressly acknowledged as being sourced from another author.
d) This dissertation does not contain other person's writing unless expressly acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
   - Their words have been re-written, but the general information attributed to them has been referenced.
   - Where their exact words have been used, their writing has been placed in italics, inside quotation marks, and referenced.
e) This dissertation does not contain text, graphics or tables copied and pasted from the internet unless expressly acknowledged, and the source is detailed in the dissertation and the Reference section.

Signed: __[redacted]___________ Date__________________________

D. ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to:

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- The team at BIDF, the passionate farmers at Amahlongwa and all customers who bought the produce.
- CSIR department of Communications for support in exhibitions, achievements and awards received. I highly appreciate it.
- Social media friends and followers for support and marketing our products to reach customers located within 50km radius and beyond.
- Department of Agriculture for continuous support and the advisory role they played in dealing with product specifications and pests.
- My children, Nolwazi and Nkanyezi for their constant support during this project and their understanding when mommy spends more time with the vegetables than them.
- My parent's and grandparent's blessings and prayers, I reached this level of education because of them.
- Heavenly Father God, for bringing everything and everyone to make this journey pleasant.

E. AWARDS AND ACHIEVEMENTS

- Thandiwe was nominated and awarded a contract worth over R1.5 million to implement her research project with CSIR.
- On the 22nd of July and 3rd of August 2022, Thandiwe Mchunu participated in exhibitions at Chesterville and Pretoria respectively; organised by Council for Scientific and Industrial Research.
- She also trained and delegated her colleague to present Bokashi project for exhibition at National Science Week, launched at Mangosuthu University of Technology on 1st of August 2022.
- On the 11th of October 2022, she was awarded R250,000 from SAB Foundation for her use of organic waste into sustainability of food production, which will be implemented at her farm.
- On the 21st of October 2022, she was part of a panellist at Curriculum Change Symposium organised by Moses Kotane Foundation, where she explains the use of organic waste into generating fresh healthy food.
- Thandiwe also participated in World Science Forum in Cape Town from 6th until the 9th of December 2022 organised by Department of Science and Innovation, where she was also interviewed live by SABC News.
- She was also interviewed by over ten local radio station (Including Ukhozi FM, SA FM, Capricorn FM and many more)
- She was also interviewed by CGTN, an international television network based in China with over one billion viewers around the globe.
- She remains a registered Chemical Engineer with South African Institute of Chemical Engineers (SAICHE).

F. Contents

The list of Tables

The list of Figures

1. Introduction

The global indications show that 0.74 kilogram of waste per capita per day is generated worldwide, resulting in 2.01 billion tonnes of municipal solid waste generated in 2016 and is expected to grow to 3.40 billion tonnes by 2050(Kaza Silpa et al., 2018). Globally, approximately 37 percent of waste is disposed in a landfill set up, 33 percent is openly dumped, 19 percent is processed through recycling, composting and 11 percent is treated through thermal decomposition.

In 2021, South Africa had a population of 60 million(The World Bank Group, 2022). Statistics show that 108 million tonnes (Oelofse, 2014) (Department of Environmental Affairs, 2012)of waste were collected, and 98 million tonnes were disposed of at landfills. Of the refuse disposed of at the landfill, 52 million tonnes were general waste. Food losses and waste are a growing reality, estimated to be in the order of 10.3 million tons in 2021, or 34.3% of local production. In 2013, the cost of food losses and waste to society was already R61.5 billion, equivalent to 2.1% of South Africa's Gross Domestic Product (GDP). Of this, 10.3 million tonnes, fruits, vegetables, and cereal accounted for over 60% of waste from the farm to the consumer.

Food comprises of six essential nutrients namely: vitamins, minerals, protein, fats, water, carbohydrates and six major elements: carbon, hydrogen, nitrogen, oxygen, phosphorus and sulphur. There are also five elements found as salts (dissolved). They include sodium, magnesium, chlorine, potassium, and calcium. These elements, metals, and salts (nutrients) enter the food supply chain through the air, water, and soil. The quantities of these nutrients in food depend on natural geographical differences, type of food, and processing stages. These elements in food make it an ideal feedstock for producing various forms of products.

How can farmers preserve the nutrients in food waste and transfer them into the soil to increase food production?

Food waste has become an environmental problem in South Africa, yet food security and population growth remain unbalanced. Food system today is polluting, wasteful and resource intensive. While food waste is transported to the landfill or incinerated, approximately a billion people remain undernourished daily. It is thus vital to build a circular economy for food to end starvation and support the global population of tomorrow which is expected to be about ten billion by 2050. This research will use food waste as a viable manure to produce fresh vegetables sold to the market. The study will be completed on or before year 2022.

Aim

The research aims to develop a business case to solve environmental problems and create employment using waste materials.

Objectives

- Determine the feasibility of using food waste as compost for farming fresh vegetables.
- Demonstrate the increase in the value of food waste.

2. Literature review

Organic waste is generated whenever animals, humans, and plants are inhabitation. The primary forms of organic waste are household, agricultural, human, and animal waste.

2.1 Types of manures used by farmers and their benefits.

Agricultural inputs like fertilisers are vital in increasing farm productivity and yield. Several types of manures are available in the market and produced in various ways. These include organic (livestock, plant manure, Biochar, and Bokashi) and chemically manufactured fertilisers such as Urea, Phosphate, and Potassium Chloride etc. The most significant elements of the fertiliser are NPK (Nitrogen, Phosphorus and Potassium). The higher the values, the better for the crops to grow to the required market size.

Nitrogen, 'the leaf maker', is part of the chlorophyll molecule, which gives plants their green colour and is involved in generating nourishment for the plant through photosynthesis. Nitrogen deficiency is demonstrated as a general yellowing of the plant and benefits leafy vegetables such as lettuce, spinach, and Bell peppers (Life is a Garden, 2022).

Phosphorus, 'the root maker', is vital to plant growth in every living plant cell. Plants need it to transfer energy and transform sugars and starches into various nutrients and photosynthesis. Furthermore, it promotes root growth and accelerates maturity. Plants are better able to resist diseases if there is an adequate amount of phosphorus in the soil. Plants that produce flowers before fruiting, like bell peppers and tomatoes, require a substantial amount of phosphorus.

Potassium, 'the flower and fruit maker', also known as potash, is an essential element to food crops as it helps plants use water, resist drought, and enhance the growth of fruits and vegetables. Potassium mainly improves the quality of flowers and fruit and the flavour of vegetables and fruits. Banana peels are known to have a high potassium content when they decompose.

2.1.1 Animal manure

Animal manure is the waste produced from digestion and is composed of faeces and urine. Faeces consists of semisolid waste that comes from the large intestine.

Cattle manure has been used for centuries in agriculture to nourish the soil and grow food. Using cattle dung as manure or fertiliser improves the soil nitrogen, phosphorus, and potassium. However, it has high ammonia levels, burning plants when the fresh manure is applied directly. Using cattle manure increases the soil's moisture-holding capacity, allowing for reduced water irrigation frequency. On average, one cow can produce approximately 9-20 kg of manure per day (Gupta et al., 2016), of which 4 000 kg (Haliru et al., 2015)are required per hectare to grow fresh vegetables. It depends on the cow's age and whether it is for meat or a milk producer.

Chicken manure is among the popularly used manures. One adult chicken can produce approximately 0.05 -0.12 kg of waste per day, whereas one goat produces 0.3 -0.6 kg per day(Akpa et al., 2002). Although Table 2-1 clearly shows that rabbit manure has the highest contents of nitrogen, phosphorus, and potassium (NPK), at 2.4 – 1.4 – 0.6, the production rate of its manure is lower compared to the others.

The cow manure's density is also higher than other manures, which take longer to dry. Drying manure reduces the transportation costs of carrying the fertiliser from the source to the farm.

When residing in rural areas, animal manure is sourced freely from farmers.

Table 2-1: Comparison of various animal manures, the qualitative and quantitative analysis

Content	Cow	Rabbit	Chicken	Pig
NPK ratio(Harrison John, 2022)	0.6 – 0.4 – 0.5	2.4 – 1.4 – 0.6	1.1 – 0.8 -0.5	0.8 – 0.7 -0.5
Average production rate per day	20 kg/cow(Rosenberg and Kornelius, 2017)	28 g/rabbit (Cholis and Nursita, 2022)	14 3g/chicken (Chastain et al., 1998a)	30 kg/pig(Chastain et al., 1998b)
Number of livestock or poultry required for manure needed of 4000 kg per hectare	100 cows once-off, or an accumulation of 10 days from 10 cows	142,857 rabbits once-off, or a collection of 365 days from 391 rabbits	27,972 chickens once-off or accumulation of 365 days from 77 chickens	133 pigs will produce 4000 kg manure per day.
Cost of sale	Most rural farmers keep the livestock manure or remove it for their private use to grow vegetables. If a neighbour needs manure, they donate it.			
Sources	Various households with livestock			

2.1.2 Plant manure

Plant manure, also called green waste, is produced by uprooting unwanted plants, pilling them up, and using them as mulch. It is effective in conserving soil moisture, reducing weed growth, and improving the fertility of the soil. While plant waste is produced freely and naturally from the undesirable plants that grow on the field, the amounts of NPK vary from the type of plant used for mulching, as shown in Table 2-2.

Leguminous plants like beans and peas have nitrogen-converting root nodules which supply nitrates to the soil.

Most synthetic fertilisers use 200 kg per hectare, while mulching varies from 15 to 21 tons per hectare. (The Nutrient Company, 2022)

Table 2-2: NPK values of various organic materials used for mulching (The Nutrient Company, 2022)

Type of mulch	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Crabgrass	0.66	0.19	0.71
Tea leaves	4.15	0.62	0.4
Tobacco leaves	4	0.5	6
Tomato leaves	0.35	0.1	0.4
Oak leaves	0.8	0.35	0.15
Potato leaves/stalks	0.6	0.15	0.45

2.1.3 Biochar

Biochar is a high carbon-rich and fine-grained residue produced from the pyrolysis of organic matter. Pyrolysis is a thermo-chemical decomposition induced in organic materials by heat without oxygen to produce biochar, bio-oil, and biogas. Biochar production typically occurs between 450 – 800 ℃ and ambient pressure to yield 30% of biomass used within 5 minutes(Gheorghe et al., 2009). Biochar has been proven to increase crop yields, improve soil health, and retain nutrients in the soil. Biochar with a pH of 9.42 may contain 0.74% nitrogen, 0.32% phosphorus and 18.90% potassium(Khan et al., 2020). Biochar costs about USD 2580 per ton (Laird David, 2022)in the United States of America markets, approximately R42,750/ton. The leading producers of biochar in South Africa charge about R10,000 per ton of biochar locally. The prices of biochar vary when procured in tons or small quantities.

