COMPARATIVE EFFECT OF SOILLESS SUBSTRATES ON GROWTH, YIELD AND FRUIT QUALITY OF GREENHOUSE GROWN CUCUMBER (*Cucumis sativus* L.).

BY

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DECLARATION

This work is the results of research undertaken by Christopher Sitsofe Ameho towards the award of the Master of Philosophy degree in Crop Science at the department of Crop Science, university of Ghana and that except for specific references to other people's work, which have been duly acknowledged, this work has neither in the whole nor in part been presented for an award of degree elsewhere.

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ABSTRACT

Although the production of cucumber under greenhouse brings about higher yields and better fruit qualities, challenges of using soil medium coupled with high cost of cocopeat are some of the limiting factors. This prompted the investigation to compare the effect of soilless substrates on growth, yield and fruit quality of greenhouse grown cucumber (*Cucumis sativus* L.) at the University of Ghana Forest and Horticultural Crops Research Centre, Okumaning – Kade in the Eastern Region of Ghana from October 2016 to March 2017. A 2 x 6 factorial was laid out in Randomized Complete Block Design with three replications. The experiment consisted of two cucumber varieties (Kenzo F1 and Darina) and six substrates (Cocopeat (C), Palm Fibre (PF), Carbonated Rice Husk (CRH), Palm Fibre-Carbonated Rice Husk mix (PF + CRH) , Cocopeat-Palm Fibre mix (C + PF) and Soil (So). Data on physiochemical properties of substrates, growth indices, yield components and quality attributes were collected. Cost benefit analysis of the substrates were also determined. Analysis of Variance (ANOVA) was used to analyze the data using Genstat 12th edition statistical package. The results show that, the different soilless agricultural wastes investigated can be used to successfully produce cucumbers under greenhouse conditions. PF, C and PF+CRH results in good growth of greenhouse cucumber plants compared to So and CRH substrate. The soilless substrates that produced the best yield of greenhouse grown cucumber are PF (227.25 t/ha), C+PF (101.40 t/ha) and PF+CRH (88.05 t/ha). The soilless substrates that produced the best fruits quality in terms of TSS are C (4.42) and PF (4.18). Dry Matter (DM) was highest in C (5.63) followed by PF (5.33). The highest Moisture Content (MC) was recoded in PF (297.04), C + PF (194.82) and C (182.98). Revenue and profit recorded by Darina grown in PF was the highest (GHC 1,275,201.00 and 1,202,431.00). Based on the results from the work conducted, it is recommended that the optimum soilless substrate or their combination that cucumber growers in Ghana can use as an alternative growth media to soil in greenhouse are PF, C, PF + CRH and C+PF substrates.

DEDICATION

To the glory of God I dedicated this piece of work to my late parents, Mr. Winnard K. Amexo and Mrs Rebecca A.A. Amexo as well as my siblings.

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ANOVA	Analysis of Variance
%	Percentage
^{0}C	degree Celsius
CEC	Cation Exchange Capacity
Cm	Centimetres
DAT	Days after transplanting
DM	Dry matter
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
FAOSTAT	FAO Statistics
FOHCREC	Forest and Horticultural Research Center
K	Potassium
kg	Kilogramme
kg/ha	Kilogramme per hectare
Max	Maximum
MC	Moisture content
Min	Minimum
N	Nitrogen
NPK	Nitrogen phosphorus potassium
O.M	Organic matter
OC	Organic carbon
OM	Organic matter
P	Phosphorus
WAT	weeks after transplanting

CHAPTER ONE

1 INTRODUCTION

1.1 Background of the study

Cucumber (*Cucumis sativus* L.) is a key monoecious vegetable that has been grown for more than 3,000 years and among the most grown cucurbitaceae family vegetables (Adetula and Denton, 2003; Okonmah, 2011, Lower and Edwards., 1986; Thoa, 1998). Cucumber ranks fourth in terms of vegetables grown in Asia (Tatlioglu, 1997) and the second in Western Europe (Phu, 1997). The crop has been identified as one of the foreign vegetables grown in Ghana and also has the potential for export (Norman, 2003, Sinnadurai, 1992).

Cucumbers comprise important vegetable utilized in the food as well as medicinal industry **(**Schaefer and Renner, 2011). Cucumber is eaten in the raw state as a fruit vegetable or in cooked form (Shetty and Wehner, 2002, Arankumar *et al*., 2011). In Ghana, cucumber can be eaten raw as a relish or used in the preparation of vegetable salad, stew or sandwich and sometimes used as an appetizer or mixed with other vegetables because of their distinctive texture and flavour (Sinnadurai, 1992, Norman, 1992). Cucumber is therefore cultivated to be consumed in the raw state or as a basis of pickles (Lucier *et al*., 2007). The crop contains nutrients such as carbohydrates, protein, vitamins such as A, C, K, E, minerals (magnesium, potassium, manganese, phosphorus, calcium and zinc) as well as carotene-B, xanthein-B and lutein (phyto-nutrients). A 100g consumable part contains 3%, 1%, 0.5% and 1% of carbohydrates, protein, total fat and dietary fibre respectively (USDA, National Nutrient Data Base, 2014 and Vimala *et al.*, 1999).

Despite the importance of the crop, there are several challenges associated with its production and cucumber farmers in Ghana are therefore faced with the problem of low yields (Frimpong, 2011). Among these challenges are the competition for arable lands by human activities, soil fertility constraints and soil borne diseases (Ogbodo, 2012, Yeboah *et al*., 2014, González *et al*., 2010). Camejo *et al*. (2005) also identified high light levels accompanied by high temperature of 40^{O}C and above which is detrimental to fruit formation and this is due to the fact that the reproductive system of the plant is affected by high light and temperature. The erratic nature of rainfall in Ghana results in water stress thus affecting nutrient absorption and translocation, photosynthesis, respiration and subsequently low yield and poor quality (Poincelot, 2004; Acquaah, 2005). At present, cultivation of cucumber is mostly done in open fields and is exposed to various abiotic factors such as low temperature and unpredictable weather. Open field also expose fruits to biotic factors such as fruit fly and incidence of downy/powdery mildew stresses and therefore, it is not possible to produce high quality cucumber in terms of size, shape and colour and free from diseases and pests as compared to cucumber produced under protected environment. Therefore, it makes it imperative to take up cucumber cultivation under green house.

Greenhouses are used in many tropical regions of the world for the production of vegetable crops (CARDI, 2014). The principle underlying the use of greenhouse technology is to offer a better and more favourable environment to ensure good plant growth, development as well as high yield including prolonging of the production cycle (Ali, 2012, Castilla, 2013). Therefore the use of greenhouses in Ghana for the production of crops and vegetables will help to improve the quality of produce (Elings *et al*., 2015). Other benefits of cultivation under greenhouse conditions include protection of crops from adverse weather conditions, pests and diseases, temperature

extremes and rain (Saavedra *et al*., 2014). The production of cucumber under greenhouse or protected environments brings about increased crop production, productivity as well as higher quality of fruits; these result in better market price and year round production. This makes cucumber one of the major lucrative vegetables cultivated under greenhouse conditions (Kumar *et al*., 2015, Ibeawuchi *et al*., 2008; El-Wanis *et al.,* 2012).

Cultivation of vegetables in soil under greenhouse conditions however, introduces the risk for soil borne diseases such as fusarium wilt, root rots, root knot nematodes and nematode-transmitted viruses that affect cucumber production negatively (Elings *et al.*, 2014, Cohen *et al*., 2015, van Bruggen, 2015, Gamliel *et al*., 2015). Other challenges associated with growing crops in soil medium under greenhouse conditions include temperature variations, low water holding capacity, lack of available nutrient supply, improper root aeration as well as disease and pest (du Plooy *et al*., 2012).

Costly soil disinfecting chemicals, low yields, poor produce quality and chemical residue in plants have enhanced the use of soilless media for crop production (De Rijck and Schrevens, 1998). The cultivation of plants in systems without the use of soil and where nutrients are supplied to the plants together with irrigation water is defined as soilless culture or substrate (Gruda, 2009, Vaughn *et al*., 2011, Savvas, *et al*., 2013). The production of crops in soilless systems helps to manage diseases effectively as well as aids in efficient input utilization and eventually increased productivity (Gullino *et al*., 2015). The benefits of replacing soil with soilless media for crop cultivation ensures elimination of soil-borne diseases, non use of expensive soil disinfecting chemicals that might cause environmental pollution, easiness in handling and fertigation which lead to high yield and quality compared to traditional

soil cultivation methods (Burrage, 2014; Savvas, *et al*, 2013, Resh, 1997, Schwarz *et al*., 2009, Bilderback *et al.*, 2005).

EnviroDome UG (EUG) and others are supporting Greenhouse vegetable cultivation in Ghana. However only Cocopeat soilless growing medium is commercially available for production and the cost is high and in short supply most of the time (Nyame, 2014). Agricultural residues are commonly accessible, renewable and almost at no cost, therefore they can be an essential resource for the production of crops. Worldwide yearly production of agricultural wastes is approximated to exceed 500 million tonnes and it is assessed that more than 4.2 million tons of Agricultural wastes are produced annually in Ghana (Quartey, 2011, Sanchez, 2009). Agricultural wastes can be used for crop cultivation and it is important to select the right substrate that is readily available at cost effective levels and at the same time enhancing crop growth, yield and quality. Although the use of soilless media has characteristics that anchor plant, supply nutrition, water and oxygen, different soilless substrates or their mixes contain diverse substances, different physical and chemical composition and different structures which may possibly have positive or negative effects on the growth, development, yield and the quality of plants (Grunert *et al*., 2008; Vaughn *et al*., 2011, Nair *et al*., 2011, Bhat *et al*., 2013). Soilless cultures thus need technical knowledge and therefore selecting the best and cost effective substrate is imperative (Sonneveld, 2000; Olympious, 1995). Substrates such as rice husk, cocopeat and palm fibre are solid materials used as alternatives to natural soil for crop production (Bielinski & Teresa, 2012). Therefore the study of the effect of these soilless substrates and their combinations to be used as soilless media/ mixtures is essential. In addition these soilless substrates and their combinations on the development

parameters, yield and fruit quality of greenhouse grown cucumber in Ghana have not been well documented.

Main objective

The main objective of the study is to compare the effect of soilless substrates on growth, yield and fruit quality of two cucumber varieties cultivated under greenhouse conditions.

Specific objectives

The specific objectives are to:

- determine the effects of soilless substrates on the vegetative growth and yield of greenhouse grown cucumber
- assess the effects of soilless substrates on the fruit quality of greenhouse grown cucumber
- determine the economic analysis of the substrates.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Origin and early cultivation of cucumber

Cucumber (*Cucumis sativus* L.) originated from India or probably Burma, where the crop has been grown for more than 3000 years and was possibly introduced to other parts of the world (Wehner, 2007; Phu, 1998; Tatlioglu, 1993). The crop is an essential monoecious vegetable plant grown for its fruits and one of the most accepted elements of the Cucurbitaceae family (Adetula and Denton, 2003; Okonmah, 2011, Lower and Edwards, 1986; Thoa, 1998).

2.2 Varieties of cucumber

The cucumber vegetable crop originated in India, where several varieties have been observed (Renner *et al*., 2007). Two fundamental cucumber types exist and these include the type eaten fresh after peeling and slicing also known as the slicing market types (Kelly *et al.*, 2000, Wehner and Horton, 1986) and those eaten in the processed form also refered to as the pickling types (Staub and Bacher, 1997). The long cucumber which has a smooth, dark-green skin are the most accepted and popular variety and are usually used for salad preparation (Jyoti *et al.*, 2014).

In terms of sexual characteristics of cucumber, there is monoecious cultivar which produces male and female blossoms separately on the same plant, gynoecious cultivar which bears only female flowers or parthenocarpic cultivar where its female flowers require no pollination/fertilization for fruit production (Papadopoulos, 1994). Cucumber varieties which are gynoecious by producing 100% female flowers are generally the most prolific varieties and its fruits have smoother skins than

monoecious varieties which has female and male flowers (Marr, 1995; Hochmuth, 2001). The main cucumber varieties grown in greenhouses are parthenocarpic which are seedless since the fruits are produced without being pollinated (Relf and McDaniel, 2000).

2.3 Economic and nutritional importance of cucumber

Okonmah (2011) stated that cucumber is among the commercial vegetables grown in the tropical region for sale. Cucumbers are important vegetable utilized in the food as well as medicinal industries **(**Schaefer and Renner, 2011). Approximately all components of most vegetables of the cucubitaceae family are utilized for food (Shrivastava and Roy, 2013). In Ghana, cucumber can be eaten raw as a relish or used in the preparation of vegetable salad, stew or sandwich (Sinnadurai, 1992). Cucumbers are also used as an appetizer or mixed with other vegetables because of their distinctive texture and flavour (Norman, 1992).

Based on their financial significance in Asia, cucumber comes after tomatoes, cabbage and onion but is the next economic crop behind tomato in Western Europe (Eifediyi and Remison, 2010, Phu, 1997). The crop is one of the foreign vegetables grown in Ghana and also has the potential for export (Norman, 2003, Sinnadurai, 1992).

In view of dietary make up of the fruit, a 100 g consumable part is made up of 96% water, 0.5 g of protein, 2.9 g of carbohydrate, 0.1 g of fats and 0.6 g of fibre. Other nutritional content of this 100g also include 13 kcal energy, 14 mg of calcium, 17 mg and 2 mg of potassium and sodium respectively as well as 0.03 mg of thiamine, riboflavin 0.02 mg, niacin 0.30 mg and ascorbic acid of 4.7 mg (Maynard and Donald,

2000). Cucumbers are an excellent supply of vitamins such as A, C, K and B6 (Vimala *et al.*, 1999). Cucumber fruit is a major source of minerals (Keopraparl, 1997) and according to USDA, National Nutrient Data Base, 2014, cucumber fruits also have phyto-nutrients such as xanthein-B, lutein and carotene-B (Vimale *et al.*, 1999).

Cucumber juice is excellent for healthy development of the skin, complexion and has anti-inflammatory properties (Abul *et al*., 2013, Duke, 1997). The fruit are consumed in the fresh stage and contain lower calories as well as pantothenic acid (Lucier and Jerardo, 2007). Phytochemical study has demonstrated scientifically that cucurbits have a lot of medicinal properties. Several compounds with medicinal properties such as momorcharins, momordenol, charantine, cucurbitins, cucurbitacins, cucurbitanes, urease, polypeptide-P insulinin used for rats and humans are isolated from cucurbits (Ananya and Raychaudhuri, 2010). Extracts from cucumber such as cucurbitacin vigorously restrain the actions of cyclooxygenase enzymes which otherwise cause inflammation (Dhiman *et al.*, 2012**)**.

2.4 World cucumber production

Even though the cucumber crop is largely essential in Asia and Western Europe where it is ranked 4th and 2nd respectively, it has not been graded in Africa due to tinadequate utilization (Phu, 1997).

China was the leading producer of cucumber in 2013 with 54,362,750 tons. In Africa, Egypt was the leading cucumber producing country with 631, 129 tons and ranked 9th among cucumber producing countries in the world. In West Africa, Cote d'Ivoire was the highest cucumber producing country with 23,000 tons and ranked 67th in the

world whilst Ghana was ranked 125th in the world with 132 tons of production (FAOstat, 2013).

2.5 Constraints of cucumber production in Ghana

Although cucumber crop perform well under environments with the following characteristics: high temperature, low humidity, moderate light intensity, good textured and structured soils with a continuous delivery of water and nutrients, cucumber farmers in Ghana are faced with the problem of low yields (Frimpong, 2011, Papadopoulos, 1994). The productivity of cucumber in terms of yield per hectare in Ghana was 12 tons as compared to 37.4 tons in Morocco and 666.7 tons average productivity in Netherlands (FAOstat, 2013).

The increasing human populations which compete for arable lands for human activities such as establishment of human settlements, recreational centres and disposal of organic wastes all results in scarcity and constraints of land limiting the area for crop cultivation as well as the yield (Ogbodo, 2012). Papadopoulos (1994) stated that some of the drawbacks of cropping under conditions of high relative humidity where water is easily concentrated on the plants is the prevalence of severe diseases such as downy and powdery mildew. The incidence of these fungal diseases according to Sinnadurai (1992) is correlated to the humidity of the atmosphere where the crop is growing. The relative humidity of 96% and temperature range of 22-27^{0}C presents most favourable condition for the germination and growth of fungi spores (Babadoost *et al.* 2004). Camejo *et al.* (2005) also stated that high light amount accompanied by high temperature of 40^{o}C or above is detrimental to fruit formation. The most appropriate soil types for the cultivation of cucumbers are sandy loams, loams and silty loams which all contain organic matter in high quantities. However

soils in Africa and for that matter Ghana are low in organic matter therefore resulting in low yields (Kelly *et al.,* 2000). The erratic nature of rainfall in Ghana result in water stress thus affects hydration, biochemical and metabolic reactions, nutrient absorption and translocation, photosynthesis, respiration and subsequently low yield and poor quality (Poincelot, 2004; Acquaah, 2005).