2.1.4 LAN fertiliser

LAN is a chemical granular fertilizer called Limestone Ammonium Nitrate (LAN) fertiliser high in nitrogen. It is a white crystalline salt consisting of ammonium and nitrate ions. Ammonium nitrate is found as a natural mineral in the driest regions of Atacama Desert in Chile and produced by mixing anhydrous ammonia and nitric acid. It contains 28% nitrogen, 50% ammonium-N and 50% nitrate-N. The retail price of 50 kg LAN costs between R800 – 1200. Since LAN is high in Nitrogen, it is deemed suitable for leafy vegetables like Bell peppers, spinach, and lettuce, said Mr Mkhize, the Agriculture advisor at Umdoni Municipality.

2.1.5 2:3:2(27) Compound fertiliser

The NPK markings on the fertiliser describe the percentages of each of the nutrients. 2:3:2 fertiliser contains two parts nitrogen, three parts phosphorus and two parts potassium. The *(27)* means that 27% represents the total pure values of NPK nutrients, the balance contains trace elements like zinc, boron, manganese to be absorbed safely by the plants. In normal cases, 2:3:2 is made from synthetic chemicals. At the market, the 50 kg bag costs between R800 – R1200. It is in the form of pellets and is recommended as a starter fertiliser.

2.1.6 Urea fertiliser

Urea is a nitrogen-rich fertiliser with an NPK ratio of 46 -0 – 0. Although humans and animals produce Urea, synthetic Urea, also known as carbamide (NH_2CONH_2), is manufactured by reacting carbon dioxide with ammonia at approximately 200 ℃ and high pressure of about 200 bar (Khan et al., 2016)After the reaction, Urea is evaporated and processed by granulating it to produce a solid product.

From March 2021 to March 2022, the local fertiliser price for Urea has increased by 129.5% (from R8 123/ton to R18 644/ton (Dempers Corne et al., 2022) as indicated in Figure 2-1. Most farmers use 201 – 250 kg of Urea per hectare, and others use 251 to 300 kilograms of Urea per hectare. The amount of Urea used depends on the soil analysis and the specific crop requirements.

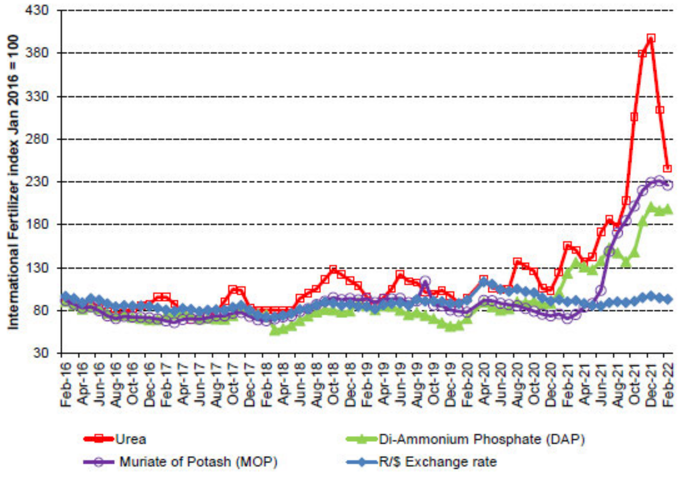


Figure 2-1: International price trends for selected fertilisers (Dempers Corne et al., 2022)

2.1.7 Bokashi

Bokashi converts organic matter like food and plant waste into a soil amendment that adds nutrients and improves soil texture. Bokashi differs from traditional manure because the organic matter is fermented using a particular bacterium. There are primary stages involved in the process.

The organic matter is mixed, not dried, with a lactobacillus bacterium in a container. The container must then be appropriately sealed to allow the fermentation process anaerobically for a few weeks at ambient temperature and pressure. Lactobacilli bacteria will convert a fraction of carbohydrates(Christel, 2017) into lactic acid, some alcohol, and other metabolites through homolactic fermentation. The fermented matter then gets fed directly to the field. As a result, carbon, energy, and several nutrients are preserved (Christel, 2017) by lactic acid. It has been noted that water in the preserve or soil dissociates lactic acid by losing protons to become lactate. Lactate is an energy carrier in biological processes, and it passes through membranes to convert them to pyruvate for energy production.

Table 2-3: Bokashi fermentation vs Traditional composting (Christel, 2017) (Wijayanto et al., n.d.)

Bokashi fermentation	**Traditional Compost**
Occurs under anaerobic conditions.	Requires oxygen. Conditions are aerobic.
The fermentation process is cold.	The process involves heat oxidation.
Organic matter is pickled.	Organic matter decay and rot.
Minimal foul odours are produced.	Produces a high concentration of foul odours.
It does not release greenhouse gases.	Releases hydrogen sulphide and methane.
Retains high levels of nutrients.	Loses nitrogen during the heat oxidation process.
It takes four to six weeks to complete.	It takes months to complete the process.
The system can be done indoors, all year round.	The process can only be done outdoor.

The NPK analysis showed that Bokashi compost made of bran and vegetables had 0.43% N, 2.15% Phosphate, and 2.68% Potassium(Pohan et al., 2019). Table 2-3 shows Bokashi compost's impact on plants compared to traditional animal manure. Using Bokashi compost made of food waste from various industries, from beverages to food canning, brings a solution to how their waste can be discarded and reused.

2.2 Waste collection

2.2.1 Who are the majority producers of food waste?

It has been noted that vegetables account for about 44% of 31 million tonnes of food waste in South Africa, which mostly happens at the farms and retail stages. Many household consumers are unintentionally guilty of permitting food to be decayed. They procure their meat, vegetables, and fruits weekly to consume; however, busy lifestyles prevent them from cooking and consuming the food. Consequently, food gets bruised, mould starts building up, the decaying process commences, and food gets thrown away.

On the contrary, restaurants and food producers have contributed to food waste. Several restaurant chains remain hesitant to bequeath their unused or uncooked food supplies to those in need.

Other food waste producers are food processors, who package the food contents in low-carbon steel. Three main reasons contribute to food spoilage:

- Inadequate application of heat allows growth and survival of microorganisms.
- Inadequate cooling after high-temperature storage, which helps germination of thermophilic spore formers.
- Contamination of cans

At food processing plants, contamination is one of the leading causes of discarding food while it is being processed. For example, canned baked beans and fish. In some cases, food companies make public announcements to recall certain food products to avoid the probability of illness and injury due to consuming those products. It is advisable not to purchase or consume cans that are leaking, rusted, dented, have bulging lids, and are cracked.

2.2.2 Where to source organic waste?

2.2.2.1 Landfill

Based on the waste hierarchy in Figure 2-2, the Department of Environment, forestry, and fisheries and policymakers have written Waste Regulations(Town, 2009), Norms, and Standards to implement South African Constitution Section 24, (Maseti Nomfundo, 2017)which states that everyone has a right to:

- An environment that is not harmful to their health or well-being.
- Have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures.

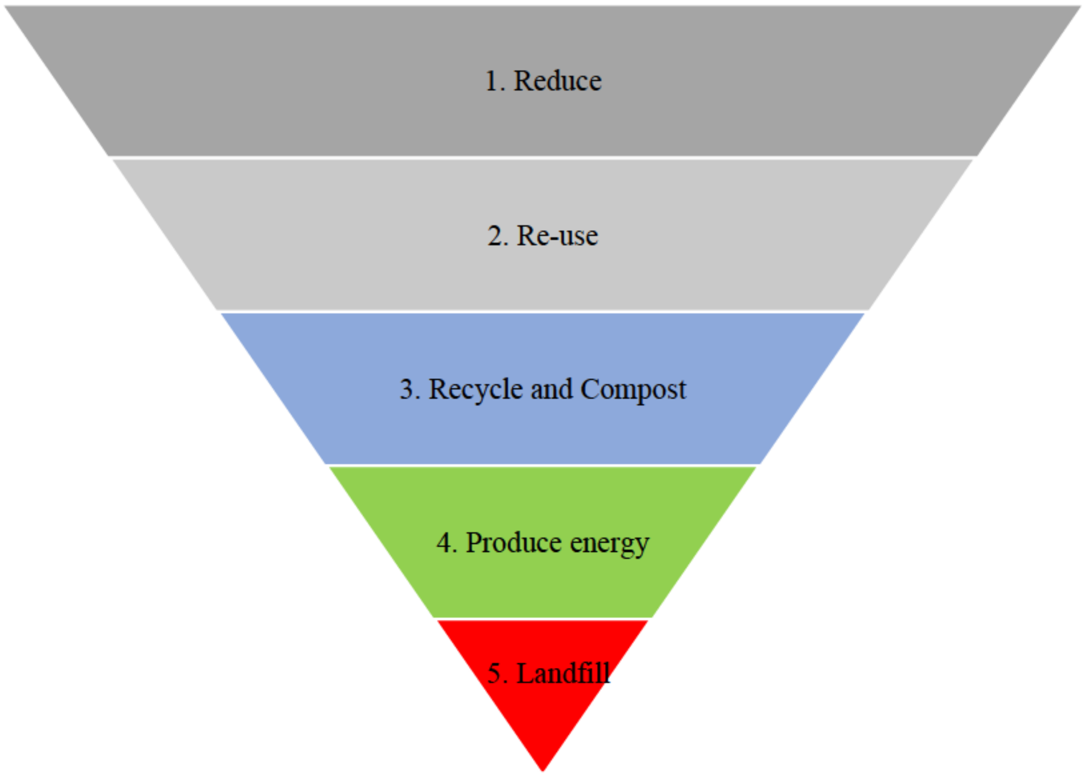


Figure 2-2: Waste hierarchy

As mandated by the Constitution of South Africa and for the love of the environment, finding value in food waste by re-integrating it back into the food chain and energy will minimise waste going to the landfill, as it is the last resort in the waste hierarchy.

Preventing organic waste from being disposed into landfills not only protects the environment and health but it creates sustainable employment for skilled and non-skilled personnel.

Although waste is available in millions of tons, it requires permission from the Department of Environmental Affairs and Forestry and the Local Municipality to grant accessibility to collect and process waste.

Waste characterisation data in South Africa is challenging as the municipality does not collect all waste. Some cities do not send their data to South African Waste Information System (SAWIS); there are duplications within the system. The waste contribution by area was calculated based on population as indicated and characterised in Figure 2-3. South Africa has over 10 million organic waste materials due to increased food supply and energy.

Generally, municipal waste requires sorting to separate organic waste from inorganic materials. Segregation of food waste is done optimally at the source as separating once mixed with general waste is less efficient.

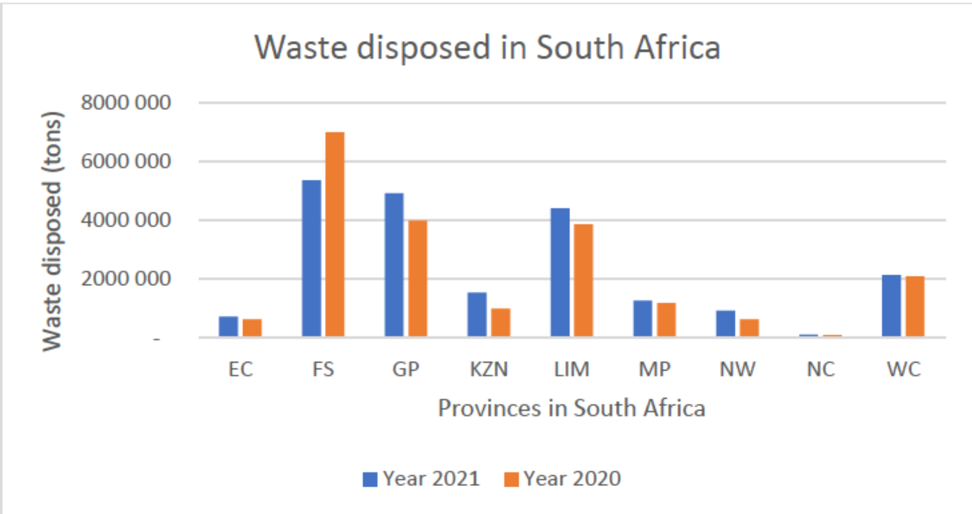


Figure 2-3: The waste disposed per province in landfill in 2020 and 2021 years

2.2.2.2 Institutions, farms, and retailers

Although food waste is abundant, organic waste must be collected to establish a micro biorefinery. Food waste can be sourced at higher education boarding institutions(Painter et al., 2016), hospitals(Melikoglu, 2020), fresh fruit markets, supermarkets, farmers, and from retailers.

Initiatives such as composting and donating excess edible food have provided solutions but only deal with food waste after it has been grown, shipped, and procured. Food prevention must be the top priority for any institution that wants to contribute positively toward climate change and reduce financial costs associated with buying food that will result in waste.

Daily quantitative measures of food waste through a digital food waste tracking system have been proven to reduce food waste drastically.

The primary crops grown in South Africa include maize, with over 9000 commercial maize producers, the majority being in North-West. Sugarcane is mainly produced along the coast. Fruits such as pineapples, citrus fruits, avocados, bananas, papaya, guavas, mangoes, and litchis are mostly grown in provinces like KwaZulu Natal, Limpopo, Mpumulanga and the Western Cape. South Africa is the ninth producer of wine, with over three million (Wines of South Africa, 2022) vines and Limpopo Province is a great producer of tomatoes and potatoes.

Although losses in vegetable farming occur at the consumer stage, Figure 2-4shows that high food losses also occur at the farms caused by the sun, storms, and drought, contributing to climate change caused by toxic gas emissions. Researchers (Ramukhwatho FR et al., 2021)further elaborated that tomatoes and butternut vegetables are mostly lost, while onions showed strong properties to withstand several stages from the farm to the consumer.

On the other hand, plant waste is used as compost in farms and animal feed after being processed by biofuel manufacturers. It is rare to find piles of plant waste in the city compared to food waste. Farmers are deemed the majority suppliers of both food and plant waste. They can convert their losses into revenue by generating energy from food and plant waste and connecting excess power to the grid to keep the lights on for several businesses.

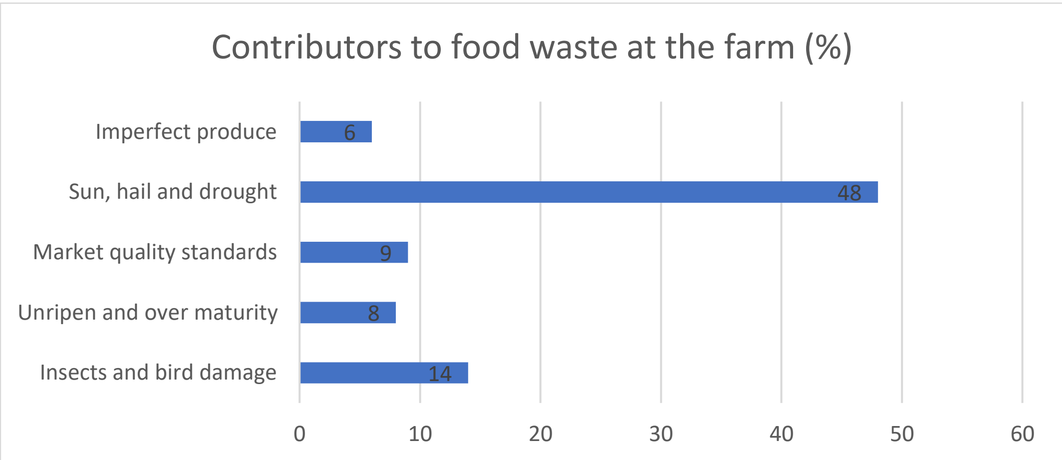


Figure 2-4: Contributors of food waste at the farm

The Durban fresh produce market located in Clairwood produces 3000 tons of food waste per month. The market receives tons of fresh fruits and vegetables within KwaZulu Natal Province, and it is located centrally to feed a broad demand within the Ethekwini Municipality. The market includes single direct buyers, restaurants, guest houses, hotels, schools, hospitals, universities, and several industries. The biggest challenge the market has is ensuring the fruits and vegetables they receive gets sold on time before it starts to decay, which is relatively within three days. The amount of waste at the market, as illustrated in Figure 2-5 has enabled the need to partner with the Durban University of Technology and Ethekwini Metropolitan Municipality to generate electricity from waste (Friedrich and Trois, 2016)

Figure 2-5: Durban Fresh Food Market located in Clairwood, KwaZulu Natal Province, South Africa

Other retailers, such as supermarkets, conduct Wednesday market day to drastically reduce fresh produce prices so that it is sold out. This market day has attracted plenty of customers in the area to maximise purchasing fresh produce on this day, to stretch the value of their hard-earned income. The economy in the country has not been in favour of low-income earners and government grant receivers as food prices have risen because of fuel prices.

2.2.2.3 Community events

Death has become a big business in South Africa, estimated to be worth ZAR75 billion(Thompson Andrew, 2021). Every weekend there are funerals in South Africa, in which the funeral parlours recently started introducing catering services as part of the burial package. It makes funeral parlours ideal catering partners for sourcing food waste. Whether people dish up for themselves or are served, food is often left over on the plates (Figure 2-6**)** at most events, especially during funerals, as the entrance is free. During the Covid-19 pandemic, the number of funerals grew, and some funerals were conducted during the week. The greatest need for food at funerals comes from the compassion of those who dug up the grave for the tombstone and those who travelled a long distance to bury their loved ones.

Figure 2-6: How food waste is generated during functions

Weddings and other events by invitation are more likely to have less food waste as they know the capacity of the people that they are preparing food for and, in some cases, their preferred diet. This then reduces food waste drastically.

2.2.3 What are food waste collection and transportation costs?

Members of the community and businesses put their food waste in plastic bags or waste bins, as seen in Figure 2-7, and the paid service provider collects the containers at a composting, recycling, or disposal site. The community and businesses mix organic and inorganic waste and wait for collection. The residential area pays between R93.57 to R210.93 for refuse removal, while corporations pay between R222.06 to R23653.75 (Khumalo WJ, 2020)

Figure 2-7: Collection of waste in various areas

The tariff highly depends on the collection frequency, amount of waste to be collected, type of waste (general or hazardous) and whether the zone is considered residential or industrial. The distance from the collection point to the landfill also counts into the tariff that needs to be paid.

According to Municipality by-laws, the municipal council is responsible for managing domestic waste within its jurisdiction.

Should the private company wish to collect waste within the local municipality area, the company must apply for a permit from the Department of Forestry, Fisheries and Environment (DFFE).

2.2.4 Who is responsible for collection and required standards to meet?

An individual, a company and a municipality can collect waste provided waste permits are granted by DFFE. A form given by DFFE must be filled in thoroughly, an environmentalist will be assigned, and a reference number is allocated on the application form and communication. All the standards to be met are given to the applicant during the report. It is essential to note the type of waste to be collected, quantities and the vehicle to use for collection (Department of Environmental Affairs, 2009)

2.3 Crop yield of various vegetables

2.3.1 How much can Swiss chard, chillies, bell peppers be grown in one hectare and packaged for the market?

2.3.1.1 Swiss chard

Swiss chard is a leafy green belonging to the *Chenopodioideae* family, which also includes beets and spinach. Swiss chard is a biennial plant with dark green, glossy, crisp leaves that grow to 37cm long and 25cm wide(Department Agriculture, 2020). It is a cool season crop that grows best at temperatures of 7 to 24 ℃, primarily produced in KwaZulu Natal, South Africa, between February and August. The crop requires frequent irrigation to ensure the soil does not dry out to less than 50% available soil water, with pHs of 6 and 7.

When planting the seedlings, the spacing between rows should be 200 to 300mm and 450 to 600 mm between rows. In one hectare, a total population of 60 000 to 80 000 seedlings can be transplanted.

Applying 500 kg per hectare of 2:3:2 fertiliser (costing approximately R 800 - 1500 per 50 kg bag) is highly recommended on fertile land before planting, and then adding 225 kilograms per hectare of LAN four to eight weeks later. The pests attacking Swiss chard include leaf miner, nematodes, cutworms, caterpillars, aphids, and loopers. Registered chemicals in the market may be applied to the crops to control pests. Weeds should be timeously removed as they can act as hosts for pests (Department Agriculture, 2020)

When the leaves have reached 10 to 12.5cm long, after two months, harvesting of the Swiss chard can begin. It is advisable to begin harvesting from the outer leaves. Harvesting from the same plant can continue for several months until the leaf spot becomes too severe, or the plant grows to produce seeds. On estimate, one hectare will yield 20 -30 tons of Swiss chard.

Swiss chard can be stored at 0℃ for 10 to 14 days and at 95 to 100% relative humidity. The well-known cultivar is the ford hook giant (Botha Lindi, 2020).

2.3.1.2 Chillies

These crops require warmer conditions and are more sensitive to cold and frost. The temperatures of between 20 – 27℃ for four to five months in a year are the optimum conditions for growth in the soil with a pH-ranges between 5.5 and 7 (Bolts Biz, 2021).The well-known cultivar is long red cayenne.

Seeds are sown in nursery trays and transplanted when there are four to five true leaves. When transplanting, the plants' space should be 40 to 50cm apart and 70 to 80cm between rows. Populations vary from 25,000 to 40,000 plants per hectare, with an expected yield of 10 to 12 tons/ha. They require 600 kg of 2:3:2 fertiliser per hectare at planting and 80 to 100 kg of LAN four to five weeks after transplanting. They are irrigated twice a week for the first two weeks after transplanting, 10mm to 15mm at a time. During the next eight weeks, 35mm of water should be irrigated weekly(Peris and Kiptoo, 2017). Chilli peppers contains protein, fats, carbohydrates, calcium, vitamin A, B1 and C in addition to the flavonoid’s capsaicin, capsicum, and bioflavonoids(Galih et al., 2019)

Chillies are generally packed into green mesh pockets holding about 7 kg of fruits. Chillies are widely used in cooking to add spicy flavour or are mainly processed into hot sauces, known in the retail shops.