At present, most cultivation of cucumber is done in open fields which is exposed to various abiotic factors such as high temperature, low temperature and unpredictable weather. Biotic factors such as fruit fly and incidence of downy/powdery mildew also stresses cucumber cultivation in open fields. Therefore, it is not possible to produce high quality cucumber in terms of size, shape and colour and free from diseases and pests as compared to cucumber produced under protected environment.

2.6 Greenhouse cucumber production

There is increasing demand for yearlong stock of fresh vegetables and safe control of pest and disease techniques, therefore the use of greenhouses or control environment for the production of crops has become necessary globally. As a result of this, Gruda (2005) revealed that in order to ensure sustainable supply of safe vegetable crops to meet its demand, the use of greenhouses is very important.

A greenhouse is an enclosed structure with a controlled environment for increased productivity of variety of crops (Mathew, 2001). Greenhouses supply most favourable environment for optimum growth of plants, high yield as well as good quality produce (Ali, 2012). In controlled environment, climatic conditions are optimal for certain species, regardless of the external environment (FAO 2013).

One of the objectives of growing crops in a controlled environment such as greenhouses is to ensure profitability of production through the provision of optimum growing condition for efficient crop growth and development (Aldrich and Bartok, 1989). Controlled environment such as greenhouses are invented to modify the intensity of light, regulate the relative humidity of the growing atmosphere as well as the temperature. Shade is employed in the production of crops in order to regulate the light that reaches the growing plants (Siwek and Lipowiecka, 2004). The regulation of light that reaches plants when shade is used ensure the reduction of temperature, high relative humidity which eventually reduce the rate of evapotranspiration by the plants and make the plant less stressed (Hashem *et al*., 2011). Hydroponics substrates used in greenhouses also help in controlling nutrient levels and root temperatures (Kendirli, 2006). According to CARDI (2014), many tropical areas of the world use greenhouses for the production of vegetable. These greenhouses increase control over quality and productivity of crops through their ability to control the growing environment. Good growth of plants that result in high yield in greenhouses is as a result of the optimum environment they offer (Castilla, 2013).

Implementation of greenhouse technology for crop production might result in significant transformation of Ghana's agriculture. High yields, better quality of produce as well as extended crop growing period are some of the benefits to be expected (Elings *et al*., 2015). Greenhouse crop production result in high protection of crops from adverse climatic conditions through temperature control and protection from rain. Crops are also protected from the activities of pests and diseases (Saavedra *et al*., 2014). Choi *et al*., (2001) suggested that the height, fresh weight and dry weight of plants grown in a closed system were higher than those cultivated in an open system. The cultivation of cucumber under greenhouse conditions is very common

and accepted in many parts of the world. Cucumber requires temperature of approximately 25°C to 29°C and a lot of sunlight for its growth and development (Hochmuth, 2001).

The production of cucumber under greenhouse, protected or in polyhouse environments brings about higher crop production, productivity as well as higher quality of fruits. These results in better market price and the crop can be grown during off-season (Kumar *et al*., 2015). One of the major lucrative vegetables cultivated under greenhouse conditions is cucumber and the crop develops effectively leading to profitable production (Ibeawuchi *et al*., 2008; El-Wanis *et al*., 2012, El-Aidy *et al*., 2007). These protected environmental conditions in greenhouses results in high vegetative growth which significantly increase yield and quality (Hashem *et al*., 2011).

2.7 Growth media for greenhouse vegetable production

A growth media is any material that supplies nutrients, air, water as well as offer support for the crop for good root and shoot growth, yield and high quality of produce (Miller and Jones, 1995, Nelson, 1991). In addition to crop plants, growth media have effects and plays an important role on the initiation, growth, height, number of leaves as well as on the value of ornamental plants grown in containers (Vendrame *et al*., 2005).

In order for a growth media to support good growth, yield as well as quality of vegetables and other crops, it should encompass good properties such as proper aeration, water holding capacity and contain sufficient nutrient when used as a single medium or in combination (Khobragade *et al*., 1997: Hartmann *et al*., 2011).

Diverse materials which are organic or in-organic are used as growing substrates for the production of crops (Olle *et al*. 2012). Substrates are utilized alone or mixed to supply the plant root zone with nutrient, water, air and anchorage (Noto, 1993). There are two main categories of growing media namely soilless and soil based growing media (Spiers and Percy, 2007).

Soilless media production of crops and plants uses either organic or inorganic materials with the application of nutrient solution for the plant sustenance. This ensures that resources are used efficiently thereby increasing yield and quality of crop production in greenhouse vegetables (Dorais *et al*., 2001, Jensen, 1997). Soilless husbandry includes liquid medium such as hydroponic system and solid medium to support the production of plants. Soilless substrate utilization is categorized into open and close system. In open system the nutrient solution that drains from the roots of the plant after irrigation is not reused whilst in closed systems the nutrient solution that drains after irrigation is collected, corrected and put back into the system (Dorais & Dube, 2011; Hansson, 2003, Winsor and Schwarz, 1990).

The main accessible growing substrate used for the production of crop plants is usually soil and it offers support, nourishment, air, moisture, etc. for their growth and development (Ellis *et al*., 1974). Soil is a mixture of minerals, organic matter, gases, liquids, organisms and is the heaviest of all growing media, usually low in organic matter which reduces its ability to hold water (Khan *et al*., 2002). Neelam and Ishtiaq *(*2001) observed in silt +clay the highest plant height (90.41 cm), greater number of leaves per plant (32) and stem thickness (0.52 cm) in a study to assess the effect of *Eucalyptus comaldulensis* seedlings in different soil media. Vineeta and Agnihotri (2005) stated that the stability and structure which has positive effect on plant growth

and development was improved as a result of straw addition leading to better texture and structure of the soil.

2.8 Constraints of using soil as medium in greenhouses

The main drawback of using soil for crop production in greenhouses is the incidence of soil-borne diseases. The management of these soil borne diseases is feasible but they involve the use of chemicals which are costly and require technical knowhow (Elings *et al.,* 2014). These soil borne root diseases results in a decline productivity (yields and quality) (El Sharkawi *et. al*., 2014). Different soil borne disease causing organisms like *Pythium* spp, *Fusarium* spp. as well as root knot nematodes (*Meloidogyne* spp.*)* affects cucumber. These pathogens are important since they reduce the yield and quality as well (Sasser and Freckman, 1987; Todd *et al*., 1991). Fusarium wilt disease negatively affects cucumber growth, yield and quality (Cohen *et al*., 2015). The control of the disease i.e. fusarium wilt is complicated. This is due to the fact that the Fusarium pathogens can survive as chlamydospores for many years in the soil or can act as a saprophytes in order to continue to exist (Sun *et al*., 2015; Agrios, 2005).

Greenhouse soil sterilization is not easy and this result in disease, salts, and waste build up and is a limiting factor for long-term profitable crop production. Other challenges associated with growing crops in soil medium under greenhouse conditions include temperature variations, low water holding capacity, low cation exchange capacity, lack of available nutrient supply, improper root aeration as well as difficulty in disease and pest control (Du Plooy *et al*., 2012).

Although soil substrates are generally available for growing plants (Ellis *et al.*, 1974), soil causes limitations such as presence of pathogens, nematodes, soil compaction, poor drainage, erosion which negatively affect plant growth, development, yield and quality (Beibel, 1960). Production of plants in greenhouses under soil medium introduces considerable threat for diseases associated with soil (Elings *et al.*, 2014). Root rots, wilts, root knot nematodes and nematode-transmitted viruses are some of the most common soil borne diseases during the production of crops under controlled environments (van Bruggen and Semenov, 2015). Losses in yield as well as quality of plants produced in greenhouses can occur as a result of soil borne diseases, pests or even weeds (Gamliel and van Bruggen, 2015).

Challenges such as the use of expensive chemicals for soil disinfection, poor growth, low yields and quality have enhanced the significance of using soilless media (De Rijck and Schrevens, 1998). According to Sweet (1975), the use of soil as a growth media turns to harbour pathogens and pests which turn to infect plants leading to low yield and quality. This necessitates the production of crops in alternative substrates. In the Netherlands, the shift from crop production from soil to other soilless substrates was done to overcome soil borne diseases, pests and pathogens such as *Gnomonia radicola* and *Phytophthora* species (Amsing, 1995).

2.9 Soilless substrates

Soilless culture refers to the cultivation of plants without using soil while fertigation is used to supply the growing plants with water and nutrients. This irrigation water contains nutrients in suitable concentration for good plant growth and development (Savvas *et al*., 2013). Substrate, growing medium or rooting medium amongst others are used as synonyms to describe growing media materials, other than soils used in a

container to grow plants. These are either organic materials or inorganic (Vaughn *et al*., 2011; Blok and Verhagen, 2009; Grunert *et al*., 2008).

The use of soilless substrate for production of crops leads to improved water management as well as fertilizer management. The major aims of using soilless substrates are therefore to maximize labour, land, increase yield and quality of plants (Mazahreh *et al*., 2015). The benefits of using soilless media include the absence of soil-borne pathogens and diseases, reduce the cost of soil disinfection, ensure even application of nutrients and water to plants, good plant growth, development, increased yield and quality (Burrage., 2014; Savvas, *et al*, 2013). The use of soilless media is one of the agro technique methods use to save the use of water, fertilizer and labour. Soilless media also help to reduce pests and diseases infestations thus result in reduce application of agro-chernicals (Davtyan 1980). Furthermore soilless media does not require electrical power. Plants can be moved, maintained and harvesting done in most suitable area when soilless culture is used (Islam *et al*. 2002).

2.10 Soilless as an alternative to soil for crop production in greenhouses

The use of different soilless media for the cultivation of vegetables and ornamental plants has been practiced for long in greenhouses (Carlile *et al*., 2015). In order to produce crops that will yield high, of quality and have minimum pollution of the environment, there is the need to control pests and diseases as well as apply nutrient more efficiently. One way to achieve the above is to change soil with soilless media. These soilless media helps to increase the amount of water retention thereby making it available to plant growing in them (Chalhoub *et al*., 2013) and suppress soil-born plant pathogens (Hadar, 2011).

The cultivation of crops in soilless culture has been publicized by different research scientists to be successful in terms of yield and quality of produce such as flowers and crops (Ghehsareh *et al.*, 2011; Ahmad *et al.*, 2012). Crops grown under soilless media have better qualities compared with those from soil-based substrates (Xu *et al.*, 1995) and some of these soilless media are natural materials such as rice husk (Savidov, and Nichols, 2010).

The use of soilless culture results in the reduction and absence of soil borne disease causing organisms, non use of chemicals for soil sterilization, and efficient application of nutrients and water, capacity for increased yield and reduction in environmental pollutions by nutrients and pesticides (Burrage, 2014; Savvas *et al*, 2013).

In addition to the demand for quality of vegetables by consumers, the effect of production activities are sustainable. The use of soilless medium thus helps to raise the output of crops irrespective of the climatic conditions, ensure efficient use of pesticides and fertilizers as well as efficient controlling of pest and diseases (Gullino *et al*., 2015). The growing of crops on both organic and inorganic soilless media ensures optimum water and oxygen holding, efficient nutrient uptake by plants which results in good growth and development (Verdonck *et al.*, 1982).

Replacing soil with soilless media for the production of crops can provide benefits in the plant nutrition management and plant protection. This will also help to reduce challenges due to monoculture of crops on the same plot of land (Fecondini *et al.*, 2011). The difficulties of crop production especially cucumber, pepper, tomatoes etc relating to soil borne pathogen and diseases will be reduced through the use of soilless media (Olympios,1995). Schueter (1989) reported that different soil-borne plant

diseases can be suppressed using different agricultural and agro-industrial wastes and thus making plants more vigorous and better able to withstand pest attack.

The functions of a good soilless growing substrate include the provision of anchorage or support to the plant, holds nutrients and water, efficient gas such as oxygen exchange between the root zone and the atmosphere. Substrates or their mixtures have different influences on how crop plants grow and develop, therefore the choice of most appropriate substrate is very important for plant productivity (Vaughn *et al*., 2011, Nair *et al*., 2011, Bhat *et al*., 2013, Olympios, 1995).

Production of vegetables under soilless as compared with traditional open field and greenhouse production in soil, permits the proficient utilization of water and nutrients (Resh, 1997). Benefits of using soilless substrates comprise more efficient nutrient and water supply, electrical conductivity, pH of the nutrient solution, and temperature. Higher yield and quality of produce is therefore obtained. Production of crops in soilless media thus offers an ultimate environment for good plant growth and development. Soilless cultivation also helps to avoid nutrient losses and thereby reducing potentially negative environmental impact (Schwarz *et al*., 2009).

2.11 Characteristics of substrates

The quality of a substrate is one of the main issues that influence good crop growth, development, high yield as well as quality of produce (Argo, 1997). The choice and collection of any organic agricultural residues to be used as potting media for the production of horticultural crops such as vegetables must mainly be established by several factors such as availability, cost, physical and chemical properties (Akanbi *et al*., 2002). Characteristics of substrates such as nutrient content, cation exchange

capacity and water holding capacity among others influences the growth, development as well as nutrient concentration of a plant (Rose and Haase, 2000). Characteristics of soilless substrate are usually preferred to soils. This is due to the fact that soilless medium has higher rate of porosity, is less heavy and has fewer or no pests and disease causing organisms. They also have distinct amount of water that is held or retained for plant utilization as in contrast to mineral soils. Saturation of soilless substrates by water can surpass 50% but can decrease to less than 10% for a small water tension increase of just 20–40 cm of water head as illustrated for a number of media by Wallach *et al*., (1992b) and Altland *et al*. (2010), among others. Samiei *et al*. (2005) demonstrated that peat moss and date-palm peat were similar in some characteristics.

2.11.1 Physical properties of soilless substrates

Physical characteristics of a growth media are considered as essential features that affect the growth, development, yield and quality of plants. Air, water and solid matter distribution in the media influences many factors such as the bulk density, water holding capacity and porosity (Awad, 2010). The physical components of a soilless media or substrates consist of four (4) parts and these include the solid volume (20% - 30%), available water (10% - 25%), air space (10% - 30%) and residual water (15% - 45%) (Spiers and Percy, 2007). The important components of the physical properties of a substrate are the air space and the accessible water that depend largely on the particle size or shape of the substrate or its mix (Acquaye, 2001). Yeager *et al*., (2000) recommend the physical properties of media to be used for container crop production as air space of 10 to 30%, water holding capacity of 45 to 50%, total porosity of 50 to 80% and bulk density of 0.19 to 0.70g/cm^3. The growth,

elongation as well as the metabolism of plant roots is affected by the interaction of these properties. The ideal substrate to be used for the production of crops must contain appropriate physical properties in order to support the plant's growth and development (Asaduzzaman *et al.*, 2015). Growth media used for the cultivation of crops in containers must retain sufficient air space and container capacity also referred to as the water holding capacity throughout the cropping season so as to provide favourable environment for plant growth and development. This is due to the fact that physical properties of substrates might vary over time (Allaire-Leung *et al.* 1999; Lemaire 1995). The success of a substrate is mostly based on the performance of the crops. High value substrates with the appropriate physical characteristics can produce good growth, yields and exceptional crop quality (Verdonck and Gabriels 1992). In addition to good cultural practices on crop growing in greenhouses, appropriate physical characteristics of the growth media is important to ensure successful production (Raviv, *et al.*, 2002). The physical characteristics such as water holding capacity and bulk density differ greatly among substrates due to elements that make up a particular substrate and small change in one of these parameters can result in poor plant growth and development (Fonteno and Harden, 2003).

2.11.1.1 Bulk density

The bulk density is an indicator of compaction of a growing substrate and it is expressed in weight per volume that media fill in addition to pore spaces. Bulk densities of loosely porous soilless substrates rich in organic matter are low hence mixing them with other substrates with higher bulk densities increases the bulk density of the mixed substrates and thus hold up the plant in lightweight containers (Arshad and Azooz, 1996, Brown and Pokorny, 1975; Fonteno *et al.*, 1981; Hanan *et*

al. 1981). Fonteno *et al*. (1981) established that contraction and settling of growth media in a container will raise the bulk density of the media. The bulk density of a growing substrate is important as it influences the growth of roots and shoots. Yeager *et al*. (1997) proposed that soilless substrates used for the production of crops in containers should have a bulk density from 0.19 to 0.7 g/cm^3.