2.3.1.3 Bell peppers

Bell peppers, scientifically known as *Capsicum annum L.*, are grown in South Africa, mainly in Limpopo, KwaZulu-Natal, Gauteng, Northern Cape, Eastern Cape, and Western Cape. The skin is smooth and shiny, and bell peppers come in green, yellow, red, and purple colours. While the plant is still immature, the fruit is green and later develops into various colours depending on the cultivar chosen.

Coloured bell peppers are more expensive to grow because a longer time is required to reach the maturity of the fruit. Bell peppers are primarily prone to leaf diseases and root rot caused by water-logged conditions lasting more than 12 hours. Drainage in the field is essential and registered pesticides are used to eradicate diseases before they spread to many plants.

Bell peppers are a warm-season crop which grows best at 20 - 25℃. Its highly recommended to grow bell peppers on fertile, well-drained soil in low humidity areas. One hectare requires 100 to 200 grams of seeds. Ten to twelve seeds can be planted at 45 cm apart on rows 75 cm apart. (Starke Ayres, 2019)

Yields of six to ten tons per hectare may be harvested after four months, depending on the customer's requirement about the colour of pepper needed. Upon preparation for the market, the fruit must be handled carefully to prevent skin breakage and puncturing, which could lead to deterioration of nutrients. The standard unit of sale is a carton which holds approximately twelve to fourteen kilograms of fruit and is packed according to the colours.

Bell peppers should be stored at temperatures of 7 to 12℃ and 90 to 95% relative humidity.

2.3.2 Demand for vegetables and the market size

Vegetables are natural sources of vitamins, minerals, and antioxidants the human population needs. As a business, vegetable farming is profitable for small-scale and commercial farmers, with an earning potential throughout the year. The cost and success of vegetable farming depend on the crop type, market, and economies of scale.

There is an increased demand for organic vegetables as South African consumers switch to healthier alternatives. Although vegetables are widely consumed in South Africa and globally, marketing products is essential as the competition is intense due to little or no barriers to entry. As the population grows, vegetable farming is expected to grow in the coming years.

The market for fresh vegetables includes fresh produce markets, supermarkets, hawkers, restaurants, hotels, catering businesses, events, school feeding scheme program, hospitals, prisons, and the public.

2.4 Pest control when growing vegetables

Garden pests can cause massive damage to leafy vegetables if they are not managed or prevented. These pests include flies, bugs, mites, aphids, beetles, root-knot nematodes, snails, and worms which attack leafy vegetables like Bell peppers, Swiss chard, broccoli, cauliflower, lettuce, turnip, and many other vegetables.

Each pest is treated differently. However, the general rule that most small and commercial farmers use to control and mitigate problems in Figure 2-8 is to rotate crops, raise soil pH and abandon the infected garden site. Another farmer suggested using three tablespoons of ground garlic and ginger diluted in one litre of water every week. However, every food farmer needs a cost-effective, lasting solution and possible organic pest control.

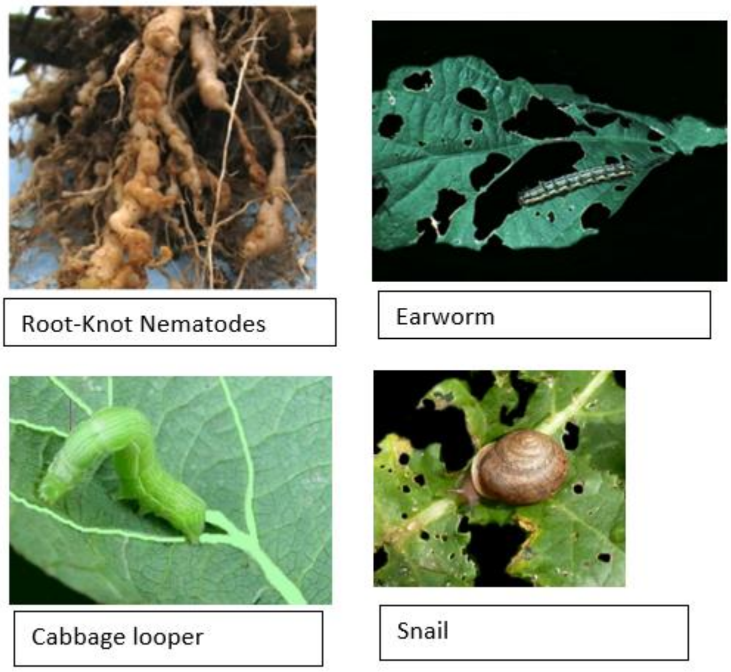


Figure 2-8: Most common pests in the coastal regions (Frederick S January, 2022)

3. Research Methodology

a. Production of Bokashi

Almost 1.5 tons of food waste (Figure 3-1) was collected from the Durban Fresh food market. The food waste included fruits like apples, oranges, nectarines, apricot, pear, strawberry, bananas etc.; and vegetables like Bell peppers, lettuce, Swiss chard, onions, beat root, squash, tomato etc.

The food waste was shredded with a mechanical shredder to break down the biomass (Figure 3-2). Food waste was later mixed in various combinations with Spent Grain, Spanish Reed, Syringa and Effective Micro-organism (E.M.)

- Spent Grain is a food waste by-product of the brewing industry that makes up eighty-five per cent of brewing waste. This waste helps to improve the fermentation process.
- Spanish Reed (*Arundo donax*) is an invasive giant perennial grass that grows three to ten meters tall, mainly along rivers.
- Syringa (*Syringa vulgaris*) is a Category 1b declared invasive weed because of its characteristics that are harmful to humans and the environment.
- Effective Microorganism (E.M.) (Figure 3-3) is a liquid mixture made up of lactic acid bacteria, photosynthesis bacteria and yeast. Using EM improves root growth, boosts the plant's immune system, increases the shelf life of vegetables, and EM is used to speed up the fermentation process.

Both invasive species Syringa and Spanish reed were crushed and mixed with Spent grain and E.M mixture. The spent grain and Spanish Reed absorbed the E.M. and increased the fermentation surface area.

The fermentation process lasted for six weeks in an anaerobic condition. This was done by placing the mixed waste in twenty-litre buckets (Figure 3-4) that were full and sealed.

Figure 3-1: Food waste collected at Durban Fresh Food market

Figure 3-2: Shredded food waste

Figure 3-3: Effective Micro-organism (E.M.)

Figure 3-4: Stored Bokashi in sealed buckets for the fermentation process.

b. The layout of the garden

After six weeks of fermentation, the compost was ready to be used. The seals of the buckets were broken, and the compost was spread evenly in the field with a rack, as shown in Figure 3-5. Applied compost was allowed for two weeks for the compost to give off the alcohol produced during fermentation.

Figure 3-5: Application of a variety of Bokashi compost mix by Miss Thandiwe Mchunu and Dr Blessed Okole

Planting holes were dug in the field two weeks after the application of the manure as indicated in Figure 3-6, the seedlings were transplanted as demonstrated below.

Figure 3-6: Transplanting of seedlings in the field

c. Experimental Design

A randomised complete block design was used for all the vegetables planted in the trials with four replication of each treatment and a control treatment. The control treatment had no compost. The vegetables planted were:

- Chillies
- Bell peppers
- Swiss chard

The seven treatments (organic manure) applied can be seen in the combinations shown in Table 3-1 below.

Table 3-1: The mixing ratios of food waste, plant waste and E.M. to make Bokashi

Codes	Food Waste	Crushed Syringa	Spanish reed, Spent grain and EM

1	90%	-	10%
2	70%	20%	10%
3	50%	40%	10%
4	30%	60%	10%
5	-	90%	10%
6	-	-	100%
7	Control	-	-

Approximately eight plants were planted per treatment (plot) apart from Swiss chard that had 10 plants per treatment as indicated in Table 3-2. The planting distances and plant population of each of the crop varieties were maintained according to Good Agricultural Practice (GAP).

Table 3-2: Allocation of Bokashi compost and seedlings in various plots.

Crops	**Chillies**	**Bell peppers**	**Swiss chard**	**Tomatoes**
Cultivar	Cayenne	California Wonder	Swiss Chard	Floradade
Size of the garden (m^2)	28.05	35.53	24.32	44.88
Number of plants transplanted	56	56	65	53
Types of Bokashi used: Zone 1	August 11 Code 6 Crops: C1 – C6	August 11 Code 6 Crops: G1 – G6	August 11 Code 6 Crops: S1 – S6	August 11 Code 1 Crops: T1 – T6
Types of Bokashi used: Zone 2	August 24 Code 5 Crops: C7 – C12	August 24 Code 3 Crops: G7 – G12	August 24 Code 1 Crops: S7 – S12	August 24 Code 4 Crops: T7 – T12
Types of Bokashi used: Zone 3	August 24 Code 3 Crops: C13 – C18	August 24 Code 7 G13 – G18	August 24 Code 4 S13 – S18	August 24 Code 5 T 13 – T18
Types of Bokashi used: Zone 4	August 24 Code 7 Crops: C19 – C24	August 24 Code 4 G19 – G24	August 24 Code 2 S19 – S24	August 24 Code 6 T19 – T24
Types of Bokashi used: Zone 5	August 24 Code 1 Crops: C25 - C30	August 24 Code 2 G25 – G30	August 24 Code 3 S25 – S30	August 24 Code 7 T25 – T30
Types of Bokashi used: Zone 6	August 24 Code 4	August 24 Code 1	August 24 Code 5	August 24 Code 3

	Crops: C31 – C36	G31 – G36		T31 – T36
Types of Bokashi used: Zone 7	August 24 Code 2 Crops: C37 – C42	August 25 Code 5 G37 – G42		July 25 Code 2 T37 – T42

4. Results and Discussion

4.1 Yield analysis

Harvesting is an exciting time for farmers and customers. It is the moment where each farmer calculates the losses or gains of the crop per hectare.

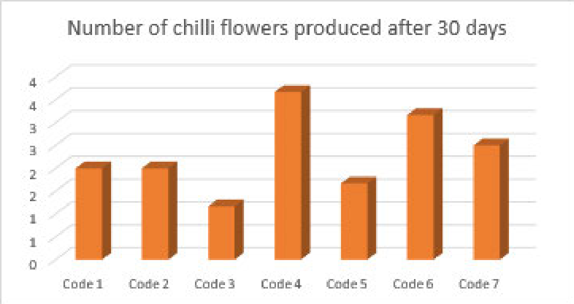
The following yield parameters were evaluated for the crops in this study:

- Number of flowers produced 30 days after planting.
- Number of fruits per plant.
- Yield

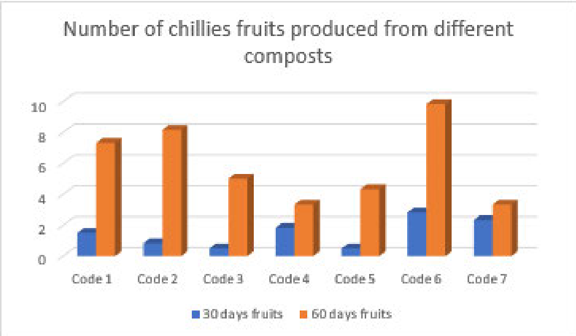
4.1.1 Chillies

Figure 4-1: Chillies flowering 30 days after planting

The chillies started flowering within 30 days after transplanting (Figure 4-1. Six out of eight plants were randomly selected per plot for statistical analysis. Chillies continued to grow from September 2021 until the end of April 2022. The crop was able to withstand the hot weather in November and floods that occurred in April 2022.



Codes	Food Waste	Crushed Syringa	Spanish reed, Spent grain and EM
1	90%	-	10%
2	70%	20%	10%
3	50%	40%	10%
4	30%	60%	10%
5	-	90%	10%
6	-	-	100%
7	Control	-	-



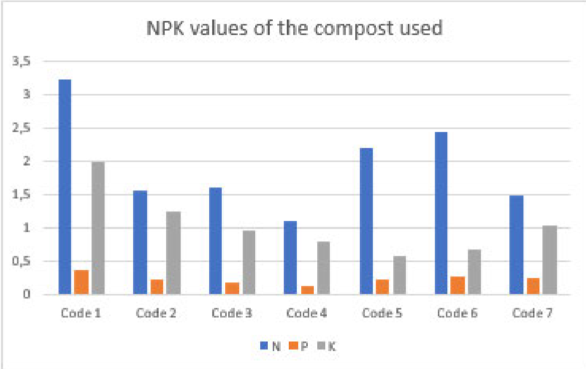


Figure 4-2: Number of flowers produced by the chillies 30 days after planting and number of fruits per plant 30 days and 60 days after planting.

The results in Figure 4-2 clearly shows that Code 4 comprising of 30% food waste, 60% crushed syringa, 10% Spanish reed, Spent grain and Effective Micro-organism (EM) followed by Code 6 = 0% food waste, 0% crushed syringa, 10% Spanish reed, Spent grain and Effective Micro-organism (EM) helped in inducing early flowering of the chillies. The treatment that gave the poorest result was Code 3=50% food waste, 40% crushed syringa, 10% Spanish reed, Spent grain and Effective Micro-organism (EM). This could have happened because of the heavy rains that set in during the planting of the plot.

Figure 4-3: Chillies fruiting with an average of at least 10 fruits per plant at each harvest.

The results on the number of fruits per plant also had a similar pattern with code4= Spent grain, code1=90% and code2=70% food waste having no significant difference in number of fruits produced. An average of at least 10 fruits per plant was observed at each harvest (Figure 4-3).

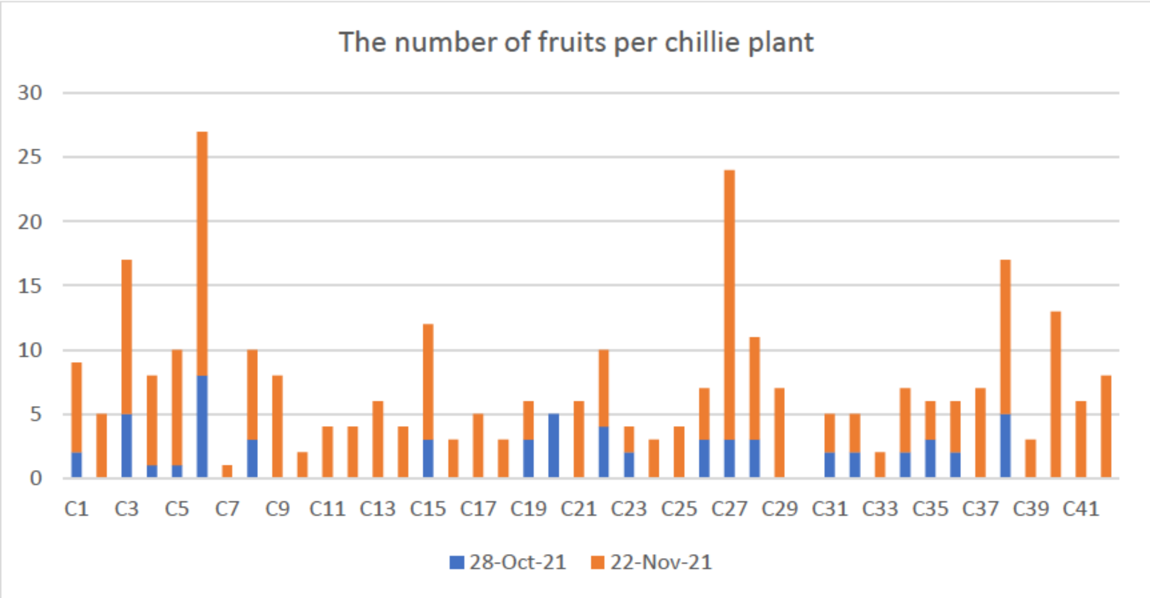


Figure 4-4: Production of Chilli fruits per plant in two months. (C – represents Chillies)

The results were also presented in graphical format looking specifically at the plots as shown in Figure 4-4. The trend was similar with the highest number of fruits in plot C27 = (Code 1=90% food waste 20 fruits per plant in the peak summer month of November, followed by C6=Code 6 spanish grain and C37-40=code 2 70% food waste. All the treatments were significantly better than the control C19=Code 7.

The yield data is presented in Table 4-1below. The total production from September 2021-April 2022 was 15 kg/ 28.5 m^2 plot. This generated revenue of R180 at R12 per kilogram. The total yield extrapolated to a hectare was 5.35 tons /hectare.

Table 4-1: Yield data for red cayenne chilli pepper

Crop	**Cultivar**	**Size of the garden (m^2)**	**Total Production (kg)**	**Pricing (Rand/ kg)**	**Revenue (Rand)**	**Yield per hectare**
Chilli Pepper (*Capsicum annum*)	Red Cayenne	28.05	15	12	180	5.35 tons

This clearly shows the importance of applying organic manure to chilli pepper plants. It increased the yields and improved the number of days for the plants to flower. It was also observed that it improved the soil texture.

The utilization of organic fertilizer such as compost and manure fertilizer can ameliorate soil texture as well as supply macro and micronutrients needed by the chili pepper. Anggraheni, et al 2018 (Galih et al., 2019) showed that the addition of compost gave the highest growth and yield on their trials on chilli peppers, followed by manure and control treatments on two Indonesian chilli pepper varieties *Lado F1* and *PM999 F1*. They further reported that the best treatment in their study was a combination organic and inorganic fertilization with urea 75 kg/ha + SP36 75 kg/ha + KCl 75 kg/ha with addition of 1.35 kg compost per planting hole giving yield results of 253.35 g of fruit per plant.

Khaitov et al. 2019 (Khaitov et al., 2019)also carried out a study on the impact of organic manure on growth, nutrient content, and yield of chilli pepper under various temperature environments. After soil analysis, they applied livestock manure compost 132.7 kg ha^{-1} and 265.4 kg ha^{-1} in their trials. Their results showed that organic manure application favourably affects the growth attributes and nutrient uptake of chilli pepper with the highest values found in chillies grown in plastic greenhouse, followed by the shade net house, over the open field cultivation condition. The highest growth of chilli pepper was at the 265.4 kg ha^{-1} of organic manure application, whereas the highest yield was found at the 1× rate (132.7 kg ha^{-1}) of organic manure application. The application of organic manure at the 1× rate in the greenhouse increased root, shoot, and fruit dry weights of chilli pepper by 21.4%, 52.4%, and 79.7%, respectively, compared to the control values. These results indicate that the rational use of organic amendments might be the best solution for chilli pepper production under variable climatic conditions.

4.1.2 Bell Peppers

Bell pepper flowering started around the 38th day after planting. According to Starke Ayres, the delay in flowering of bell pepper plants may be because of heat stress. Ambient temperatures in Durban-KwaZulu Natal around October 2021 reached a high of 38℃ and a low of 10℃, (Figure 4-5). This high temperature conditions occurred a few weeks after planting in September 2021. The heat stress causes the plants to lose flowers and buds which are essential for fruiting. Losing buds delays flowering by several weeks as elaborated by Code 5 in Figure 4-6 which started flowering around 45 days after planting. The Department of Agriculture, Forestry and Fisheries also emphasized that bell peppers require an optimum temperature of 25/21℃ during flowering. Low temperatures slow down seedling growth and exposure to temperatures 33°C and above deforms pollen leading to flower abscission and reduced yields.

High & Low Weather Summary for September 2021

	Temperature	Humidity	Pressure
High	31 °C (3 Sep, 15:00)	94% (1 Sep, 21:00)	1031 mbar (1 Sep, 21:00)
Low	10 °C (9 Sep, 05:00)	40% (3 Sep, 15:00)	1003 mbar (27 Sep, 15:00)
Average	18 °C	76%	1019 mbar

* Reported 1 Sep 00:00 — 30 Sep 23:00, Durban. Weather by CustomWeather, © 2022

High & Low Weather Summary for November 2021

	Temperature	Humidity	Pressure
High	29 °C (22 Nov, 13:00)	94% (1 Nov, 01:00)	1027 mbar (1 Nov, 01:00)
Low	13 °C (10 Nov, 05:00)	47% (24 Nov, 09:00)	999 mbar (17 Nov, 18:00)
Average	21 °C	78%	1014 mbar

* Reported 1 Nov 01:00 — 30 Nov 23:00, Durban. Weather by CustomWeather, © 2022

High & Low Weather Summary for October 2021

	Temperature	Humidity	Pressure
High	37 °C (14 Oct, 10:00)	94% (2 Oct, 18:00)	1032 mbar (2 Oct, 18:00)
Low	10 °C (12 Oct, 02:00)	20% (14 Oct, 09:00)	1000 mbar (22 Oct, 16:00)
Average	19 °C	77%	1017 mbar

* Reported 1 Oct 00:00 — 31 Oct 23:00, Durban. Weather by CustomWeather, © 2022

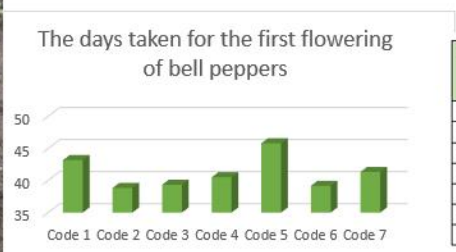
High & Low Weather Summary for December 2021

	Temperature	Humidity	Pressure
High	30 °C (11 Dec, 09:00)	94% (2 Dec, 01:00)	1029 mbar (2 Dec, 01:00)
Low	15 °C (18 Dec, 00:00)	53% (18 Dec, 11:00)	1001 mbar (15 Dec, 16:00)
Average	22 °C	80%	1014 mbar

* Reported 1 Dec 00:00 — 31 Dec 23:00, Durban. Weather by CustomWeather, © 2022

Figure 4-5: Average temperatures from September to December 2021

Figure 4-6 below indicate that code 2,3, and code 5 started flowering closer to each other around 38 days after planting while code 4 and 7 flowered 40 days after planting.