2.11.1.2 Total porosity

The total porosity of a media is the total volume of pore space within that media. The bulk density of a media can be used to determine the total porosity since they are related inversely (Beardsell *et al*., 1979; Hanan *et al*., 1981). The total porosity of a substrate regulates the movement of water through the soil and this is important since water is made available at the root zone for plant uptake. Aeration porosity and water holding capacity of a media are essential physical characteristics since they control the available air and water to plant roots for their growth and development (Richard, 2006, De Boot and De Waele, 1968). Verdonck *et al*. (1983) proposed that a growing substrate to be used for the production of crops should consist of 20% air and 20 to 30% available water by volume.

2.11.1.3 Water holding capacity

Water holding capacity is the total amount of water that is held by the substrate or the growth media for the plants growth and development (Awad, 2010). In order to prevent the incidence of drought or excess water especially on a low depth and minimum volume of media, it is imperative to keep the most favourable aeration and water levels since the capacity of the growing media to maintain the equilibrium between water content and gases is essential for good growth and development of

plants (Dresboll, 2010). Soilless substrates can be controlled or combined in diverse volumes to provide better physical and chemical atmosphere for optimal plant growth. As a result good plant growth and development depends on the ability of the growth substrate to provide adequate water and oxygen to the root zone of the plant (Michel, 2010; Khayyat *et al*., 2007). Therefore the availability of water to growing plants is the most important parameter that determines good growth, high quantity as well as quality of produce.

2.11.2 Chemical properties of soilless substrates

The chemical property of a substrate that influences the growth and development of plants includes the pH, electrical conductivity (EC) and cation exchange capacity (CEC) (Cuervo *et al.*, 2012). The chemical characteristics of a substrate influence the growth, yield and quality of crops since they directly influence nutrient solubility and retention, thus availability for plant root uptake for growth and development (Bunt, 1988).

2.11.2.1 pH

The pH of a substrate is the power of hydrogen and also refers to the acidity or alkalinity present in a substrate water solution and thus influences the availability of nutrients to plants (Hartman *et al*., 1997). The availability of nutrients in a substrate as affected by the pH is influenced by lime concentration, the plant species, plant uptake of nutrients and water alkalinity (Richard, 2006).

Larson (1980), reported that a substrate for good plant growth and development must have an appropriate pH. For soilless substrate, the pH should be 5.4 to 6.0 and 6.2 to 6.8 for soil substrates (Hartman *et al*., 1997).

In substrates of increased pH, mineral ions such as aluminium (Al), iron (Fe) and manganese (Mn) precipitate and become less accessible for plant uptake. Plants growing in such pH may express deficiencies of Fe as well as other plant nutrients such as Boron (B), Zinc (Zn), Copper (Cu) and molybdenum (Mo) (Mathers, 2003).

2.11.2.2 Cation Exchange Capacity (CEC)

The CEC is the capacity of a substrate or substrate mix to hold nutrients or the measure of nutrient in a growing substrate for plant uptake for growth and development (Spiers and Percy, 2007). The CEC can also be described as the overall transferable or exchangeable cations that a media can attract and hold per weight in order to make it available to the growing plant (Bunt, 1988).

Fertilizers of positive charges are attracted to clay or organic particles since they have negative charges. CEC is thus a pool of nutrients where plant can take them up for their growth and development. There are various factors that affect the availability of these nutrients and one of such is pH (Helling *et al*., 1964).

Substrate with low CEC implies low availability of ions therefore needs increased and regular application of fertilizers so as not to cause nutrient deficiency to plants growing in them (Mathers, 2004). The higher the value of CEC of the substrate the more nutrients are available, accessible to the plant and the least nutrient lost as a result of over watering (Acquaye, 2011).

The CEC however depends on the volume of the soilless substrate. The larger the surface area of the growing substrate, the more its CEC content therefore the volume of a substrate must be high so as to hold nutrient for good development, optimum

growth, high yield and good quality of produce (Spiers and Percy, 2007, Hartman *et al*., 2002).

2.11.2.3 Electrical conductivity (EC)

The EC is the measure of salt content of water or a substance based on the flow of electrical current (Richard, 2006). The soluble salt level of a substrate is determined by measuring the EC of a substrate (Pettinelli and McAvoy, 1995). Electrical conductivity (EC) of irrigation water determines the quality of water to be used for crop production (Hoffman and Shannon, 2007).

Different nutrient solution, EC level of a media determines the level of growth and development of crops. A nutrient solution EC level which is more than optimum might affect the growth, yield of the growing crop and thereby leading to a decrease in fruit yield e.g. EC level more than 3.5 dS m^{-1} of a media can affect crop performance and cause reduction in yield (Sonneveld, 1985). Lang (1996) recommended 1.0 to 2.0 dS/m and 2.0 to 3.0 dS/m for seedlings and established plants respectively for good growth and development. According to Saied *et al.*, (2005), high EC (2.5 dS m^{-1}) caused low plant growth, development, low yield as well as low quality of strawberries grown in soil media. In contrast EC of 2.5 dS m^{-1} resulted in higher strawberry weights, high fruit yields, and better quality than lower EC values under soilless conditions (D'Anna *et al*., 2003).

2.12 Soilless substrates effect on growth, yield and fruit quality of cucumber

2.12.1 Soilless substrates on physical growth indices of cucumber

Results demonstrated by Peyvast *et al*., (2010), indicated that substrates had an important influence on the growth and development of plants. Ghehsareh *et al*. (2012)

disclosed that date-palm leaves are used as substrate for cultivation of cucumber resulted in high plant height and root weight as compared to soil. Alifar *et al* (2010), recommended that stem diameter of cucumber were greater in cocopeat media than other media like perlite-cocopeat (50-50, v/v), perlite-cocopeat-peatmoss (50-20-30 and 50-30-20, v/v).

2.12.2 Soilless substrates on growth analysis

The method of deducing how plants grow and develop mathematically is known as plant growth analysis and this growth analysis instrument describes how plants function based on their dependence on genotype and surroundings (Lambers *et al*., 1989). Growth analysis of plants has been recognized as the most excellent and suitable way for assessing the performances of plant since these plants adjust to their immediate environment through morphological or functional plant adaptations (Tedeschi *et al*., 2011).

A number of growth analyses can be done on plants, depending on key factors for growth (Smeet and Garretsen, 1986). The most common secondary growth analysis usually carred out by researchers include Leaf Area Ratio (LAR), Relative Growth Rate (RGR), Leaf Weight Ratio (LWR), Net Assimilation Rate (NAR) and Specific Leaf Area (SLA).

Relative Growth Rate (RGR) is the rate of increase in plant dry weight per unit of plant dry weight already present (Lambers and Poorter, 1992). The two variables that determine the RGR are the Leaf Area Ratio (LAR) and the Net Assimilation Rate (NAR) with the formula RGR = LAR x NAR (Smeet and Garretsen, 1986). De Swart

et al., (2007) concluded that alterations in both NAR and LAR under lowered temperatures results in the reduction of RGR.

Plant growth is important since it determines the survival, reproduction and competitiveness. The relative growth rate (RGR) of plants varies extensively within and among habitats (Grime *et al*., 1975, Poorter and Remkes, 1990, Garnier, 1992, Paine *et al*., 2015), with results for centre of population structure and dynamics (Kraft *et al*., 2008, Grime, 2002, Hunt, 1982,). RGR (in $gg^{-1}day^{-1}$) can be issued into net assimilation rate (NAR), specific leaf area (SLA,) and leaf mass ratio in order to establish the basis of variation in growth, (Rees *et al.*, 2010, Konings, 1989). According to Bruggink and Heuvelink (1987), the RGR for cucumber and tomato plants grown under greenhouse conditions were about the same. Relative growth rates are close to highest when seedlings are at a juvenile stage and then reduce over time. Variations in RGR between species are generally visible when production is done under most favourable conditions. Plants thus develop slower in poorer nutrient levels and the consequential variations in RGR among species are greatly less or absent (Causton and Venus, 1981).

Leaf Area Ratio (LAR) is the total leaf area per unit total plant dry weight. It is the product of the Specific Leaf Area (SLA) and the Leaf Weight Ratio (LWR) (Poorter and Remkes, 1990). Several growth analysis studies done on herbaceous C3 plant species show significant positive correlations of RGR with LAR, LWR and SLA but not usually with NAR. A decrease in RGR is mainly as a result of decrease in LAR (Smeet and Garretsen, 1986).

Net Assimilation Rate (NAR) is the rate of increase in total plant dry weight per unit leaf area. It is mainly the net effect of the rate of carbon gain in photosynthesis per

unit leaf area and that of carbon use by plant leaves, stems and roots for respiration (Poorter and Remkes, 1990). Thus the NAR determines the normal photosynthetic effectiveness of plant leaves or in a growing crop stand (Hunt, 1990; Lambers *et al*., 1989). The main essential factor that explains difference in RGR within plants of the same family, genus, species and even among closely related plant species is NAR (Hunt, 1982). RGR depends on the NAR, and upon LAR. This proposes that the variations in the initial RGR may be as a result of the instability of its components (Hunt, 1982 and Hunt, 1990).

SLA refers to the leaf area per unit leaf mass and it calculates the leaf area of a plant to the leaf dry weight. SLA is expressed in cm^2g^{-1} (Konings, 1989, Poorter, 1989, Kvet *et al.* 1971).

Leaf weight ratio is the dry weight of leaves to entire plant dry weight. The LWR is calculated in g g^{-1} (Kvet *et al.,* 1971). Demural *et al*., (2005) proposed that the declining values of LWR are related with increasing allocation of dry matter to other parts of plant as the plants grow.

Quick growing plant species apportion fairly less biomass and N to their stems when contrasted with slow growing plants. Likewise, variety of crop with high yielding capacities normally contains a small distribution to the stems. Situations where more distribution of biomass and N is contained in stem reveals resources are being channelled from growth to storage (Lambers and Poorter, 1992).

Ghehsareh *et al*. (2012) disclosed that when date-palm leafs is used as substrate for cultivation of cucumber, superior biomass weight, Leaf Area Index (LAI) and root weight were achieved as compared to soil. Xu *et al.,* (2010) concluded that LAI is an

essential variable and highly correlated with canopy photosynthesis based on a model for calculating LAI of some vegetables grown in the greenhouse including cucumber.

2.12.3 Soilless substrates on cucumber yield

The utilization of soilless substrate has been demonstrated by different researchers to be successful in terms of production quantity and quality of flowers and edible crops (Ghehsareh *et al.*, 2011; Ahmad *et al.*, 2012).

Ghehsareh (2013) positioned that the yield of cucumber in different growth substrate was significant compared to other treatments. Maximum and minimum yield of fruit was attributed to palm waste (pa) and S (soil) + Pa (Palm waste), 5% of pa + Rh (Rice hull) at 5% treatments respectively. Organic growth media has been identified to generate more number of fruit thereby translating to higher yield than the usual cultivation methods of tomato grown under protected horticulture (Olle *et al*., 2012; Rippy, 2004). Alifar *et al* (2010) reported maximum yield of cucumber fruit gained from cocopeat media than other media like perlite-cocopeat (50-50, v/v), perlite-cocopeat-peatmoss (50-20-30 and 50-30-20, v/v) and other development indicators such as fruit's number, fruit size and fruit diameter were greater in cocopeat. Borji *et al*. (2010) found that fruit yield, fruit number and stem length of tomato has no significant differences in some growing media include date-palm peat, perlite, cocopeat and mix of these materials.

2.12.4 Soilless substrates on cucumber fruit quality

Fruit quality is an important factor in the successful cultivation of crops under greenhouse conditions. Fruit quality attributes that influence consumers choice are physical appearance (colour, shape, size, absent from defect and decay), firmness,

flavour (aroma and taste) and nutrient content (Jones, 1999). The taste as a quality attribute of produce is determined by the amount of soluble solids and organic acids content in the produce (Kader, 2002; Cantwell *et al*., 2007). Plant nutrients are believed to have high influence on fruit quality and according to Paiva *et al.* (1998), the function of nutrients on plants metabolism influences the effect of nutrient on growth, yield and quality.

Growing crops in soilless substrates under protected environment does not only ensure high yields but in addition results in higher produce quality (Robbins and Evans, 2004). Horticultural crops grown on soilless substrates have superior qualities than those cultivated from soil-based media (Xu *et al*., 1995; Varis and Altay, 1992; Abak and celikel, 1994; Alan *et al*., 1994). Appearance and inner quality of fruit vary for fresh as well as processing market types (Wehner and Cramer, 1996, Lower and Edwards, 1986). Even though the precise distinctions of crops cultivated in soil or soilless substrates are not easy to establish (Schnitzler and Gruda, 2003), soilless substrate for the production of cucumbers and other high-value crops under greenhouse conditions may be a substitute. Massantini *et al*. (1988) in a study established that soilless substrates produced high quality attributes of fruit such as superior taste, homogeny, appearance, texture and nutritional content than the fruits grown in soil. Mohammadi Ghehsareh *et al*. (2011) reported higher amount of total soluble solids (TSS) in tomato grown in soilless substrates such as coco peat + perlite, date-palm peat + perlite, perlite and date-palm treatments. Various researches also recorded high vitamin C, dry matter and nitrogen in tomato fruits cultivated in organic media than rockwool (Kowalczyk, 2011b). Fernández-Trujillo *et al*., (2004) also reported that higher fruit quality of cucumber was obtain when cultivated in nutrient film technique than in perlite media. The total soluble solid is a measure of the

amount of sucrose that is in a plant's sap. The measure of brix can be used to establish sweetness of fruits and vegetables. According to Salunkha *et al*. (1974), the increase in the amount of soluble solids in fruits is affected by the biosynthesis processes or degradation of polysaccharides during maturity.

2.13 Challenges of using soilless substrates

In spite of many benefits, soilless substrate has some drawbacks (Sonneveld, 2000). The use of soilless substrates for commercial crop production needs scientific information as well as more preliminary funds.

Scientific information as regard to the use of soilless medium coupled with high expenditure will advance if the soilless substrate is being used under greenhouse conditions (Sonneveld, 2000). In using soilless substrates, some agronomic practices such as nutrient solution preparation, disease diagnosis and control, pest control, maintenance of optimum pH and EC as well as controlling the environment for optimum productivity requires advanced level of management skills (Van Os *et al*., 2002). In view of its high capital expenditure, soilless substrate is restricted to the production of high value crops within the area of production where profitability can be achieved. Soilless media needs regular irrigation and high fertilization rates in order to support maximum growth, yield and quality of crops (Van Os and Benoit, 1999)

Soilless substrates unlike soils have much lower water holding capacity. This was demonstrated by Wallach *et al.* (1992a, b) and Altland *et al*. (2010) that the saturation water content can frequently surpass 50% but it can decrease quickly to less than 10% for a small water tension increase of just 20–40 cm of water head. Chemically,

cocopeat has high CEC which can cause nutrient imbalance within the root zone and affect availability of nutrients for good plant growth and development (Verhagen, 1999).

2.14 The use of agricultural wastes as soilless substrates

The choice of a soilless substrate for the production of crop is based on the physical attributes of the substrate, its accessibility and price (Lieten *et al*., 2004).

Agricultural residues are commonly accessible, renewable and almost at no cost, therefore they can be an essential resource for the production of crops. Worldwide yearly production of agricultural wastes is approximated to exceed 500 million tonnes and it is assessed that more than 4.2 million tons of Agricultural wastes are produced annually in Ghana (Quartey, 2011, Sanchez, 2009).

Agricultural residues can be described as ravages generally connected with the cultivation and processing of crops and fibre on farms, feedlots, ranches, ranges and forests. These may comprise animal droppings and crop remains (Sase and Christianson, 1990). Even though some of these residues are recycled back into the soil or use as livestock feed, large amounts are burnt on the field which causes pollution and waste of useful energy (Quartey, 2011). The method of disposal of agricultural residues determines its pollution on the environment and not necessarily on the quantity generated (Sabiiti *et al*., 2004; Tumuhairwe *et al*., 2009; Sabiiti, 2011). Unfortunately most agricultural wastes are not disposed off well thereby posing negative impact not only on the environment but also have negative effects on the quality of water and air (Sabiiti, 2011).