Codes	Food Waste	Crushed Syringa	Spanish reed, Spent grain and EM
1	90%	-	10%
2	70%	20%	10%
3	50%	40%	10%
4	30%	60%	10%
5	-	90%	10%
6	-	-	100%
7	Control	-	-

Figure 4-6: Flowering of bell peppers using various Bokashi composts

Although Code 2 was the first to generate flowers and Code 5 the last (45days after planting), Code 3 which was grown in a field composted with 50% food waste, 40% crushed syringa and 10% EM showed highest production of bell peppers Figure 4-7).

It’s interesting to note that although Code 2 showed the first flowers, Code 6 however showed the first fruit, but it is Code 3 that finally produced more fruits although it was not the first in flowering nor fruiting.

According to Figure 4-7 bell peppers grown in Code 3 (50% food waste) had highest yield followed by Code 6 (100% Spanish Reed and Spent grain). Although bell peppers do require frequent irrigation, heavy rains affected the flowering process because of low yields.

Temperature plays a vital role in the growth of vegetables, for bell peppers best temperature range is at 20 - 25℃. Their sensitivity to high temperature compared to chillies makes them ideal to be grown in greenhouses or covered tunnels.

They started flowering a month later, and the produce was grown in the third month. The heavy rains and extreme heat destroyed the plants in the third month. Only eight kilograms of bell peppers were harvested and sold to the local supermarket. There were seedlings that were lost to pests; however, no pesticide was used during the duration of research.

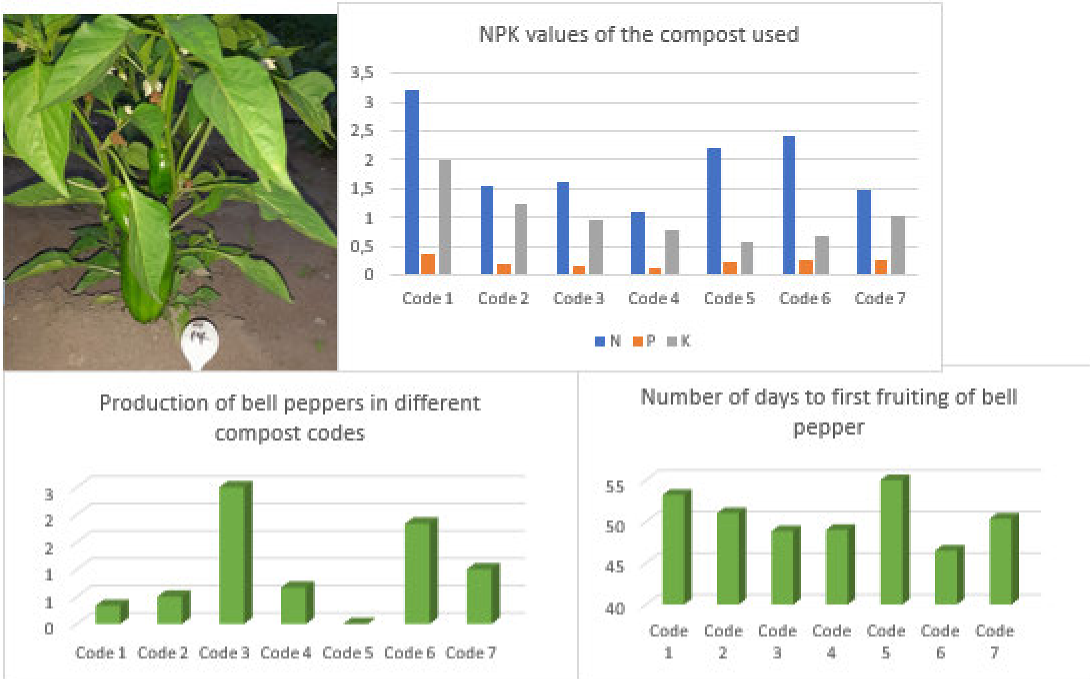


Figure 4-7: The growth of bell peppers in different Bokashi composts

Table 4-2: Yield data for bell pepper.

Crop	Cultivar	Size of the garden (m^2)	Total Production (kg)	Pricing (Rand/ kg)	Revenue (Rand)	Yield per hectare
Bell peppers	California Wonder	35.53	8	15	120	2.25 tons

Only eight kilograms of bell peppers were harvested and sold to the local supermarket. There were seedlings that were lost to pests; however, no pesticide was used during the duration of research. The equivalence of 2.25 tons production per hectare was very low as compared to the desired 6 tons according to literature.

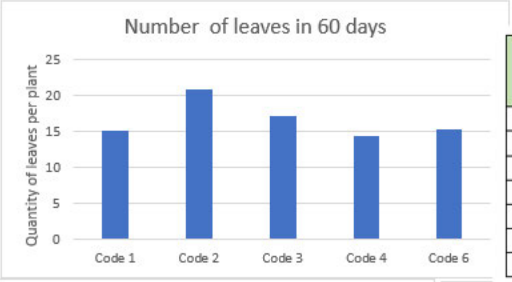
(Adhikari P et al., 2016)carried out a similar study on the effect of different sources of organic manure on growth and yield of sweet pepper. The results from their studies revealed better growth and yield performance by vermicompost followed by poultry manure over control and farmyard manure. Vermicompost has almost the same qualities as the Bokashi mixes.

(Shahein1 M.M, 2015) also carried out an experiment on producing sweet pepper (bell pepper) organically using different sources of organic fertilizers under plastic house conditions. The aim of their study was to evaluate the organic production of two hybrid bell peppers (Bunjii red fruit and Shunghi yellow fruit) using five different sources of organic fertilizers (quail, turkey chicken, rabbit manures and compost). Their results revealed that applying organic fertilizers had significant effect on yield component. However, the highest values of early and total yield of bell pepper plants were produced by compost treatment; chicken manure treatment came in the second order, turkey manure treatment came in the third order, then rabbit manure treatment, finally the lowest values of early and total yield were recorded by quail manure. Using compost and chicken manures produced the highest values of fruit weight, total soluble sold and vitamin C content of pepper fruits. They further stated that organic fertilizers provide the nutritional requirements of plants, increase the microbial activity in the soil, anion and cation exchange capacity, organic matter, and carbon-content of soil.

4.1.3 Swiss Chard/Spinach

Swiss chard is a green leafy vegetable whose bioactive compounds have been studied due to its effects on health. Magda Gamba, 2020 highlighted that Swiss chard leaves have higher content of fiber, magnesium and vitamic C, while its stems are rich in potassium. Most households do not use the stems, making it a good compost material to boost potassium content.

70% Food waste had the highest number of leaves per plant. There was no significant difference between 90%, 50% 30% and spent grain as shown Figure 4-8 below.



Codes	Food Waste	Crushed Syringa	Spanish reed, Spent grain and EM
1	90%	-	10%
2	70%	20%	10%
3	50%	40%	10%
4	30%	60%	10%
5	-	90%	10%
6	-	-	100%
7	Control	-	-

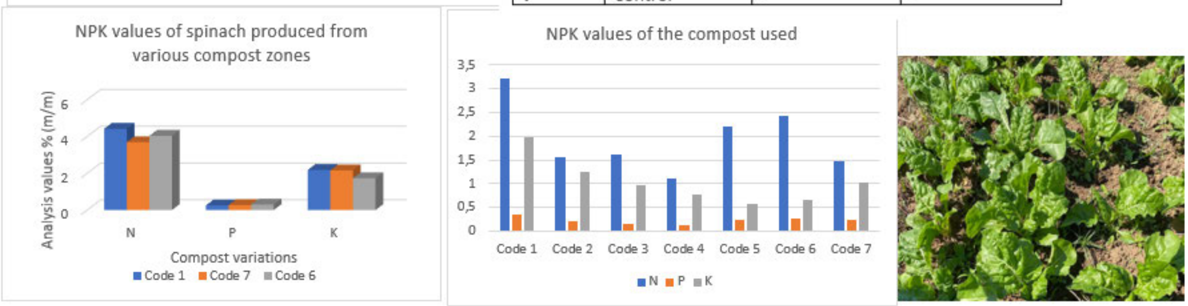


Figure 4-8: Yield analysis of Swiss Chard

The results on the leaf analysis can be seen in Figure 4-8 and Figure 4-9. The results showed that 90% food waste had the highest Nitrogen values however 70% food waste had the highest number of leaves.

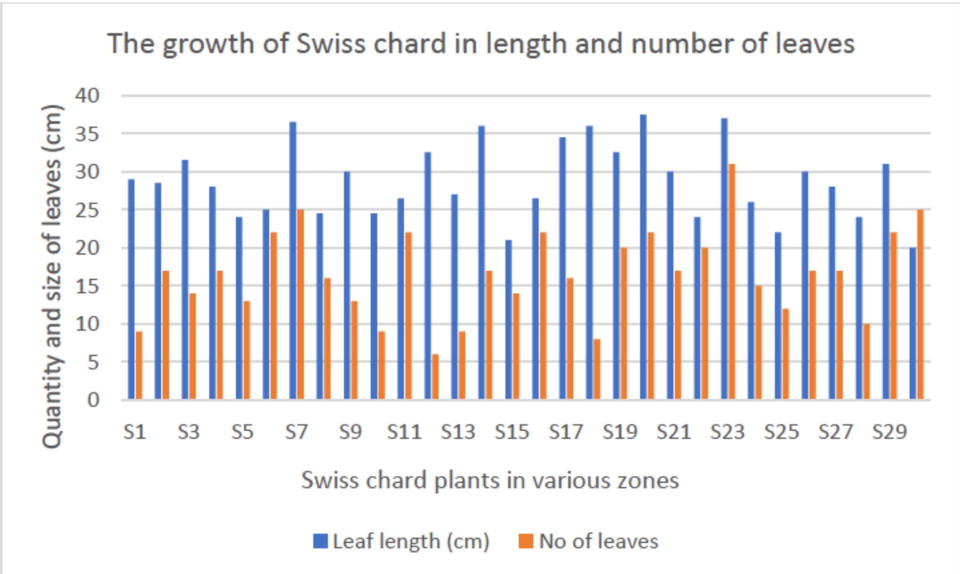


Figure 4-9: The growth of Swiss chard in the length and quantity of leaves

The South African Nursery Association mentioned that nitrogen is a leaf maker, giving plants the green colour through photosynthesis. This was evident in the greenness of leaves. These results of using food waste to generate fresh food indicate the amount of nutrition needed by plants which often end up in the landfill.