In Ghana, the method mostly use for the disposal of agricultural wastes is burning which leads to air pollution. The burning of these agricultural residues discharges pollutants and these pose a lot of harm to human and ecological health through acid deposition (Sabiiti, 2011; Ezcurra *et al*., 2001; Hegg, 1987; Lacaux *et al*., 1992).

The farming and agro-manufacturing residues such as coconut shells, palm trunk and frond, rice husk, saw dust, sugarcane bagasse and cocoa husk among others when managed well, can be valuable to agriculture in the production of crops, since these materials have essential nutrients like nitrogen, phosphorus, potassium and magnesium (Adamtey, 2005). Hseih and Hsieh (1990), stated that agricultural wastes can be rightly handled by utilizing them as soil improvements to enhance the degraded soils with very little organic material content. Organic materials both fresh and composted play a significant function in sustaining nutrient availability and consequently enhancing good plant growth, development and productivity. This is due to the fact that organic matter supplies crops with essential plant nutrition and soil microorganisms with energy thereby improving on decomposition of waste materials and improvement of aeration in the soil which in effect benefit crop plants for maximum production (Ajayi *et al*., 2007; Marinari *et al*., 2000; Nyberg *et al*., 2006). Composted agricultural and agro- industrial based wastes provide adequate nutrient to seedlings as well as control soil borne pests and diseases from attacking them (Muhammad *et al*.,2001).

The utilization of different alternative growth media other than soil such as sawdust and rice husk is one of the techniques that have been practiced for nursery management and raising seedlings (Gungula and Tame, 2006). Studies have revealed that leaf mulch, rice husk as well as agricultural agro industrial waste materials such

as cocopeat, cocoa pod husk and kola pod husk have been utilized as growing media for raising seedlings (Adejobi *et al*., 2011). These waste residues from agriculture and agro-processing industries are inexpensive, available, accessible, rich sources of different plant nutrients and can be developed and utilized as a soilless substrate for the cultivation of plants (Khan *et al*., 2012).

2.15 Soilless substrate components

2.15.1 Cocopeat

Cocopeat also known as coir dust is a spongy like industrial waste left over following the removal of fibre from the coconut husk. Cocopeat is a binding material that comes from the fibre fraction of coconut husk and among the soilless substrates commonly available in the tropics for use in the production of plants (Cresswell, 2007, Verhagen, 1999, Martinez *et al*. 1996, Abad *et al*., 2002).

Cocopeat is categorized in terms of physical characteristics with good water holding capacity and aeration to growing plants (Noguera *et al*., 2003). Cocopeat has other unique properties such as high total pore spaces, little shrinkage and lower bulk densities (Prasad, 1997). Cocopeat as an organic substrate, can encourage more root growth, usually identified to have high moisture holding capacity and supply water which provides a cushion against high temperatures and crop water demand with adequate air supply (Galukucocopeat, 2011, Meggelen-Laagland 1995). Evans *et al*. (1996), studied the chemical and physical properties of cocopeat from many supplies and stated that characteristics were usually within tolerable ranges apart from the electrical conductivity and chloride levels, which repeatedly exceeded accepted levels.

Cocopeat provides a good growing substrate for hydroponics, soil mixes and container crop production (Yau and Murphy, 2000). Different researches have been done in Kenya by using cocopeat as a growing substrate (Ketter *et al.*, 2013; Kipngeno *et al.*, 2015 and Gechemba *et al.*, 2015) to attain the best results. It can be utilized for the cultivation of various crops with good yield and satisfactory quality (Yahya and Mohd 1996). Cocopeat as a growth media has performed better as measure up to other substrate in ornamental plants (Aniel *et al.*, 2007; Abad *et al.*, 2002). Studies found that it has comparable characteristics to peat moss and can support thriving growth of plants (Meerow, 1994; Noguera, 2000). In research carried out by Rezaee *et al.*, (2013) in Iran using different substrates on rose production, better performance was noticed on cocopeat alone or cocopeat mixture with perlite. In contrast loam soil did better on the shoot dry weight than cocopeat and peat-cocopeat mixture in a study carried out on oriental lily in California, USA (Merhaut and Newman, 2005). Most gerbera producers are replacing soil use in trays and plugs with cocopeat in Brazil (Mathias, 2006). Khalaj *et al.*, (2011) reported that gerbera grown in cocopeat and cocopeat perlite mixtures perform less as compared to peat or perlite alone or their combinations in a study done in India. In terms of rose Fascella and Zizzo, (2005), in a research carried out in Italy reported that cocopeat combined with perlite performed better than perlite alone in the production of roses. Cocopeat substrate use for growing fruits, vegetables as well as ornamental plants provides an optimized fertigation regime and better nutrient availability as compared to soil growing medium resulting in higher growth, development and a higher total weight of stems (Pardossi *et al.*, 2011).

Toxicity of plants growing in cocopeat substrates as a result of salinity is one of the challenges of using cocopeat for growing plants. The salinity must therefore be

observed prior to and during the production cycle of plants (Meerow, 1994). In order to address the challenges of cocopeat toxicity to plants and to make it suitable for use as a growing medium, there is the need to wash several times in fresh water or add calcium nitrate to displace harmful concentrations of sodium and potassium (Nichols, 2013; Poulter, 2014).

2.15.2 Carbonated rice husk

Rice husk also refer to as rice hulls is the outermost layer covering the rice grain, a by-product of the rice milling industry and commonly accounts for about 20 % of the whole rice grains (Esa *et al*. 2013). In Ghana, 164,726 and 14,475 metric tons of rice straw and rice bran were produced in 1994 respectively (Sawyerr, 1994). Tettey and Mahu (2011) stated that the available rice husk produced in tons by Kpong Irrigation Project, Prairie Volta Ltd and Brazil Agro Business among others is 1,117.10, 2,304.00 and 3,916.80 metric tons respectively.

Rice husk is generally seen as a useless rice by-product by many rice millers and farmers (Ebara, 2005). Currently most of these rice producing projects in the country as well as other small holder farmers into rice cultivation dispose – off rice husk from the mill through open burning leading to air pollution (Issaka *et al*., 2012).

Burning rice husk generates rice husk ash and if the burning process is incomplete, carbonized rice husk is produced. Studies has shown that these incomplete burnt rice husk known as carbonated rice husk can be used for different purposes (Pablico, 2003). The carbonization process of rice husk has many advantages such as improving the water holding capacity, sterilize the media as well as addition of carbon (Oshio *et al.*, 1981). Biomass experts at PhilRice (Philippine Rice Research Institute)

have perfected the carbonization process and are able to develop a low-cost equipment for rice hulls not just for local use but also for export (Pablico,2003).

Rice husk is cheap and locally available, granular in composition, does not dissolve in water, is stable and has high mechanical strength (Awang *et al*. 2009). Carbonated rice husk is very light in weight, uniform in quality with a micro-porous structure, resistant to decomposition, allow drainage of water and has a bulk density of about 0.150g cm^{-3} (Haefele *et al*., 2009, Hartman *et al*.,1997). Carbonated Rice Husk (CRH) contain plant macro nutrients like phosphorus, potassium, calcium, magnesium and other micronutrients essential for the production of crops. CRH also contains silica that infuriates insects and other pests (Tanguinod, 2002). Also rice straw and rice husk have been known to be very rich in cellulose (Datta and Chakravarty, 2001; Obodai *et al*., 2003). CRH helps to increase the pH of soil, thus increasing available phosphorus (P), increase the levels of exchangeable potassium (K) and magnesium (Mg) (FFTC, 2001).

CRH is an agricultural waste material that causes severe environmental challenges. However it had been utilized as a medium or as a soil amendment for the production of crops (Anda, 2006). The utilization of rice husk as an organic nourishment is vital as it plays the function of improving soil physical properties, nutrition and water holding capacity (Solimann *et al*., 1990). Investigations have proven that rice husk have been used in media trials as an alternative to peat and peat/perlite mixes in the production of crops (Jarahian, 2010). Rice husk can be used as mulch, compost or mixed with soil to improve the water holding capacity and improve aeration for high yield and good quality crop production (Hirschey, 2003). Smith (2009), stated that the best organic way to amend a clay soil in order to loosen it, provide organic matter,

retain water and nutrients that improve crop growth and development was to use rice husk.

Even though CRH is of low production cost, the microanalysis of rice husk reveals that C (37 %), ash (20 %) and the main components of the ash is SiO^2 (94 %) can act as an sorbent for nutrients due to its high content from silica (Aly 1992, Tran *et al*. 1999)

2.15.3 Palm Fibre

Oil Palm Biomass (OPB) is a waste regularly obtained from of replanting or pruning processes of oil palm (Alam *et al*. 2009). These include the fronds, empty fruit bunch and the trunk which accounts for 70%, 10% and 5% respectively of the total biomass (Ratnasingam 2011).

Oil palm waste produces considerable ecological difficulty when abandoned on the fields (Abdul Khalil 2004). Felled palm trunks due to replanting activities signify one of the most important biomass sources (Sumathi *et al.*, 2008; Shuit *et al*., 2009). Unfortunately, most of these trunks are burned at the plantation site for faster disposal causing environmental pollutions and bush fires (Tay *et al.*, 2013). According to researchers, these residues can be used as renewable materials and by–products thereby helping to reduce their adverse effect on the environment such as pollution (Sulaiman *et al*. 2011, Sumathi *et al*. 2008).

These residues can be used as a soilless media for the production of plants since they have physical and chemical properties suitable for the growth and development of plants, and more over available and at little or no cost (Mohammadi-Ghehsareh *et al.* 2011). Chemical elements of the biomass differ as a result of their origins and types

(Chew and Bhatia 2008). The oil palm biomass comprised of cellulose, hemicellulose, lignin and ash (Raveendran *et al.*1995, Meier and Faix 1999; Demirbaş 2000).

Palm Fibre (PF) mixed with Sewage Sludge (SS) at volume rate of 1 PF to 1 SS was used as a substrate for soilless cucumber production (Ahmed *et al.*, 2013). Ghehsareh *et al*. (2012) disclosed that when date-palm leafs is used as substrate for cultivation of cucumber, superior biomass weight, Leaf Area Index (LAI) and root weight were achieved. According to Ahmed *et al*. (2013), physical properties such as total porosity, bulk density, moisture content, rate of drainage and chemical characteristics like pH and electrical conductivity of the PF substrate were relatively positive for cucumber plant growth, development and fruit production of cucumber in the PF substrate mix and was 40% higher than the control.

2.15.4 Substrate mix

In general, seedlings are grown in various types of substrates with different physical and chemical properties which affect the root zone of the crop (Shah *et al.*, 2006). Different substrates are utilized to accomplish the right equilibrium of aeration and water holding capacity for good growth and development of the plants (Nair *et al.*, 2011). Various substances have been employed to create growth substrate for the production of vegetable and the materials used differ throughout the world as a result of local accessibility (Schmilewski, 2009). These substances are inorganic or organic and are frequently prepared from a blend of different raw materials in order to attain the accurate balance of air and water holding capacity for good plant growth, development and for the long-term stability of the medium (Bilderback *et al.*, 2005; Nair *et al.*, 2011). A study has shown the possible boost in the amount of water held by a growth media when cocopeat is included (Hernández-Apaolaza, *et al.*, 2005).

There is no universal substrate or mixture but any organic or inorganic material to be used as substrate mix must support the plant, provide air, water, nutrients to the roots, must be free from pathogens and should not be phytotoxic **(**Di Lorenzo, *et al.* 2013**)**.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Experimental site

The experiment was carried out under an envirodome greenhouse condition located at the University of Ghana Forest and Horticultural Crops Research Centre (FOHCREC), Okumaning near Kade, in the Denkyembour district (formally Kwaebibrem district) of the Eastern Region of Ghana. The centre is located in the semi-deciduous forest agro-ecological zone of Ghana and lies at latitude 6º 09 and 6º 06 N and longitude 0º 55 and 0º 49 W and 135.9 m above sea level.

3.1.2 Climate

The climate of the area is humid tropical. The monthly average minimum temperature is about 25-26 ^{0}C, in July/August with an average maximum monthly temperature of about 28 – 29 ^{0}C, in February and March. The rainfall pattern is bi-modal with peaks 150 – 200 mm May/June and September/October. There is a brief dry spell in August and the dry season is from December to March. The highest relative humidity of 75% to 80% was recorded during the major rainy season whilst the lowest of 65% to 75% were recorded in the minor rainy season. The potential evapotranspiration varies between 3 mm daily in the rainy season to 5 mm in the dry season and may reach an annual value of 140 mm. Table1 shows the temperature and humidity conditions that prevailed in the greenhouse during the experimental period (October, 2016 to March, 2017).

Table 1: Greenhouse temperature and humidity values during the experimental period (October, 2016 to March, 2017).

MONTH	TEMPERATURE (°C)		HUMIDITY (%)	
	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
October, 2016	28.3	36.9	45.1	75.9
November, 2016	28.8	35.0	44.8	76.9
December, 2016	28.3	34.6	46.4	61.4
January, 2017	28.2	33.4	34.5	61.8
February, 2017	27.8	35.2	38.2	63.7
March, 2017	31.1	36.8	28.7	51.1

Source:FOHCREC, Okumaning

3.2 Experimental Material

3.2.1 Inputs

Kenzo 2 and Darina mix cucumber seeds were purchased from Agriseed Ltd and Louis Dreyfus Commodities Ghana Ltd respectively for the study. The Accra Compost And Recycling Plant Ltd organic compost was procured from the Ashaiman Irrigation Farmers Cooperative Society. NPK (19-19-19) and Potassium Nitrate inorganic fertilizers were acquired from Dizengoff Ghana Ltd and Agrimat Ltd respectively. Topcop and Trimangol 80WP fungicides used for the experiment were purchased from Dizengoff Ghana Ltd and Chemico Ltd respectively whilst natural oil and Protect insecticides were bought from Dizengoff Ghana Ltd and Chemico Ltd respectively.

3.2.2 Sources of substrates materials and preparation

Cocopeat used for the study was purchased from Fibrewealth Ltd at Adjei Kojo near Ashaiman in the greater Accra Region.

Rice husk was obtained from a rice mill at Kade and carbonated. The carbonization of the rice husk was done by setting up fire on a concrete floor. An open-end drum with perforations was placed on the fire and a quantity of rice husk was piled around the hot drum with the aid of a shovel. The rice husk was turned every 30 minutes to ensure uniformity in its final colour (black). As the rice husk turned black it was frequently turned over to prevent it being burnt to ashes, until it was finally charred. The hot carbonated rice husk was cooled by applying water to it and later bagged.

Palm fibre was taken from decaying axils and trunks of oil palm trees located at the FOHCREC, Kade. The palm fibre was sterilized by heat method. This was done by setting fire under an old bath filled with the palm fibre for about 45 minutes.

The soil used as a control is classified as the forest Ochrosol Great Soil by the Ghanaian soil classification system and was collected from FOHCREC, Kade.

3.3 Experimental details

Two experiments were conducted in an envirodome greenhouse. The collection/ purchasing of substrate, substrate preparation and the filling of troughs were done prior to the experiments. The first experiment began in October, 2016 and ended in December, 2016. The second experiment commenced in January 2017 and ended in March, 2017.

3.4 Experimental design, Treatments and replication

The design used was 2 x 6 factorial laid out in Randomized Complete Block Design (RCBD). This involved two (2) varieties of cucumber and six (6) substrates made up

of three soilless substrates and their mixtures in the ratio of 1:1 by volume and soil. In all, the total number of treatments was twelve (12) and replicated three (3) times.

Table 2: Substrates and substrate codes.

Substrate	Substrate Code
Cocopeat	C
Palm fibre	PF
Carbonated rice husk	CRH
Palm fibre+ Carbonated rice husk	PF+CRH
Cocopeat + Palm fibre	C+PF
Soil	So

3.5 Substrate analysis

Physical and chemical characteristics of the substrates were carried out at the FOHCREC Science Laboratory and at the Department of Soil Science Laboratory of the University of Ghana, Legon respectively.

The physical analysis conducted on the substrates was the Bulk Density (BD) and Water Holding Capacity (WHC). The pH and the Electrical Conductivity (EC) were also done at FOHCREC. Organic Carbon (OC), Nitrogen (N), Phosphorus (P) and Potassium (K) were also some of the chemical analysis carried out at the Department of Soil Science Laboratory of the University of Ghana.

3.5.1 Bulk density

The bulk density of the substrates was determined using the container method a week after preparation. An empty container (500 ml) was weighed using a digital balance. The container was then filled with substrate and slightly compressed to ensure the

absence of large void spaces. The filled container with substrate was then weighed. The bulk density of the samples was calculated by subtracting the weight of the empty container (W1) from the weight of the container plus sample (W2) and the result divided by the volume of the container (V).

3.5.2 Water holding capacity

The submerged method of determining water holding capacity of growth media was used. A 1 L pot with five (5) perforations about 1cm above the bottom was filled with substrate and measured quantity of water was gently added. A basin was placed under the pot to collect the drained water and the setup was left for 24hours. The volume of water collected in the basin after 24 hours was determine and recorded. The Water Holding Capacity (WHC) of the substrate samples were then computed by subtracting the volume of the drained water from the total volume of water added to the sample in the pot.

3.5.3 pH of substrates

The pH of the substrates was determined using the distilled water method (White, 1969). This was done by weighing 10g of air dried substrate into 50ml beakers and 50ml of distilled water was added to each of the beakers containing the different substrate samples. The suspensions were then stirred for 15-20 minutes using magnetic stirring rod. The pH of the suspensions was then measured using an electrometric pH meter after 10 minutes when almost all the substrate particles had settled.

3.5.4 Electrical conductivity (EC)

The Jenway conductivity meter was used to measure the electrical conductivity of the substrates using the sample suspensions prepared for the pH determination.

3.6 Greenhouse operations

3.6.1 Nursery operations

Cells of seedling trays were filled with substrate after which seeds were sown and watered. The trays were then covered with plain sheet of paper to conserve moisture particularly at the surface. The pieces of paper were removed as soon as seed emergence began. A total of 500 each of Kenzo 2 and Darina mix seeds were grown. A starter solution of 1g/L of NPK (19:19:19) was applied 7 days after germination. The pH of the solution was determined before application.

3.6.2 Transplanting

Transplanting of seedlings was done 10 days after sowing. A total of 864 seedlings consisting of 432 of each variety were transplanted according to the different treatments in troughs (50cm x 50 cm) filled with the respective substrates. Seedlings were transplanted 30cm apart.

3.6.3 Nutrient management and Irrigation (Fertigation)

Agrodynamics recommendation for soilless media was used. NPK 19:19:19 was applied at EC of 1.2 mS/cm, 1.8 mS/cm and 2.2 mS/cm at 2 - 10 DAT, 14 – 21 DAT and 25 - 50 DAT respectively. KNO3 (20%) + NPK (80%) applied at an EC of 2.2 mS/cm at flowering through fruiting to harvest. Plants were irrigated in the greenhouse using the gravity drip irrigation system which is part of the environdome greenhouse setup.

3.6.4 Crop protection (Pest and disease control)

Topcop with sulphur and copper sulphate as active ingredients and having fungicidal, bactericidal and miticidal properties was foliar applied at a rate of 10mL/L. Trimangol 80WP and natural oil was also applied to control diseases and pests. In addition, Protect, a botanical insecticide with enamectin benzoate as the active ingredient was applied at the rate of 2 mL/ 3L water to control incidence of white flies and other insects when necessary.

3.6.5 Trellising

Cucumber plants were trellised using rope to offer support to the plants. This was done by tying a string lightly on the cucumber plant and then gently twining the string around the plant to avoid snapping the stem early after transplanting in order to reduce plant damage. Supporting the crop permits air circulation, reduces the relative humidity and thus reducing disease incidences. Trellising also ensured that plants were upright, facilitated light interception, aided agronomic practices and ensured quality of fruits.

3.6.6 Pruning

A weekly scouting was done and unwanted vines and leaves were pruned. This was to allow for free ventilation and translocation of nutrients to developing flowers and fruits.

3.7 Data Collected

Data were collected on the following parameters: growth parameters, yield parameters and quality attributes.

3.7.1 Temperature and relative humidity

Daily minimum and maximum temperature and relative humidity were recorded using a thermo hydro meter throughout the experiment.

3.7.2 Growth indices

Measurement of growth parameters such as plant height, stem girth, number of leaves, leaf area and chlorophyll content were done at 2, 4 and 6 weeks after transplanting (WAT). Ten (10) plants per treatments were used for the recording of the growth parameters. On the, 5^{th} and 7^{th} WAT, data on root length, fresh and dry weights of shoot and root as well as the shoot –root ratio were determined. Secondary response variables (growth analysis) were also calculated using the dry matter weights of the plants. These included Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Specific Leaf Area (SLA), Leaf Area Ratio (LAR) and Leaf Weight Ratio (LWR).

Plant Height - Plant height (cm) was measured from the soil level to the apical tip of the plant.

Stem girth - Stem girth (mm) was measured with a pair of vernier calliper at 1cm from the substrate level.

Number of leaves - The number of leaves was determined by counting all fully opened leaves on the plants.

Chlorophyll Content - Chlorophyll content ($\mu mol.m^{-2}$) of leaves was determined using the chlorophyll meter (Minolta Model SPAD-502). These readings were done both at the vegetative and reproductive growth phases of the plant.

3.7.3 Plant dry matter

Four plants per treatment two each at vegetative and reproductive stages were used for the plant dry matter determination. The plants were uprooted gently from the various growing substrate and the roots washed to remove excess media on them. Water was removed from the roots by using a piece of cloth to dry them. The plants were then separated into leaves, roots, stem and their fresh weights determined using weighing scale. The samples were oven dried at 70 ^{O}C for 72 hours and the corresponding dry weights determined.

Mean leaf area - Five leaves per plant were chosen from different parts of the plant at random and the leaf area determined by the cork borer method.

Root length - Plants used for the determination of dry matter were the same used to determine the root length and this was done by placing the root on a meter rule and the length measured.

Determination of shoot: root ratio - The shoot: root ratio was determined as the ratio of shoot dry weight/ root dry weight.

Relative Growth Rate (RGR) - The following formula was used to calculate the RGR.

$$RGR = \frac{\log_e W2 - \log_e W1}{T2 - T1}$$

Where, W1 and W2 are whole plant dry weight at vegetative and reproductive stages respectively. T1 and T2 are days plant destructive samples were done at vegetative and reproductive stages after transplanting respectively.

Net Assimilation Rate (NAR) - Net Assimilation Rate (NAR) was calculated by using the formula.

$$NAR = \frac{(W2 - W1)}{(T2 - t1)} \times \frac{(\log_e A2 - \log_e A1)}{(A2 - A1)}$$

Where, W1 and W2 are whole plant dry weight at vegetative and reproductive stages respectively. T1 and T2 are days plant destructive samples were done at vegetative and reproductive stages after transplanting respectively. A1 and A2 are leaf areas at vegetative and reproductive stages respectively.

Leaf Weight Ratio (LWR) - The LWR was calculated using the formulae below.

$$LWR = \frac{\text{Leaf dry weight}}{\text{Plant dry weight}}$$

Specific Leaf Area (SLA) - The formula below was used to determine the SLA.

$$SLA = \frac{\text{Leaf area}}{\text{Leaf weight}}$$

Leaf Area Ratio (LAR) - The LAR was calculated using the formulae below.

$$LAR = \frac{\text{Leaf area per plant}}{\text{Plant dry weight}}$$

3.7.4 Yield and yield attributes

Number of fruit /Plant - Average number of fruits per plant was calculated by dividing the total number of fruits harvested from the tagged plants by the total number of tagged plants.

Weight of fruit /Plant (kg) - An electronic weighing scale was used to weigh all harvested fruits per treatment and the average calculated.

Fruit Diameter (cm) - Diameter was measured from ten (10) randomly sampled fruits per treatment. A pair of calliper was used to measure the diameter at the centre of the fruit.

Fruit Length (cm) - Fruit length was measured from ten (10) randomly sampled fruits per treatment. A flexible measuring tape was used to measure the length of fruits.

Yield (t/ha) - This was calculated by multiplying the weight of the fruit (kg) by the plant population per hectare and dividing by 1000.

3.7.5 Fruit quality determination

The quality attribute analysis of the samples was done at FOHCREC Laboratory, Kade. Total Soluble Solids (TSS) content, moisture and dry matter were the parameters for the quality determination.

Total Soluble Solids - About 1 g of the cucumber juice was placed on the lens of digital refractometer (ATAGO N1, Japan) and the value was read and recorded

Total dry matter - The dry matter of the fruits was determined using weighing scale after they were oven dried at 70 ^{O}C for 72 hours.

Total moisture - The moisture content of the fruits was determined by the formula.

Moisture content = Fresh fruit weight – Dry fruit weight

3.7.6 Cost Benefit Analysis

In order to evaluate which of these treatments was most profitable, the economics of individual treatment was worked out at prevailing input and output rates in the market. Profit was calculated as: Profit = Revenue - Cost.

3.8 Statistical Analysis

Treatment effects were subjected to Analysis of Variance (ANOVA) using Genstat 12th edition statistical package. Treatment means which were significantly different at $P < 0.05$ were separated by the Least Significant Difference (LSD) tests.

CHAPTER FOUR

4 RESULTS

4.1 Physical and chemical characteristics of substrates

4.1.1 Physical characteristics of substrates

The physical characteristics of substrate components and their mixtures are shown in Table 3. The highest bulk density was recorded by soil (1.2), followed by palm fibre (0.9) and the carbonated rice husk had the least (0.1) bulk density. The highest water holding capacity was recorded in the palm fibre – carbonated rice husk mixture substrate (87.5) followed by soil (77.5). Cocopeat – palm fibre mixture and palm fibre recorded 73.8 and 70.0 respectively whereas the least was measured in carbonated rice husk (45.0).

Table 3: Physical characteristics of substrate components and their mixtures

Substrate	Bulk density (g/cm^3)	Water holding capacity. (%)
Cocopeat	0.2	50.0
Palm fibre	0.9	70.0
Carbonated Rice Husk	0.1	45.0
Cocopeat + Palm fibre	0.6	73.8
Palm fibre + Carbonated Rice Husk	0.5	87.5
Soil	1.2	77.5

4.1.2 Chemical characteristics of substrates

Table 4 indicates the chemical characteristics of substrate components and their mixtures. The results in the table indicate that C + PF substrate had the highest pH

followed by So whereas the lowest pH was recorded in C substrate. Electrical Conductivity (EC) was observed to be highest in C followed by S and the lowest EC was recorded in PF substrate. Carbonated rice husk substrate recorded the highest organic carbon content followed by cocopeat substrate and the lowest content of organic carbon was recorded in the soil. Cocopeat had the highest nitrogen content of 0.87. This was followed by carbonated rice husk (0.74) and the soil recording the lowest nitrogen content of 0.23. Phosphorus content was highest in carbonated rice husk (0.08) followed by cocopeat (0.07) with palm fibre having the least phosphorus content. Cocopeat substrate recorded highest potassium content. This was followed by carbonated rice husk and cocopeat – palm fibre mixture had the same value of 0.27 and palm fibre had the lowest content of potassium.

Table 4: Chemical characteristics of substrate components and their mixtures

SUBSTRATE	pH	EC(mS/cm)	OC (%)	N (%)	P (%)	K (%)
C	6.08	1.26	32.48	0.87	0.07	0.32
PF	6.64	0.17	3.00	0.27	0.02	0.24
CRH	6.49	0.40	34.17	0.74	0.08	0.27
C + PF	6.94	0.19	10.73	0.50	0.04	0.27
PF + CRH	6.59	0.29	8.31	0.34	0.03	0.25
So	6.77	1.13	1.63	0.23	0.04	0.26

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **pH**= Power of Hydrogen, **EC**= Electrical Conductivity, **OC**= Organic Carbon, **N**= Nitrogen, **P**=Phosphorus, **K**=Potassium.

4.2 Cucumber plant growth indices

4.2.1 Mean plant height of different cucumber varieties in different substrates and their interaction at 2, 4 and 6 WAT.

Table 5 and 6 show plant height of different cucumber varieties in different substrates and their interaction at 2, 4 and 6 WAT during Experiment 1 and 2 respectively.

Substrate effect: At 2 WAT during Experiment 1, the tallest plant height was recorded in PF (61cm) followed by C+PF (60.6 cm) and CRH (56.6 cm). PF (142.2 cm and 248.0 cm) recorded the highest height followed by C (136.6 cm and 246.6 cm) and PF + CRH (131.9 cm and 240.9 cm) at 4 and 6 WAT respectively. There was however no significant difference between them. Cucumber plants grown in CRH substrate had the least recorded heights at 4 WAT (104.7 cm) and 6 WAT (199.5 cm).

Variety effect: The results from experiment 1 show that mean plant height of Kenzo and Darina cucumber varieties were significantly different ($p<0.05$) at 2 WAT but not at 4 and 6 WAT. Kenzo (57.0 cm) variety was significantly ($p<0.05$) taller than Darina (51.2 cm) at 2 WAT (Table 5). In experiment 2, Kenzo cucumber variety was significantly taller than Darina at 4 WAT. There was no significant ($p>0.05$) difference among the varieties at 2 and 6 WAT (Table 6).

Interactive Effect: There was no interaction between substrate and variety from experiment 1 but interaction was observed at 4 and 6 WAT during experiment 2 (Table 6). Kenzo in PF recorded the highest plant height of 155.3 cm and 251.5 cm at 4 and 6 WAT respectively (Table 6). At 6 WAT, Kenzo grown in PF (251.5 cm) produced the tallest plants but was not significantly taller than Darina grown in C (251.3 cm), PF+CRH (248.3 cm), PF (242.5 cm) and C+PF (239.7 cm). Darina

cucumber variety grown in CRH (91. 5 and 182.1 cm) substrate recorded the shortest plant at both 4 and 6 WAT respectively during experiment 2 (Table 6).

Table 5: Mean plant height (cm) of different cucumber plant varieties in different substrate and their interaction at 2, 4 and 6 WAT (Experiment 1)

WAT	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
2	Kenzo	45.0	62.9	60.7	61.5	60.4	50.5	**57.0**			
	Darina	38.6	59.1	52.4	49.8	60.9	46.4	**51.2**	7.6**	4.4*	NS
	Mean	**42.3**	**61.0**	**56.6**	**55.7**	**60.7**	**48.5**				
4	Kenzo	130.1	149.9	105.5	131.8	132.0	115.1	**127.4**			
	Darina	143.1	134.5	103.9	131.9	121.9	124.1	**126.6**	12.9**	NS	NS
	Mean	**136.6**	**142.2**	**104.7**	**131.8**	**126.9**	**119.6**				
6	Kenzo	235.5	244.4	194.0	240.4	229.9	221.3	**227.6**			
	Darina	257.6	251.6	204.9	241.3	236.5	228.5	**236.7**	17.8**	NS	NS
	Mean	**246.6**	**248.0**	**199.5**	**240.9**	**233.2**	**224.9**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **WAT**= Week After Transplanting, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 6: Mean plant height (cm) of different cucumber plant varieties in different substrate and their interaction at 2, 4 and 6 WAT (Experiment 2)

WAT	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
2	Kenzo	48.8	66.4	53.4	63.0	65.3	52.0	**58.2**			
	Darina	42.8	64.7	59.4	58.3	56.7	50.9	**55.5**	7.0**	NS	NS
	Mean	**45.8**	**65.6**	**56.4**	**60.7**	**61.0**	**51.5**				
4	Kenzo	125.9	155.3	112.1	139.7	128.8	118.5	**130.1**			
	Darina	135.1	132.1	91.5	136.7	123.3	121.1	**123.3**	11.7**	6.8*	16.6*
	Mean	**130.5**	**143.7**	**101.8**	**138.2**	**126.1**	**119.8**				
6	Kenzo	225.1	251.5	220.6	239.5	233.1	236.8	**234.4**			
	Darina	251.3	242.5	182.1	248.3	239.7	234.9	**233.1**	19.1**	NS	26.9*
	Mean	**238.2**	**247.0**	**201.4**	**243.9**	**236.4**	**235.9**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **WAT**= Week After Transplanting, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.2.2 Mean number of leaves of different cucumber varieties in different substrate and their interaction at 2, 4 and 6 WAT

Mean number of leaves per cucumber varieties in the different substrates and their interaction in experiment 1 and 2 are indicated in Table 7 and 8 respectively.

Substrate effect: The highest number of leaves per plant was recorded in C and PF at 2 WAT (6) and 4 WAT (12). Even though PF recorded 21 leaves at 6 WAT, it was not significantly different from C (19). CRH plants recorded the lowest number of leaves (17) at 6 WAT. In experiment 2, at 6 WAT, PF, PF + CRH and So produced the highest leaf number of 20 whilest CRH recorded the lowest number (16).