Table 4-3: Yield results of Swiss chard

Crop	**Cultivar**	**Size of the garden (m^2)**	**Total Production (kg)**	**Pricing (Rand/bunch)**	**Revenue (Rand)**	**Yield per hectare**
Swiss Chard	Fordhook Giant	24.32	17 bunches	10	170	13.28 tons

According to literature from Department of Agriculture, a hectare of Swiss Chard produces 20 tons. The yield was 66.4% to the desired quantity per hectare. Although climate conditions (heat stresses) contributed negatively to the yield, the results indicate the positive use of food waste as indicated in Figure 4-9.

4.2 Soil and nutrients in Bokashi

Table 4-4: NPK analysis of Bokashi compost

Analysis	Code 7 Control	Code 6 10% S Grain	Code 5 90% PW	Code 4 30% FW	Code 3 50% FW	Code 2 70% FW	Code 1 90% FW
Moisture	49.52	66.57	86.25	65.53	71.53	78.69	60.87
pH	6.6	3.7	5.2	4.9	5.3	5.5	4.9
Nitrogen	1.48	2.42	3.21	1.11	1.61	1.55	2.20
Phosphorus	0.25	0.26	0.36	0.12	0.16	0.21	0.23
Potassium	1.02	0.67	1.98	0.78	0.96	1.25	0.57

Table 4-5: Analysis report of Swiss Chard with micro and macro nutrients (FW is food waste; PW is plant waste syringa and S Grain is Spent Grain)

Bokashi Compost	Code 1 90% Food waste & Spanish Reed	Code 7 Control	Code 6 Spent Grain and Spanish Reed
Nitrogen %	4.42	3.69	4.04

Phosphorus %	0.25	0.27	0.30
Potassium%	2.18	2.16	1.73
Calcium %	0.59	0.45	0.48
Magnesium %	0.26	0.22	0.28
Sodium (mg/ kg)	7213	9038	8531
Manganese (mg/ kg)	32	24	37
Iron (mg/ kg)	142	184	154
Copper (mg/ kg)	6	5	5
Zinc (mg/ kg)	50	65	86
Boron (mg/ kg)	15	14	16

According to the compost analysis in Table 4-4, Code 1 (90% Plant) had the highest percentage of Nitrogen closely followed by Spent Grain. The analysis of Swiss chard in Table 4-5 showed the macro-Nitrogen, Phosphorus, Potassium, and Magnesium were highest in the 90% Food waste compost, and microelements (Iron, Zinc, Manganese etc.) were relatively lower. These results correlated positively to the yield observed in all the crops. The compost analyses reported in Table 4-5 shows that Bokashi compost is much better than cow manure and chicken manures. It is close to the rabbit manure as indicated in the literature.

Although the Bokashi compost in was found acidic there are remedies available in the market to make the compost organically neutral. It is recommended that in future, the inclusion of alkaline organic waste such as lentils, beans, may result in producing a closer to neutral pH compost. On the contrary, there are fruits (blackberry) and vegetables (potatoes) that do well in acidic soil. This compost may be sold to farmers who will grow foods grown in acidic soil.

4.3 Employment created.

The research project created a minimum of ten temporary jobs, namely:

- Installation of an irrigation system – It was done by a male with Matric and advanced plumbing skills with over twenty years of experience in the industry.
- Repairing of the fence done by a male youth, with Matric, welding and building skills.
- Construction of a pump stand – By a male youth- with building skills with over five years of experience.
- Making Bokashi – Supplied by a company called Green Corridors, with a team of over five employees.
- Driver – Selling produce locally and advertising locally.
- Application of Bokashi and transplanting of seedlings. Two young men were hired, and each has over five years of experience in farming and a Matric certificate. Thandiwe Mchunu and Dr Okole assisted them.
- Removal of weeds - It was done by a young male who could not finish school and has three years of experience farming vegetables.
- Watering of vegetables – It was done by a young female who has Matric without any experience in farming. She was trained and assisted by Thandiwe Mchunu.

4.2 Value proposition canvas

The following segment extends on the feasibility of utilising Bokashi compost at a commercial scale. The Bell peppers was selected to make calculations simpler for farmers at any scale and to make implementation easier to improve food security in South Africa. Although pest control measures were not utilized during the experiments, however it is highly recommended to spray crops at least twice a month for pest control. Also, although growing vegetables on open field is cost effective, each farmer should invest in having greenhouses, so that risks associated with climate changes are minimized.

4.2.1 Customer segment

The primary market is the fresh food agents and supermarkets, as they buy vegetables at wholesale prices and quantities. The secondary market is the communities located around the farm.

Jobs

Customer jobs describe what customers are trying to get done in their lives and their place of work. The primary market includes supermarkets like Spar, Pick n' Pay, Food Lovers and restaurants within Umdoni Local Municipality. They supply their customers with fresh fruits, vegetables, dairy products, meat variety, and household needs. They buy in bulk (minimum one hundred items) from suppliers at a wholesale price and sell at a higher price than retailers. They have over five thousand items stored, both perishable and non-perishable. They have over twenty staff members employed. They own infrastructure and several assets like a fleet of trucks to collect from suppliers, which requires maintenance.

Customer Pains

Customer pains are the risks, obstacles and bad outcomes released to the customer's job.

The pains of the primary market are to get fresh vegetables, of great quality, at low cost and in bulk (minimum order of 100). They have been in the market for many years and have established farms; however, due to *political instability*, some well-experienced farmers are migrating to other continents, leaving farms stranded. The constant increase of *fuel prices* has affected the prices of the vegetables in the supermarkets as they need to account for increased transportation costs; however, this limits the amounts of products sold; eventually, they put the products on sale, cutting down the prices before the products get decayed. The spending rate of customers has decreased drastically because middle and low-class customers have lost their occupations. Consequently, they are struggling financially and are highly dependent on social grants. Basic food, however, remains a necessity daily.

Gains

This describes the outcomes the customer wants to achieve and the tangible benefit they seek.

The customers need a reliable supplier of the products. The products must be of high quality. Their supplier must be sustainable and, ideally, maintain good prices. The main outcome of having a business is to make a profit. The bigger the profit, the better for business. They want to remain sustainable for many decades and keep their staff members in service much longer. They also want to be the preferred retailer and stand out from the competitors; this leads to an increase in market scope.

4.2.2 Value Proposition

Products and services

This is the *list of products* and services that a value proposition is built around.

While the target market has a variety of products and services they require, the products and services offered were quality vegetables at a wholesale market price. The vegetables ordered were also delivered.

Pain reliever

The pain relievers describe how the products and services will alleviate the customer's pains. A sustainable vegetable supplier based locally is a pain reliever as they worry less about transportation and insufficient stock for their customers.

Gain Creators

The gain creators describe how the products and services create customer gains. The primary market has also gained to be supplied by a female black-owned entrepreneur, which rewards them when they are acquiring investments and government grants. The products are organic, nutritious, healthy, grown locally which eases on transportation costs and are affordable to the public. The customers also gain opportunities of selling organic waste to the entrepreneur to convert into compost which results in the reduction of organic waste going to the landfill.

4.3 Business model canvas

4.3.1 Customer segment

The customers are the supermarkets and fresh food agents who buy vegetables in bulk. They are well established, have chain stores countrywide, have a good reputation amongst their customers and are known for quality food at affordable prices.

4.3.2 Customer relationship (marketing)

Figure 4-10: Making relationships with the consumers, marketing, and distribution of products

A verbal relationship was created because the land utilised is less than one hectare. Whenever the harvest is ready, direct communication to the vegetable section manager at the local supermarket is sent, who will then notify the farmer when produce may be brought to the supermarket. Farmers owning above a hectare normally have a contract with them to secure the availability of the produce. The fresh produce section manager also conducts quality checks and stock taking, ensuring that vegetables in stock are sold well before their best dates.

Another way for customers to know your product is to travel door to door. This option is viable when using a wheelbarrow and customers are within reach, as shown in Figure 4-10.

4.3.3 Distribution channels

A distribution channel represents a chain of businesses through which the consumer purchases the goods. These include wholesalers, retailers, distributors, and the internet. Having many intermediaries involved in the distribution channel increases the price of goods and quality, especially if it is fresh food. The ideal distribution channel is in line 1 in Figure 4-11.

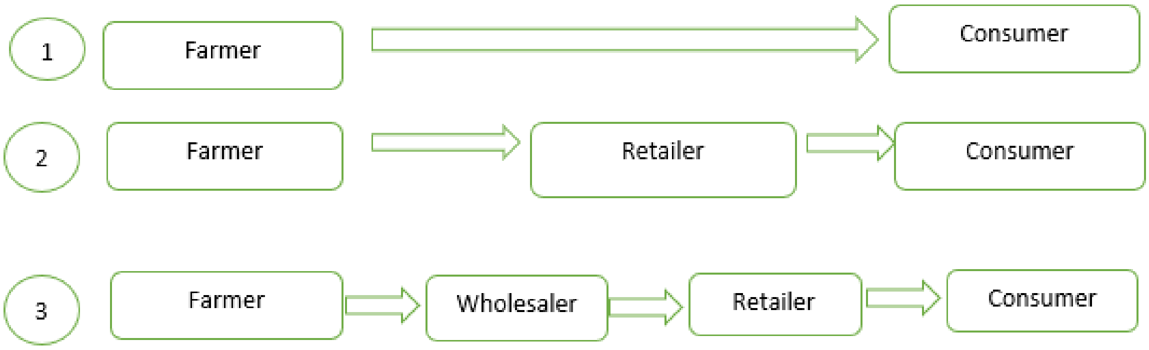


Figure 4-11: Distribution Channels from manufacturer to the consumer

4.3.4 Value propositions

The value proposition to the customer is providing quality vegetables at a wholesale market price and transporting the vegetables to the shop for free.

4.3.5 Key activities

The following are key activities that will ensure that vegetables are of good quality:

Table 4-6: Projected activities and costing when using Bokashi compost

Month	**Activity**
Month 0	Receiving funding and installation of fencing and or greenhouses. Installation of irrigation system and interviewing and hiring of staff. Ordering 14500 Bell peppers seedlings. Add Bokashi on the ground – 1 hectare at once.
Month 1 – Bell peppers 1	Transplanting seedlings ordered at month 0. Ordering seedlings for month 2.
Month 2 – Bell peppers 2	Transplanting seedlings ordered at month 1. Ordering seedlings for month 3.
Month 3 – Bell peppers 3	Hire 4 temporary workers on week 4 Three zones have 14500 Bell peppers at different stages of growth. Harvest Bell peppers 1 on week 4, days 1 and 2. Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: R425 430 if the market price is R18/ kg and 23635 kg is harvested from 14500 plants.

Month 4 – Bell peppers 4	Hire 4 temporary workers on week 4 Harvest Bell peppers 1 & 2. Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: (R425 430 x2 = R850 860) if the market price is R18/ kg.
Month 5 – Bell peppers 5	Hire 4 temporary workers on week 4 Harvest Bell peppers 1,2 and 3. Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: (R425 430 x3 = R1 276 290) if the market price is R18/ kg.
Month 6 – Bell peppers 6	Hire 4 temporary workers on week 4 Harvest Bell peppers 2,3, 4 Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: (R425 430 x3 = R1 276 290) if the market price is R18/ kg.
Month 7 – Bell peppers 7	Hire 4 temporary workers on week 4 Harvest Bell peppers 3,4,5 Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: (R425 430 x3 = R1 276 290) if the market price is R18/ kg
Month 8 – Bell peppers 8	Hire 4 temporary workers on week 4 Harvest Bell peppers 4, 5, 6 Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: (R425 430 x3 = R1 276 290) if the market price is R18/ kg
Month 9 – Bell peppers 9	Hire 4 temporary workers on week 4 Harvest Bell peppers 5, 6, 7 Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: (R425 430 x3 = R1 276 290) if the market price is R18/ kg
Month 10 – Bell peppers 10	Hire 4 temporary workers on week 4 Harvest Bell peppers 6,7, 8 Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: (R425 430 x3 = R1 276 290) if the market price is R18/ kg
Month 11 – Bell peppers 11	Hire 4 temporary workers on week 4 Harvest Bell peppers 7,8, 9 Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: (R425 430 x3 = R1 276 290) if the market price is R18/ kg
Month 12 – Bell peppers 12	Hire 4 temporary workers on week 4 Harvest Bell peppers 8,9,10 Transplant seedlings (week 4, day 3 - 7) and order seedlings for the following month. Revenue: (R425 430 x3 = R1 276 290) if the market price is R18/ kg

- Spent grain and Spanish reed Bokashi have proven to be the best. This requires a good relationship with Green Corridors to be established, so this variety of Bokashi is prepared in bulk as shown in Table 4-6.
- Food waste was allowed to release fermented alcohol for two weeks after decomposition, before planting.

- The land to be utilised needs to be prepared by removing weeds. The land size needs to be one hectare divided into three parts to ensure that harvest is achieved monthly.
- The seedlings need to be ordered in a month from a well-established nursery with control measures to manage pests and grow seedlings in a greenhouse.
- The water source for irrigation needs to be available all seasons, and the proper irrigation system needs to be installed after the land has been prepared.
- Due to the high rate of rainfalls in the region of KwaZulu Natal, a proper set-up of a greenhouse must be in place to protect seedlings and plants from being washed away.
- A team of four people will be hired to remove weeds, transplant seedlings, water the farm, harvest the produce and categorise it according to size (small, medium, and large). Two more people will be required to market the product on social media, agents, and supermarkets, monitor irrigation schedules, and conduct pest control measures. One manager will be required to manage the team and be responsible for the procurement and training of staff. A total of seven people will suffice to maintain one hectare of vegetables and various stages of growth.
- It is vital to select one kind of vegetable to focus on per hectare to make it easy to control pests and plant management.
- A constructed space with proper ventilation is often required to store the harvest temporarily. This space gets utilised more when vegetables like onions, beans, potatoes etc., are harvested as they require more handling after harvest.
- Twice a month, add pesticides to prevent various pests into the crops.
- Ensure that irrigation is done properly.
- Each zone must be filled with Bokashi two weeks before ploughing.

4.3.6 Key partners

The key partnerships include:

- Tribal Council for providing land to use for growing food. Each community in rural areas has a Chief who is part of the Tribal Council and builds relationships between entrepreneurs and the community.
- Green Corridors for preparing and supplying Bokashi to the farm.
- CSIR for sourcing funding to conduct research and demonstration of organic waste beneficiation.

- Spar and Pick n' Pay Supermarkets for buying produce in bulk monthly.
- Food waste producers like fresh food markets, supermarkets, farmers, spaza shops selling fried chips and several factories in the food industry.
- The local community where the farm is based guards their livestock away from the farm.

4.3.7 Key resources

- Three or more greenhouses will cover a one-hectare space of land.
- The irrigation system includes a water tank stand, a borehole system, and a built-in water pump to pump from a borehole to the storage tank and crops.
- Owning a vehicle that will be used for collecting seedlings, Bokashi and delivering products to the customers. Hiring a vehicle will be much more costly than owning a vehicle. Vehicle ownership will also provide reliability in delivering goods on time.
- Funding to cover all operational costs and capital costs.
- A room to store and process the harvest.
- Sourcing organic pesticides.
- Seedlings at a monthly interval. The focus will be on the Bell peppers as it remains in demand throughout the year.
- Marketing materials to promote the use of Bokashi as an ideal solution to alien plant minimisation. This also opens an opportunity to have Bokashi with a mix of spent grain, Spanish reed and some food waste and observe results.

4.3.8 The cost structure for one-hectare land

Table 4-7: Cost structure for growing Bell peppers in one hectare

Capital Expenditure		
Item	Quantity	Cost
Irrigation 5000 liter tank Water Pump Borehole Irrigation pipes, valves, connections Tank stand	 2 1 1 1 2	 12000 3000 89000 47500 24500
Fencing/Greenhouses	1	478350
Room for harvest	1	15000
Room to store manure and pesticide	1	15000
Security camera and lights	6	37500
Seedlings (14500 per month)	43500	26100
Tools	8	4150
Personal Protective Equipment (PPE)	8	12300
Computer	2	23450
Bakkie	1	198453
Total		**986303**
		Operational Expenditure (monthly)
Electricity	1	2500
Labour	8	48000
Petrol	1	7500
Airtime and Internet	2	2500
Bokashi	1	6500
Seeds	2	600
Total		**67600**

4.3.9 Revenue streams

Table 4-6 elaborates that each month, 14500 seedlings of Bell peppers will be transplanted on 0.33 hectares each and 23 635 kg of bell peppers will be harvested. Selling the Bell peppers after ninety days at R18/kg will provide a revenue of R1 276 290 per month when whole one hectare has produced. To break even (covering operational costs), a harvest of 3755 kg Bell peppers must be harvested and sold for R18.

Expected revenue in year shown in Table 4-6 one is R11,5 million from selling 145,000 Bell peppers at R18. The market price of vegetables varies each week according to supply and demand.

5. Conclusion

The organic waste collected from the fresh produce market and spent grain from a private company were all mixed with Spanish reed and effective micro-organism, to produce various forms of Bokashi compost.

The demonstration for the feasibility of using food waste to produce fresh vegetables was successful. Although climate conditions affected the yield, chillies, bell peppers and Swiss chard produced was all sold to the market. There was no variance with regards to the expected quality. Tomatoes were destroyed by heavy rains and were not able to produce ripe fruits. The experiment showed the importance of keeping an eye on weather conditions as climate changes frequently.

The value of food waste was demonstrated in the production of nutritious compost and utilizing the compost in producing fresh food that was sold well in the market. This increased the value of food waste drastically, from being regarded as waste suitable for landfill to being competitive with fertilizers available in the market.

This research further elaborated the creation of minimum ten jobs from the collection of organic waste, production of compost and using the compost at the farm to produce fresh vegetable for the ever-growing population. By utilizing organic waste to produce fresh food for humans or animal, closed the loop of organic waste material and food security.

Using Bokashi compost and applying it once a year in the field, reduced the need to procure other kinds of synthetic fertilizers as the produce met the requirements at the market.

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7. Appendices

7.1 Analysis for spinach samples

SGS

Analysis Report

Job number: CT21-09249

Client:	**CSIR** PO BOX 395 PRETORIA 0001 SOUTH AFRICA	**Received:** **Completed:** **Order No:**	2021-11-29 2021-12-04 1000780009 - CSIR

Lab ID	Sample ID	Depth	Camp	Nitrogen %(m/m)	P %(m/m)	K %(m/m)	Ca %(m/m)	Mg %(m/m)	Na mg/kg	Mn mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg	B mg/kg	Na% %(m/m)
CT21-09249.001	-	-	S11	4.42	0.25	2.18	0.59	0.26	7213	32	142	6	50	15	0.721
CT21-09249.002	-	-	S13	3.69	0.27	2.16	0.45	0.22	9038	24	184	5	65	14	0.904
CT21-09249.003	-	-	S24	4.04	0.30	1.73	0.48	0.28	8531	37	154	5	86	16	0.853

Applied methods:

Nitrogen content in leaves - In-house method *

Nutrient element determination in leaves - In-house method; ICP-OES *

Tests marked "*" in this report are not included in the SANAS Schedule of Accreditation for this laboratory .

Reported: 04-12-2021

[redacted]

Stuart Shepherd
Laboratory Services Manager

7.2 Analysis for Bokashi compost

LABORATORY ANALYSIS REPORT

REG No: 1949/032643/07 VAT REG No: 456 011 7428

REP. NO. : 701
TELEPHONE NO. : 012 841 3823
FAX OR E-MAIL : bokole@csir.co.za
DATE RECEIVED : 22/11/2021
REPORT DATE : 30/11/2021
REPORT NO. : 21C K103

ORDER NO. :
NAME : CSIR
ADDRESS : BUILDING 18 MEIRING NADEE ROAD
CSIR
PRETORIA

W.R. Quinan Boulevard
Paardevlei Industrial
Somerset West
Tel: (021) 852 7899
Fax: (021) 851 5319

						RESULTS ON DRY BASIS														
Lab No.	ID	H_2O	Dry matter	pH	Conductivity	Ash @ 500°C	C:N	N	C	P	K	Ca	Mg	S	Na	Fe	Cu	Zn	Mn	B
		%			dS/m			%							mg/kg					
21C K103	COMPOST CONTROL	49.52	50.49	5.5	3.24	28.72	26.95	1.48	39.88	0.25	1.02	1.62	0.34	0.32	1956	7927	29	82	296	21
21C K104	COMPOST SPANISH REED	66.57	33.43	3.7	4.11	4.85	20.69	2.42	50.08	0.26	0.67	0.27	0.15	0.39	317	487	5	33	44	2
21C K105	COMPOST 30% FOOD	65.53	34.47	4.9	3.57	4.41	44.96	1.11	49.90	0.12	0.78	0.65	0.16	0.16	1152	446	5	27	29	8
21C K106	COMPOST 50%	71.53	28.47	5.3	4.46	7.24	31.00	1.61	49.91	0.16	0.96	0.82	0.20	0.22	2586	884	9	33	50	11
21C K107	COMPOST 70%	78.69	21.31	5.5	5.60	9.35	30.77	1.55	47.70	0.21	1.25	0.85	0.21	0.22	2403	1604	9	37	61	13
21C K108	COMPOST 90% PLANT	60.87	39.13	4.9	3.11	4.67	23.02	2.20	50.65	0.23	0.57	0.86	0.16	0.42	601	284	8	33	42	9
21C K109	COMPOST 90% FOOD WASTE	86.25	13.75	5.2	9.55	12.20	14.49	3.21	46.50	0.36	1.98	0.71	0.31	0.55	5245	986	12	52	93	14

[redacted]

R Wilds[redacted]r

This laboratory participates in the AgriLASA Quality Control Scheme and makes use of the Standard Method of Analysis.