Variety effect: The result shows that mean number of leaves per Kenzo and Darina cucumber varieties were significant at 2, 4 and 6 WAT during experiment 1 (Table 7). At 6 WAT, Kenzo produced significantly ($p<0.05$) higher number of leaves than Darina (Table 7). In experiment 2 (Table 8), significant ($p<0.001$) difference were observed in varietal effect on mean number of leaves. The number of leaves produced per Kenzo plant was significantly ($p<0.001$) higher than Darina cucumber varieties at 6 WAT.

Interactive effect: There was no interaction between the substrate and the varieties at 2 and 6 WAT in experiment 1 as well as 2, 4 and 6 WAT in experiment 2. At 4 WAT during experiment 1(Table 7), interaction was observed and the highest number of leaves of 14 was recorded from Kenzo grown in PF whilst the lowest number (9) of leaves was produced by Darina grown in CRH and C+PF.

Table 7: Mean leaf number of different cucumber plant varieties in different substrate and their interaction at 2, 4 and 6 WAT (Experiment 1)

WAT	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
2	Kenzo	6	6	5	6	5	6	**6**			
	Darina	6	5	4	4	5	4	**5**	0.73**	0.42*	NS
	Mean	**6**	**6**	**5**	**5**	**5**	**5**				
4	Kenzo	12	14	11	12	12	12	**12**			
	Darina	11	10	9	10	9	10	**10**	0.83**	0.48**	1.18*
	Mean	**12**	**12**	**10**	**11**	**11**	**11**				
6	Kenzo	18	23	18	21	21	20	**20**			
	Darina	19	19	15	19	18	18	**18**	2.33*	1.35*	NS
	Mean	**19**	**21**	**17**	**20**	**19**	**19**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **WAT**= Week After Transplanting, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 8: Mean leaf number of different cucumber plant varieties in different substrate and their interaction at 2, 4 and 6 WAT (Experiment 2)

WAT	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
2	Kenzo	6	6	5	5	5	6	**6**			
	Darina	6	5	5	4	5	5	**5**	0.53**	0.31**	NS
	Mean	**6**	**6**	**5**	**5**	**5**	**6**				
4	Kenzo	12	15	11	13	13	12	**12**			
	Darina	11	11	8	11	10	10	**10**	1.20**	0.69**	NS
	Mean	**11**	**13**	**9**	**12**	**11**	**11**				
6	Kenzo	19	22	19	20	19	21	**20**			
	Darina	18	19	14	19	16	18	**17**	2.21*	1.28**	NS
	Mean	**19**	**20**	**16**	**20**	**17**	**20**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **WAT**= Week After Transplanting, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.2.3 Mean stem girth (mm) of different cucumber varieties in different substrate and their interaction at 2, 4 and 6 WAT

Mean stem girth of different cucumber varieties in different substrate and their interaction at 2, 4 and 6 WAT for experiment 1 and 2 are indicated in Table 9 and 10 respectively.

Substrate Effect: Significant difference ($p<0.05$) in plant girth were recorded at 2 and 4 WAT in both experiment. However there was no significant difference ($p>0.05$) at 6 WAT during both experiments. At 2 WAT during experiment 1, the highest recorded stem girth was in plants grown in C (0.38) and this was not significantly ($p>0.05$) higher than PF (0.35) substrates. Stem girth recorded in C (0.45) was not significantly ($p>0.05$) higher than PF (0.42) but was significantly ($p<0.05$) higher than the other substrates at 4 WAT (Table 9). During experiment 2, C and PF recorded the same value of stem girth (0.36) but were not significantly ($p>0.05$) higher than S (0.35) and PF+CRH (0.33) at 2 WAT. C + PF (0.31) and CRH (0.30) recorded significant lowest stem girth at 2 WAT. Significant difference were not observed among C, PF, C+PF and PF+CRH substrates at 4 WAT.

Variety Effect: The results show that mean stem girth of Kenzo cucumber varieties were significantly ($p<0.05$) higher than Darina cucumber variety at 6 WAT in both experiments (Table 9 and 10). There was however no significant difference ($p>0.05$) between the varieties at 2 and 4 WAT in both experiment (Table 9 and 10).

Interactive Effect: There were no interactions between substrate and variety with regards to stem girth in both experiments (Table 9 and 10).

Table 9: Mean stem girth (cm) of different cucumber varieties in different substrate and their interaction at 2, 4 and 6 WAT (Experiment 1)

WAT	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+PF	So	Mean	S	V	S x V
2	Kenzo	0.35	0.35	0.32	0.31	0.31	0.34	**0.33**			
	Darina	0.41	0.34	0.30	0.32	0.30	0.34	**0.34**	0.03*	NS	NS
	Mean	**0.38**	**0.35**	**0.31**	**0.31**	**0.31**	**0.34**				
4	Kenzo	0.46	0.43	0.39	0.40	0.41	0.41	**0.41**			
	Darina	0.44	0.41	0.37	0.40	0.40	0.39	**0.40**	0.04*	NS	NS
	Mean	**0.45**	**0.42**	**0.38**	**0.40**	**0.40**	**0.40**				
6	Kenzo	0.45	0.52	0.44	0.50	0.47	0.50	**0.48**			
	Darina	0.44	0.47	0.46	0.44	0.45	0.45	**0.45**	NS	0.02*	NS
	Mean	**0.45**	**0.50**	**0.45**	**0.47**	**0.46**	**0.48**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **WAT**= Week After Transplanting, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 10: Mean stem girth (cm) of different cucumber varieties in different substrate and their interaction at 2, 4 and 6 WAT (Experiment 2)

WAT	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+PF	S	Mean	S	V	S x V
2	Kenzo	0.35	0.38	0.31	0.32	0.31	0.35	**0.34**			
	Darina	0.38	0.34	0.30	0.33	0.30	0.35	**0.33**	0.03**	NS	NS
	Mean	**0.36**	**0.36**	**0.30**	**0.33**	**0.31**	**0.35**				
4	Kenzo	0.43	0.45	0.38	0.40	0.45	0.42	**0.42**			
	Darina	0.45	0.40	0.37	0.41	0.40	0.39	**0.40**	0.04*	NS	NS
	Mean	**0.44**	**0.43**	**0.37**	**0.41**	**0.43**	**0.41**				
6	Kenzo	0.46	0.49	0.46	0.51	0.50	0.50	**0.49**			
	Darina	0.44	0.46	0.42	0.42	0.43	0.48	**0.44**	NS	0.02**	NS
	Mean	**0.45**	**0.48**	**0.44**	**0.46**	**0.47**	**0.49**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **WAT**= Week After Transplanting, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.2.4 Chlorophyll content of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages

Substrate Effect: Chlorophyll content of cucumber leaves differed significantly among treatments in both vegetative and reproductive stages during experiment 1

(Table 11), at vegetative stage during experiment 2 but not significant at reproductive stage of experiment 2 (Table 12). The chlorophyll content of plants grown in So was not significantly ($p>0.05$) higher than PF at both vegetative and reproductive stages but was significantly ($p<0.05$) higher than C and PF+CRH during experiment 1.

Variety effect: The results show that mean chlorophyll content of Kenzo cucumber variety was significantly ($p<0.001$) higher than Darina cucumber variety in both experiment at the reproductive and vegetative stages (Table 11 and 12).

Interactive Effect: The interaction between substrate and variety was only significant ($p<0.05$) at the vegetative stage during experiment 1. Kenzo grown in PF (30.22) recorded the highest chlorophyll content but was not significantly ($p> 0.05$) higher than Kenzo grown in So (29.81). Darina grown in C+PF (16.44) recorded the lowest chlorophyll content but was not significantly ($p> 0.05$) lower than Darina grown in CRH (19.87) (Table 11).

4.2.5 Mean number of nodes of different cucumber varieties in different substrate and their interaction.

The mean number of nodes of different cucumber varieties in different substrate and their interaction for experiment 1 and 2 are reported in Table 11 and 12.

Substrate Effect: Type of substrate significantly ($p<0.001$) affected the number of nodes of cucumber plants during experiment 1 and 2. Cucumber plants grown in PF had significantly ($p<0.001$) highest nodes than cucumber plants grown in the other substrates in both experiment with plants in CRH having the least number of nodes.

Variety Effect: The different varieties did not significantly influenced the number of nodes during experiment 1 but were significant ($p<0.05$) at experiment 2. Although Kenzo cucumber variety recorded the highest number of nodes than Darina cucumber variety, there was however no significant difference between them.

Interactive Effect: Interaction between substrate and cucumber varieties was significant ($p<0.05$) at both experiment 1 and 2 (Table 11 and 12). During experiment 1, the highest number of nodes was recorded on Darina grown in PF (33) and Kenzo cucumber variety grown in PF (32). The interaction that gave the least node number were Kenzo grown in CRH (20) and Darina grown in C (Table 11). Darina grown in PF (31) produced the highest nodes whilest Darina in C (18) and Kenzo in CRH (19) recorded the least number of nodes during experiment 2 (Table 12).

Table 11: Mean chlorophyll content at vegetative and reproductive stages and number of nodes of different cucumber varieties in different substrate and their interaction (Experiment 1)

Growth paramater	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
Chlorophyll Content at Vegetative Stage	Kenzo	23.99	30.22	26.97	25.89	22.83	29.81	**26.62**			
	Darina	26.39	22.63	19.87	21.10	16.44	26.72	**22.19**	2.82**	1.63**	3.99*
	Mean	**25.19**	**26.43**	**23.42**	**23.50**	**19.64**	**28.27**				
Chlorophyll Content at Reproductive Stage	Kenzo	30.33	36.83	28.56	32.55	32.81	39.53	**33.44**			
	Darina	23.42	28.56	23.99	24.37	24.55	31.29	**26.03**	5.30*	3.06**	NS
	Mean	**26.88**	**32.70**	**26.28**	**28.46**	**28.68**	**35.41**				
Number of Nodes	Kenzo	28	32	20	27	27	28	**27**			
	Darina	21	33	24	26	24	24	**25**	2.51**	NS	3.55*
	Mean	**24**	**33**	**22**	**27**	**25**	**26**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 12: Mean chlorophyll content at vegetative and reproductive stages and number of node of different cucumber varieties in different substrate and their interaction (Experiment 2)

Growth parameters	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	So	V	S x V
Chlorophyl Content at Vegetative Stage	Kenzo	26.33	28.61	27.59	24.17	21.41	32.31	**26.74**			
	Darina	23.88	25.19	23.15	19.70	17.92	26.60	**22.74**	3.19**	1.85**	NS
	Mean	**25.11**	**26.90**	**25.37**	**21.94**	**19.67**	**29.46**				
Chlorophyl Content at Reproductive Stage	Kenzo	30.39	32.99	31.79	32.78	29.57	31.49	**31.50**			
	Darina	24.94	32.19	22.59	28.72	20.79	34.25	**27.25**	NS	3.76*	NS
	Mean	**27.67**	**32.59**	**27.19**	**30.75**	**25.18**	**32.87**				
Number of Nodes/ Plant	Kenzo	26	29	19	24	23	25	**24**			
	Darina	18	31	22	22	21	21	**23**	2.30**	1.33*	3.25**
	Mean	**22**	**30**	**21**	**23**	**22**	**23**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.2.6 Mean leaf area of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

Table 13 and 14 indicates data on the leaf area of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage for experiment 1 and 2 respectively.

Substrate effect: The type of substrate significantly affected the leaf area of the cucumber plants at both reproductive stages of experiment 1 and 2 (Table 13 and 14). However at the vegetative stage of experiment 1, significant differences were observed but was not significant at vegetative stage of experiment 2. The leaf area of the cucumber plants grown in So (102.15 cm^2) was not significantly ($p>0.05$) higher than the rest of the substrates except CRH (60.55 cm^2) at the vegetative stage but was significantly higher than the rest of the substrates at the reproductive stages of experiment 1.

Variety effect: The varieties affected the mean leaf area at both vegetative and reproductive stages during experiment 1 but did not affect the leaf area at both stages during experiment 2. The highest mean leaf area was recorded in the Darina cucumber variety and this was significantly ($p<0.05$) higher than the Kenzo cucumber variety during both vegetative and reproductive stages in experiment 1 (Table 13).

Interactive effect: Significant ($p<0.05$) interaction was observed between the substrate and the varieties at the reproductive stage during experiment 1 (Table 13). The highest leaf area was recorded by Darina grown in So (254 cm^2) and this was significantly ($p<0.05$) higher than the others. The lowest leaf area was recorded by Kenzo grown in C+PF(88.80), Darina cucumber varieties grown in PF + CRH (95.90) and C+PF (98.30). However, Darina grown in PF + CRH was not significantly different from Darina cucumber varieties grown in C+PF.

Table 13: Mean leaf area (cm^2) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 1)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+PF	So	Mean	So	V	S x V
Vegetative Stage	Kenzo	87.00	63.80	53.80	94.30	85.80	94.10	**79.80**			
	Darina	102.90	90.80	67.30	98.10	107.50	110.20	**96.13**	26.42*	15.26*	NS
	Mean	**94.95**	**77.30**	**60.55**	**96.20**	**96.65**	**102.15**				
Reproductive Stage	Kenzo	107.60	154.90	125.30	104.10	88.80	99.30	**113.33**			
	Darina	135.90	128.90	141.10	95.90	98.30	254.40	**142.42**	39.54*	22.83*	55.91*
	Mean	**121.75**	**141.90**	**133.20**	**100.00**	**93.55**	**176.85**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 14: Mean leaf area of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 2)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+CRH	C+PF	So	Mean	S	V	S x V
Vegetative Stage	Kenzo	340.90	241.10	271.90	300.50	274.70	203.80	**272.15**			
	Darina	306.20	315.80	254.80	297.00	339.60	317.50	**305.15**	NS	NS	NS
	Mean	**323.55**	**278.45**	**263.35**	**298.75**	**307.15**	**260.65**				
Reproductive Stage	Kenzo	141.30	117.80	97.40	126.60	78.20	147.00	**118.05**			
	Darina	139.10	108.50	123.40	115.00	115.60	253.90	**142.58**	50.31*	NS	NS
	Mean	**140.20**	**113.15**	**110.40**	**120.80**	**96.90**	**200.45**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.3 Cucumber plant biomass

4.3.1 Mean longest root length of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

Table 15 and 16 shows mean longest root length of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage for experiment 1 and 2 respectively.

Substrate effect: The mean longest root length of different cucumber plant varieties was not significantly affected by the substrates at the vegetative and reproductive stages for both experiment 1 and 2.

Variety effect: The type of variety did not significantly affect the root length of cucumber plants at both vegetative and reproductive stages of the experiment.

Interactive effect: Interaction was not observed between the substrates and the varieties in terms of root length of cucumber plants at both vegetative and reproductive stages during both experiments.

Table 15: Mean longest root length (cm) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 1)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+CRH	C+PF	So	Mean	S	V	S x V
Vegetative Stage	Kenzo	8.83	9.67	9.50	9.33	11.17	10.67	**9.86**			
	Darina	8.83	7.17	6.67	10.67	9.33	9.33	**8.67**	NS	NS	NS
	Mean	**8.83**	**8.42**	**8.09**	**10.00**	**10.25**	**10.00**				
Reproductive Stage	Kenzo	12.20	14.00	22.70	17.50	29.80	18.50	**19.12**			
	Darina	15.00	14.70	20.20	14.00	21.70	13.00	**16.43**	NS	NS	NS
	Mean	**13.60**	**14.35**	**21.45**	**15.75**	**25.75**	**15.75**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD** = Least Significant Difference, **NS** =means not significant at 5%.

Table 16: Mean longest root length (cm) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 2)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+PF	So	Mean	So	V	S x V
Vegetative Stage	Kenzo	10.33	12.50	9.50	9.67	9.67	11.83	**10.58**			
	Darina	13.17	9.00	6.67	9.67	9.33	9.83	**9.61**	NS	NS	NS
	Mean	**11.75**	**10.75**	**8.09**	**9.67**	**9.50**	**10.83**				
Reproductive Stage	Kenzo	14.50	13.50	22.80	20.70	26.80	15.30	**18.93**			
	Darina	16.60	11.50	20.80	20.70	22.00	17.20	**18.13**	NS	NS	NS
	Mean	**15.55**	**12.50**	**21.80**	**20.70**	**24.40**	**16.25**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD** = Least Significant Difference, **NS** =means not significant at 5%.

4.3.2 Mean plant dry weight of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

Table 17 and 18 represent the mean plant dry weight of different cucumber plant varieties in different substrate and their interaction at vegetative and reproductive stage for experiment 1 and 2 respectively.

Substrate effect: Substrate had significant effect on the dry plant weight of the cucumber plants at the vegetative stage of both experiments, but only at the reproductive stage of experiment 2. The highest total plant dry weight was recorded by C (2.06 g) but was not significantly ($p>0.05$) higher than So (2.04 g) and PF (1.98 g) at vegetative stage of experiment 1 (Table 17). During experiment 2, C, PF and S were not significantly different in terms of plant dry weight at the vegetative stage. Likewise, PF+CRH (15.21), C+PF (11.59) and C (11.13) were not significantly ($p>0.05$) different at reproductive stages whilst CRH recorded the lowest plant dry weight at both vegetative and reproductive stages of experiment 2.

Variety effect: The result indicated that the type of cucumber variety has no significant effect on the total plant dry weight.

Interactive effect: Significant ($p<0.05$) interaction was observed between the substrate and the varieties at the vegetative stages during experiment 1 (Table 17). The highest total plant dry weight was recorded in Darina grown in So (2.3). This was however not significantly ($p>0.05$) higher than Kenzo in C (2.22) and Darina grown in PF (2.10). The lowest dry plant weight was recorded in Kenzo grown in CRH (1.30), Darina grown in CRH (0.88) and C +PF (1.3) (Table 17).

Table 17: Mean plant dry weight (g) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 1)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
Vegetative Stage	Kenzo	2.22	1.87	1.30	1.60	1.50	1.78	**1.71**			
	Darina	1.90	2.10	0.88	1.83	1.30	2.30	**1.72**	0.31**	NS	0.44*
	Mean	**2.06**	**1.98**	**1.09**	**1.72**	**1.40**	**2.04**				
Reproductive Stage	Kenzo	10.04	13.80	11.54	10.34	9.24	7.75	**10.45**			
	Darina	14.61	7.66	7.97	8.35	7.86	8.11	**9.09**	NS	NS	NS
	Mean	**12.33**	**10.73**	**9.76**	**9.35**	**8.55**	**7.93**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 18: Mean plant dry weight (g) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment2)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	So	V	S x V
Vegetative Stage	Kenzo	2.25	2.38	1.40	1.65	1.50	1.88	**1.84**			
	Darina	2.42	1.97	0.98	1.90	1.40	2.22	**1.81**	0.51**	NS	NS
	Mean	**2.33**	**2.18**	**1.19**	**1.78**	**1.45**	**2.05**				
Reproductive Stage	Kenzo	12.88	9.01	7.68	17.44	10.73	6.77	**10.75**			
	Darina	9.37	11.19	7.54	12.97	12.44	9.88	**10.57**	4.09*	NS	NS
	Mean	**11.13**	**10.10**	**7.61**	**15.21**	**11.59**	**8.33**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.3.3 Mean shoot dry weight of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

The mean shoot weight of different cucumber plant varieties in different substrate and their interaction at vegetative and reproductive stage for experiment 1 and 2 are presented in Table 19 and 20 respectively.

Substrate effect: Results indicates that the substrate affected the shoot dry weight of the cucumber plants at the vegetative stage of both experiment and the reproductive stage of experiment 2. The highest shoot weight was recorded by C (1.98) but was not significant different from So (1.97) and PF (1.92) whilst CRH (0.98) recorded the lowest shoot dry weight at the vegetative stage of experiment 1 (Table 19). There was no significant different among C (2.28), PF (2.09) and So (1.99) whereas CRH (1.10) plants recorded the lowest shoot dry weight at the vegetative stage of experiment 2 (Table 20). Although there was no significant different between PF + CRH (15.09) and C+PF (11.35) at the reproductive stage of experiment 2, PF+CRH was significantly different from the other substrates. However there were no significant differences among C (10.86), PF (9.81) C+PF (11.35).

Variety effect: The result indicated that the type of cucumber variety has no significant effect on the shoot dry weight.

Interactive effect: Significant ($p<0.05$) interaction was observed between the substrate and the varieties at the vegetative stages during both experiments. The highest dry shoot weight was recorded by Darina grown in So (2.23) during experiment 1. This was however not significantly ($p>0.05$) higher than Kenzo grown in C (2.13) and Darina grown in PF (2.05). Both varieties recorded lowest shoot dry weight in CRH (Table 19). During experiment 2, the highest shoot dry weight was

recorded from Darina in C (2.35) but was not significantly higher than Kenzo grown in C (2.21) and PF (2.28) as well as Darina in S (2.17) and PF (1.90). The lowest dry shoot weight was recorded by Darina grown in CRH (0.93) and this was not significantly different from Kenzo grown in CRH (1.27).

Table 19: Mean shoot dry weight (g) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 1)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	So	V	S x V
Vegetative Stage	Kenzo	2.13	1.78	1.20	1.50	1.45	1.70	**1.63**			
	Darina	1.83	2.05	0.77	1.77	1.25	2.23	**1.65**	0.31**	NS	0.44*
	Mean	**1.98**	**1.92**	**0.98**	**1.63**	**1.35**	**1.97**				
Reproductive Stage	Kenzo	9.87	13.51	11.54	10.12	8.97	7.56	**10.26**			
	Darina	14.20	7.55	7.84	8.14	7.57	7.94	**8.87**	NS	NS	NS
	Mean	**12.04**	**10.53**	**9.69**	**9.13**	**8.27**	**7.75**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 20: Mean shoot dry weight (g) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 2)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
Vegetative Stage	Kenzo	2.21	2.28	1.27	1.60	1.68	1.82	**1.81**			
	Darina	2.35	1.90	0.93	1.83	1.45	2.17	**1.77**	0.49**	NS	0.69*
	Mean	**2.28**	**2.09**	**1.10**	**1.72**	**1.57**	**1.99**				
Reproductive Stage	Kenzo	12.62	8.70	7.44	17.39	10.53	6.61	**10.55**			
	Darina	9.10	10.91	7.24	12.79	12.16	9.65	**10.31**	4.09*	NS	NS
	Mean	**10.86**	**9.81**	**7.34**	**15.09**	**11.35**	**8.13**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD** = Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.3.4 Mean Leaf dry weight of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage.

Mean dry leaf weight of different cucumber plant varieties in different substrate and their interaction at vegetative and reproductive stage of experiment 1 and 2 are presented in Table 21 and 22 respectively.

Substrate effect: The substrates had a significant ($p<0.05$) effect on the leaf dry weight at the vegetative stage of both experiments. There was however no significant different ($p>0.05$) among C, So and PF during both experiments. CRH (0.60 and 0.68) plants recorded the lowest leaf dry weight in both experiments at the vegetative phase.

Variety effect: The results show that mean leaf dry weight of cucumber plants were not significantly ($p>0.05$) affected by the type of variety.

Interactive effect: There was no significant ($P>0.05$) interaction between the substrate and the varieties.

Table 21: Mean leaf dry weight (g) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 1)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
Vegetative Stage	Kenzo	1.10	1.07	0.73	0.85	0.90	1.02	**0.94**			
	Darina	1.07	1.18	0.47	0.78	1.07	1.33	**0.98**	0.19**	NS	NS
	Mean	**1.08**	**1.13**	**0.60**	**0.82**	**0.98**	**1.18**				
Reproductive Stage	Kenzo	5.13	7.99	6.93	7.08	5.59	4.54	**6.21**			
	Darina	6.16	3.29	5.05	5.59	4.32	4.79	**4.87**	NS	NS	NS
	Mean	**5.65**	**5.64**	**5.99**	**6.34**	**4.96**	**4.67**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 22: Mean leaf dry weight (g) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 2)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
Vegetative Stage	Kenzo	1.30	1.38	0.75	0.93	0.95	1.13	**1.07**			
	Darina	1.37	1.12	0.62	1.08	0.85	1.27	**1.05**	0.31*	NS	NS
	Mean	**1.33**	**1.25**	**0.68**	**1.01**	**0.90**	**1.20**				
Reproductive Stage	Kenzo	7.27	5.33	4.55	8.92	5.87	4.38	**6.05**			
	Darina	5.61	6.85	4.26	8.11	6.66	5.94	**6.24**	NS	NS	NS
	Mean	**6.44**	**6.09**	**4.41**	**8.52**	**6.27**	**5.16**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%

4.3.5 Mean root dry weight of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

The mean root dry weight of different cucumber plant varieties in different substrate and their interaction at vegetative and reproductive stage are presented in Table 23 and 24 respectively.

Substrate effects: At the reproductive stage of experiment 1, C+PF (1.22) recorded significantly ($p<0.05$) highest mean root dry weight compared to the other substrates whilst CRH (0.51) had the lowest (Table 23).

Variety effect: The highest mean root dry weight was recorded in the Kenzo cucumber variety but was not significantly ($p<0.05$) higher than the Darina cucumber variety (Table 23).

Interactive effect: Data in Table 24 indicates that substrate and variety interaction has a significant effect on the mean root dry weight of the cucumber plants at the vegetative stage of experiment 2. Kenzo cucumber variety grown in PF (0.13) and

CRH (0.13) recorded significantly ($p<0.05$) higher mean root dry weight than the other interactions. Kenzo grown in C (0.04) had the less root dry weight although it was not significantly different from Kenzo grown in PF + CRH (0.05), Darina grown in CRH (0.05), C + PF (0.05) and So 90.05).

Table 23: Mean root dry weight (g) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 1)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	SxV
Vegetative Stage	Kenzo	0.08	0.08	0.10	0.08	0.05	0.08	**0.08**			
	Darina	0.07	0.05	0.12	0.07	0.05	0.07	**0.07**	NS	NS	NS
	Mean	**0.08**	**0.07**	**0.11**	**0.08**	**0.05**	**0.08**				
Reproductive Stage	Kenzo	0.54	0.68	0.45	0.50	1.15	0.87	**0.70**			
	Darina	0.73	0.61	0.58	0.54	1.30	0.67	**0.74**	0.35*	NS	NS
	Mean	**0.63**	**0.64**	**0.51**	**0.52**	**1.22**	**0.77**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD** = Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%

Table 24: Mean root dry weight (g) of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 2)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
Vegetative Stage	Kenzo	0.04	0.13	0.13	0.05	0.07	0.07	**0.08**			
	Darina	0.07	0.07	0.05	0.07	0.05	0.05	**0.06**	0.03*	0.02*	0.04*
	Mean	**0.06**	**0.10**	**0.09**	**0.06**	**0.06**	**0.06**				
Reproductive Stage	Kenzo	0.93	0.82	0.60	0.81	0.91	0.82	**0.82**			
	Darina	0.70	0.69	0.76	0.96	1.18	1.02	**0.88**	NS	NS	NS
	Mean	**0.82**	**0.75**	**0.68**	**0.89**	**1.05**	**0.92**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD** = Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%

4.3.6 Mean shoot/root of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

Data on the mean shoot/root ratio of cucumber varieties in different substrate and their interaction at vegetative and reproductive stage of experiment 1 and 2 are presented in Table 25 and 26 respectively.

Substrate effect: The result indicates that the substrates affected the mean shoot/root ratio of the cucumber plants at the vegetative stage in experiment 2 and reproductive stage in both experiments. Cucumber plants in C (45.5) recorded the highest shoot/root ratio but this was not significantly ($p>0.05$) higher than So (37.05) and PF+CRH (31.50) with the CRH (15.00) recording the lowest at the vegetative stage of experiment 2 (Table 26). At the reproductive stage of experiment 1 (Table 25), CRH (20.99) recorded the highest shoot/root ratio but this was not significantly ($p>0.05$) higher than C (19.23), PF+CRH (19.14), PF (16.98) and C (19.23). Shoot/ root ratio of plants in PF+CRH (17.49), PF (14.58) and C (13.28) were not significantly different at the reproductive stage of experiment 2 (Table 26).

Variety effect: The results show that variety had a significant effect on the shoot/root ratio of cucumber plants at the reproductive stage of experiment 1 (Table 25). However no significant difference was recorded between Kenzo and Darina cucumber varieties.

Interactive effect: Substrate and variety interaction was not significant ($p>0.05$) with regard to shoot/root ratio during both experiments.

Table 25: Mean shoot: root ratio of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 1)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+PF	So	Mean	S	V	SxV
Vegetative Stage	Kenzo	31.10	26.10	13.80	19.80	29.00	23.70	**23.92**			
	Darina	31.30	41.00	12.10	28.20	25.00	38.80	**29.40**	NS	NS	NS
	Mean	**31.20**	**33.55**	**12.95**	**24.00**	**27.00**	**31.25**				
Reproductive Stage	Kenzo	19.04	19.57	27.11	21.59	10.06	8.99	**17.73**			
	Darina	19.41	14.38	14.87	16.68	5.96	11.81	**13.85**	6.80*	3.93*	NS
	Mean	**19.23**	**16.98**	**20.99**	**19.14**	**8.01**	**10.40**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 26: Mean shoot: root ratio of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 2)

Growth stage	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+PF	So	Mean	S	V	SxV
Vegetative Stage	Kenzo	54.00	18.10	11.30	32.00	26.50	30.80	**28.78**			
	Darina	37.00	32.20	18.70	31.00	29.00	43.30	**31.87**	15.00*	NS	NS
	Mean	**45.50**	**25.15**	**15.00**	**31.50**	**27.75**	**37.05**				
Reproductive Stage	Kenzo	13.63	11.12	12.97	21.43	11.71	7.97	**13.14**			
	Darina	12.92	18.04	11.10	13.55	10.19	9.87	**12.61**	4.76*	NS	NS
	Mean	**13.28**	**14.58**	**12.04**	**17.49**	**10.95**	**8.92**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.4 Growth Analysis of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

4.4.1 Leaf area ratio of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

Leaf area ratio of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage of experiment 1 and 2 are specified in Table 27 and 28 respectively.

Substrate effect: The type of substrate significantly affected the leaf area ratio of the cucumber plants at the vegetative stage of experiment 2 and at the reproductive stage of both experiments. At the vegetative stage, CRH (274.0) recorded the highest leaf area ratio but was not significantly ($p<0.05$) different from C+PF (227.0). At the reproductive stage, highest leaf area ratio was recorded in S (23.5) during experiment 2 and this was significantly higher ($p<0.05$) than the rest of the substrates (Table 28).

Variety effect: Leaf area ratio was significantly affected ($p<0.05$) by the varieties at the vegetative and reproductive stages during experiment 1. Darina cucumber variety produced significantly ($p<0.05$) higher leaf area ratio than Kenzo at both vegetative and reproductive stages.

Interactive effect: Significant ($p<0.05$) interaction was observed between the substrate and the varieties at the reproductive stage of experiment 1 (Table 27). The Darina cucumber variety grown in So (32.2) recorded the highest leaf area ratio followed by Darina in CRH (17.91) and PF (17.6).The lowest leaf area ratio was recorded in Kenzo grown in C+PF (9.12).

4.4.2 Leaf weight ratio of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

Data on the mean leaf weight ratio of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages during experiment 1 and 2 are indicated in Table 27 and 28 respectively.

Substrate effect: The type of substrate significantly ($p<0.05$) affected the leaf weight ratio of cucumber plants at the reproductive stage during experiment 1 (Table 27). PF+CRH recorded the highest mean leaf weight ratio of 0.7 and this was significantly ($p<0.05$) different from all the other treatments.

Variety effect: Kenzo cucumber variety produced significant ($p<0.05$) higher leaf weight ratio (0.6) than the Darina cucumber plant (0.5) during the reproductive stage of experiment 1 (Table 27).

Interactive effect: There was no significant ($p>0.05$) interaction between the substrate and the varieties with regard to mean leaf weight ratio.

4.4.3 Specific leaf area of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stage

Specific leaf area of different cucumber plant varieties in different substrate and their interaction at vegetative and reproductive stage of experiment 1 and 2 are shown in Table 27 and 28 respectively.

Substrate effect: The type of substrate significantly affected the specific leaf area of the cucumber plants at the vegetative stage of experiment 2 and at the reproductive stage of both experiments (Table 27 and 28). At the vegetative stage, CRH (274.0) recorded the highest specific leaf area but was not significantly different from C+PF (227.0) (Table 28).

Variety effect: Specific leaf area was significantly affected ($p<0.05$) by the varieties at the vegetative and reproductive stages during experiment 1 (Table 27). Darina cucumber variety produced significantly ($p<0.05$) higher specific leaf area (31.7) than Kenzo at the vegetative (19.7) stage but the differences was not significant at the reproductive stage (Table 27).

Interactive effect: Significant ($p<0.05$) interactions were observed between the substrate and the varieties at the reproductive stage of experiment 1(Table 27). Darina cucumber variety grown in So (54.4) recorded the highest specific leaf area followed

by Darina in PF (41.2) and the lowest specific leaf area was recorded by Kenzo grown in C+PF (15.1) (Table 27).

Table 27: LAR, LWR and SLA of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 1)

Growth Analysis	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	SxV
LAR at Vegetative Stage	Kenzo	40.7	35.1	42.1	59.9	58.6	52.5	**48.2**			
	Darina	56.5	45	83.9	53.3	85.4	48.6	**62.1**	NS	9.93*	NS
	Mean	**48.6**	**40.1**	**63.0**	**56.6**	**72.0**	**50.6**				
LAR at Reproductive Stage	Kenzo	11.2	12.2	12.31	11.5	9.12	13.8	**11.7**			
	Darina	9.37	17.6	17.91	11.87	12.76	32.2	**17.0**	5.39**	3.11*	7.63*
	Mean	**10.3**	**14.9**	**15.1**	**11.7**	**10.9**	**23.0**				
LWR at Vegetative Stage	Kenzo	0.5	0.6	0.6	0.6	0.6	0.6	**0.6**			
	Darina	0.6	0.6	0.5	0.6	0.6	0.6	**0.6**	NS	NS	NS
	Mean	**0.5**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**				
LWR at Reproductive Stage	Kenzo	0.51	0.59	0.59	0.72	0.61	0.59	**0.6**			
	Darina	0.42	0.43	0.64	0.68	0.52	0.59	**0.5**	0.09**	0.05*	NS
	Mean	**0.5**	**0.5**	**0.6**	**0.7**	**0.6**	**0.6**				
SLA at Vegetative Stage	Kenzo	84.2	62.1	75.1	106	103.8	92	**87.2**			
	Darina	103	78.8	162.2	93.3	140.6	85.3	**110.5**	NS	21.03*	NS
	Mean	**93.5**	**70.5**	**118.7**	**99.7**	**122.2**	**88.7**				
SLA at Reproductive Stage	Kenzo	21.8	20.6	21.5	15.7	15.1	23.5	**19.7**			
	Darina	22.7	41.2	28.1	18.2	25.6	54.4	**31.7**	9.87*	5.7**	13.95*
	Mean	**22.3**	**30.9**	**24.8**	**17.0**	**20.4**	**39.0**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LAR**= Leaf Area Ratio, **LWR**= Leaf Weight Ratio, **SLA**= Specific Leaf Area, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 28: LAR, LWR and SLA of different cucumber varieties in different substrate and their interaction at vegetative and reproductive stages (Experiment 2)

Growth Analysis	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+PF	So	Mean	S	V	SxV
LAR at Vegetative Stage	Kenzo	176	103	198	187	192	106	**160.3**			
	Darina	132	160	350	160	262	144	**201.3**	96.2*	NS	NS
	Mean	**154.0**	**131.5**	**274.0**	**173.5**	**227.0**	**125.0**				
LAR at Reproductive Stage	Kenzo	11.71	15.92	13.23	7.67	7.16	20.47	**12.7**			
	Darina	15.08	10.52	16.79	8.73	9.69	26.61	**14.6**	5.6**	NS	NS
	Mean	**13.4**	**13.2**	**15.0**	**8.2**	**8.4**	**23.5**				
LWR at Vegetative Stage	Kenzo	0.57	0.58	0.55	0.57	0.64	0.60	**0.6**			
	Darina	0.56	0.57	0.64	0.57	0.63	0.57	**0.6**	NS	NS	NS
	Mean	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**				
LWR at Reproductive Stage	Kenzo	0.574	0.592	0.581	0.501	0.529	0.633	**0.6**			
	Darina	0.597	0.613	0.579	0.626	0.536	0.602	**0.6**	NS	NS	NS
	Mean	**0.6**	**0.6**	**0.6**	**0.6**	**0.5**	**0.6**				
SLA at Vegetative Stage	Kenzo	176	103	198	187	192	106	**160.3**			
	Darina	132	160	350	160	262	144	**201.3**	96.2*	NS	NS
	Mean	**154.0**	**131.5**	**274.0**	**173.5**	**227.0**	**125.0**				
SLA at Reproductive Stage	Kenzo	20.2	27.6	23.6	15.6	13.3	32	**22.1**			
	Darina	25.4	17.1	29.7	14.3	18.2	44.3	**24.8**	9.85**	NS	NS
	Mean	**22.8**	**22.4**	**26.7**	**15.0**	**15.8**	**38.2**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LAR**= Leaf Area Ratio, **LWR**= Leaf Weight Ratio, **SLA**= Specific Leaf Area, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.4.4 Relative growth rate of different cucumber varieties in different substrate and their interaction.

Data on the mean relative growth rate of different cucumber varieties in different substrate and their interaction are recorded in Table 29 and 30 respectively.

Substrate effect: The type of substrate significantly ($p<0.05$) affected the relative growth rate of the cucumber plants in both experiment 1 and 2 (Table 29 and 30).

Data from both experiments shows that plants grown in the C+PF, PF+CRH, CRH and C had significantly same value but were higher than PF and S. The value of PF and S were not also significantly different.

Variety effect: The type of variety did not significantly affect the relative growth rate of cucumber plants in both experiments (Table 29 and 30).

Interactive effect: Significant interaction in relation to relative growth rate was not observed between the substrate and the variety during both experiments (Table 29 and 30).

4.4.5 Net assimilation rate of different cucumber varieties in different substrate and their interaction.

Net assimilation rate of different cucumber varieties in different substrate and their interaction data of experiment 1 and 2 are presented in Table 29 and 30 respectively.

Substrate effect: The type of substrate significantly affected the NAR of the cucumber plants during experiment 2 only (Table 30). All the soilless substrates recorded significantly same net assimilation rate.

Variety effect: Net assimilation rate was not significant ($p>0.05$) in terms of varietal effect in both experiment 1 and 2 (Table 29 and 30).

Interactive effect: There was no interaction between the substrate and the varieties in terms of NAR (Table 29 and 30).

Table 29: RGR and NAR of different cucumber varieties in different substrate and their interaction (Experiment 1)

Growth Analysis	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+PF	So	Mean	S	V	S x V
RGR	Kenzo	0.020	0.022	0.023	0.021	0.022	0.020	**0.022**			
	Darina	0.023	0.018	0.023	0.020	0.022	0.019	**0.021**	0.002	NS	NS
	Mean	**0.022**	**0.020**	**0.023**	**0.021**	**0.022**	**0.019**				
NAR	Kenzo	0.002	0.002	0.002	0.002	0.003	0.002	**0.002**			
	Darina	0.002	0.001	0.001	0.002	0.002	0.001	**0.002**	NS	NS	NS
	Mean	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.001**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **RGR**= Relative Growth Rate, **NAR**= Net Assimilation Rate, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 30: RGR and NAR of different cucumber varieties in different substrate and their interaction (Experiment 2)

Growth Analysis	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+CRH	C+PF	So	Mean	S	V	S x V
RGR	Kenzo	0.022	0.017	0.022	0.024	0.023	0.018	**0.021**			
	Darina	0.020	0.022	0.023	0.022	0.023	0.020	**0.022**	0.003	NS	NS
	Mean	**0.021**	**0.019**	**0.022**	**0.023**	**0.023**	**0.019**				
NAR	Kenzo	0.002	0.001	0.002	0.003	0.004	0.001	**0.002**			
	Darina	0.001	0.003	0.001	0.003	0.002	0.001	**0.002**	0.001	NS	NS
	Mean	**0.002**	**0.002**	**0.002**	**0.003**	**0.003**	**0.001**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **RGR**= Relative Growth Rate, **NAR**= Net Assimilation Rate, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.5 Yield of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction

4.5.1 Mean number of fruit/ plant of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction.

Table 31 and 32 indicates mean number of fruit/ plant of two cucumber varieties (Kenzo and Darina) in different substrates and their interaction for experiment 1 and 2 respectively.

Substrate Effect: Mean number of fruit/ plant of different cucumber varieties was significantly ($p<0.001$) affected by the type of substrate used during experiment 1 and 2. During experiment 1, highest fruit number/ plant were recorded in PF (23) substrate and were significantly more than the rest of the substrates. CRH (12) and C (14) produced the lowest fruit number per plant (Table 31). Data from experiment 2 with respect to mean number of fruit/ plant followed the same trend as observed in experiment 1 (Table 31 and 32).

Variety Effect: The results show no effect of variety on the mean number of fruit/ plant during experiment 1 but significant different in the mean number of fruit/ plant as a result of varietal different during experiment 2 was observed. The mean of Kenzo (14) was not significant different ($p>0.05$) compared to Darina (13) variety (Table 32).

Interactive Effect: The interaction between substrate and variety was significant ($p<0.05$) during experiment 1 and highly significant ($p<0.001$) during experiment 2. The highest fruit number was recorded in Darina grown in PF (23) but was not significantly different from Kenzo fruit from PF (22) substrate whilest the interaction that produced the least number of fruit was Kenzo and CRH (10) as well as Darina and C (11) (Table 31). Experiment 2 results shows that Darina and Kenzo grown in PF (21 and 19) produced the highest fruit whilest Darina in C (8) and Kenzo in CRH (9) recoeded the least (Table 32).

4.5.2 Mean weight/ fruit (g) of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction.

The mean weight/ fruit (g) of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction are presented in Table 31 and 32 for experiment 1 and 2 respectively.

Substrate effects: The type of substrate significantly ($p<0.001$) affected mean weight/ fruit. The heaviest fruit was recorded by plants grown in PF (302.37) whereas the least fruit weight was produced by plants grown in CRH (153.51) (Table 31 and 32).

Variety effects: The results show that mean fruit weight of Darina (204.86) cucumber variety was significantly ($p<0.001$) heavier than Kenzo (185.37) (Table 31 and 32).

Interactive effect: The interaction between substrates and variety was significant ($p<0.001$). Darina grown in PF (328.46) produced heaviest fruit followed by Kenzo in PF (276.28) and Darina in C+PF (210.10) whereas Darina in So (150.53) had the least heavy fruit during experiment 1 (Table 31). Results from experiment 2 also shows Darina in PF (320.86) recorded the heavierst fruit whilest Darina grown in So (145.06) had the lightest fruit (Table 32).

4.5.3 Mean yield (Kg/m^2) of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction.

The mean yield (Kg/m2) of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction are indicated in Table 31 and 32.

Substrate effect: Significant ($p<0.001$) differences was observed among the substrates in terms of yield (Kg/m^2) during both experiments. The highest mean yield

(Kg/m^2) during experiment 1 and 2 was achieved in PF substrates and the lowest yield (Kg/m^2) was recorded in CRH substrate (Table 31 and 32).

Variety effect: The different varieties did not significantly ($p>0.05$) influenced the mean yield (Kg/m^2) during both experiments.

Interactive effect: The highest yield (Kg/m^2) of cucumber during experiment 1 was recorded by Darina grown in PF (23.91) followed by Kenzo in PF (18.7) whereas Kenzo cultivated in CRH recorded the least yield (4.78) (Table 31). In experiment 2, Darina grown in PF yielded most in terms of Kg/m^2 (21.03) and was significantly ($p<0.001$) higher than the rest of the substrates. Kenzo grown in PF (16.03) produced the second highest yield. Kenzo and CRH interactions produced the least (3.97) yield (Table 32).

Table 31: Mean number of fruits/ plant and mean weight/ fruit of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction (Experiment 1)

Yield	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
Number of Fruit/ Plant	Kenzo	18	22	10	17	17	18	**17**			
	Darina	11	23	14	16	14	14	**15**	2.51**	NS	3.55*
	Mean	**14**	**23**	**12**	**17**	**15**	**16**				
Weight/ Fruit (g)	Kenzo	167.35	276.28	152.80	152.80	188.33	174.66	**185.37**			
	Darina	209.85	328.46	165.11	165.11	210.10	150.53	**204.86**	6.26**	3.61**	8.85**
	Mean	**188.60**	**302.37**	**158.96**	**158.96**	**199.22**	**162.60**				
Yield (Kg/m^2)	Kenzo	9.24	18.7	4.78	8.28	9.82	9.66	**10.08**			
	Darina	7.22	23.91	7.41	8.24	9.18	6.74	**10.45**	1.79**	NS	2.53**
	Mean	**8.23**	**21.31**	**6.10**	**8.26**	**9.50**	**8.20**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 32: Mean number of fruits/ plant and mean weight/ fruit of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction (Experiment 2)

Yield	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
Number of Fruit/ Plant	Kenzo	16	19	9	14	13	15	**14**			
	Darina	8	21	12	12	11	11	**13**	2.30**	1.33*	3.25*
	Mean	**12**	**20**	**11**	**13**	**12**	**13**				
Weight/ Fruit (g)	Kenzo	165.35	270.21	146.60	149.83	183.98	158.59	**179.09**			
	Darina	204.45	320.86	160.41	166.17	202.40	145.06	**199.89**	6.51**	3.76**	9.19**
	Mean	**184.90**	**295.54**	**153.51**	**158.00**	**193.19**	**151.83**				
Yield (Kg/ m^2)	Kenzo	8.44	16.03	3.97	6.72	7.48	7.42	**8.34**			
	Darina	5.12	21.03	6.20	6.37	6.74	5.14	**8.43**	1.49**	NS	2.12**
	Mean	**6.78**	**18.53**	**5.09**	**6.55**	**7.11**	**6.28**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.5.4 Mean yield (t/ha) of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction

The mean yield (t/ha) of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction are presented in Figure 1 and 2.

Substrate effect: The substrates significantly ($p<0.001$) affected mean yield (t/ha) of cucumber plant. The highest mean yield (t/ha) during experiment 1 was produced in PF (227.25 t/ha) substrates whilst the lowest yield (t/ha) was recorded by CRH (65.00) (Figure 1). Results from experiment 2 followed same trend as observed during experiment 1 (Figure 1 and 2).

Variety effect: Yield (t/ha) of the cucumber plants in both experiment were not affected by the type of varieties used.

Interactive effect: The highest yield (t/ha) of cucumber during experiment 1 was recorded by Darina in PF (255.00) followed by Kenzo in PF (199.50) and Kenzo in C+PF (104.80) whereas Kenzo in CRH (51.00) recorded the least yield (t/ha) (Figure 1). In experiment 2 Darina grown in PF (224.30) yielded most in terms of tonnes/

hectare and was significantly ($p<0.001$) higher than the rest of the substrates. Kenzo grown in PF (171.00) produced the second highest yield and was followed by Kenzo in C (90.10) and Kenzo in C+PF (79.80). The interactions that produce the least yield (42.30) were Kenzo and CRH (Figure 2).

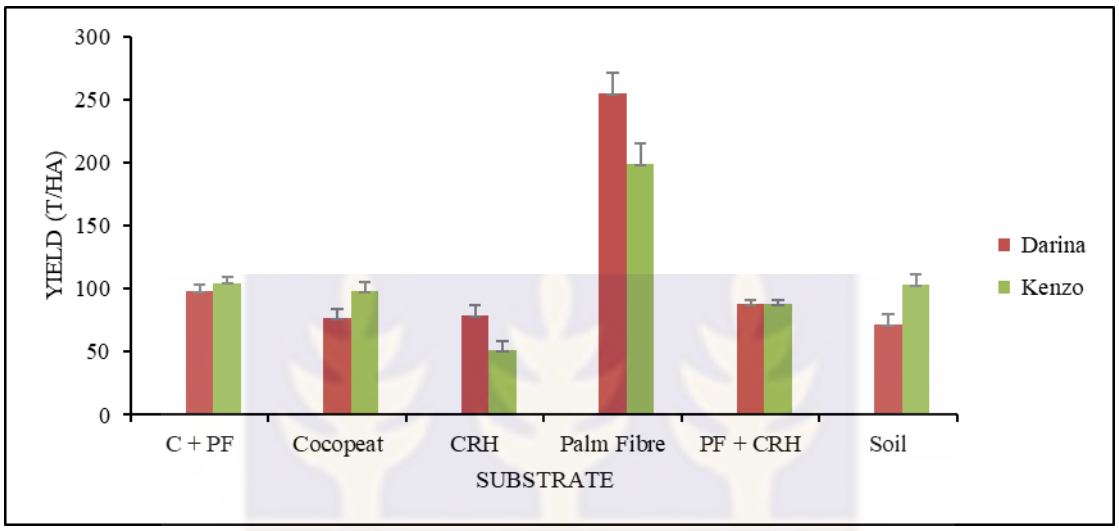

Figure 1: Mean Yield (t/ha) of different cucumber plant varieties in different substrate and their interaction (Experiment 1). CRH= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture. Bar represent means ± SEM of 3 replicates.

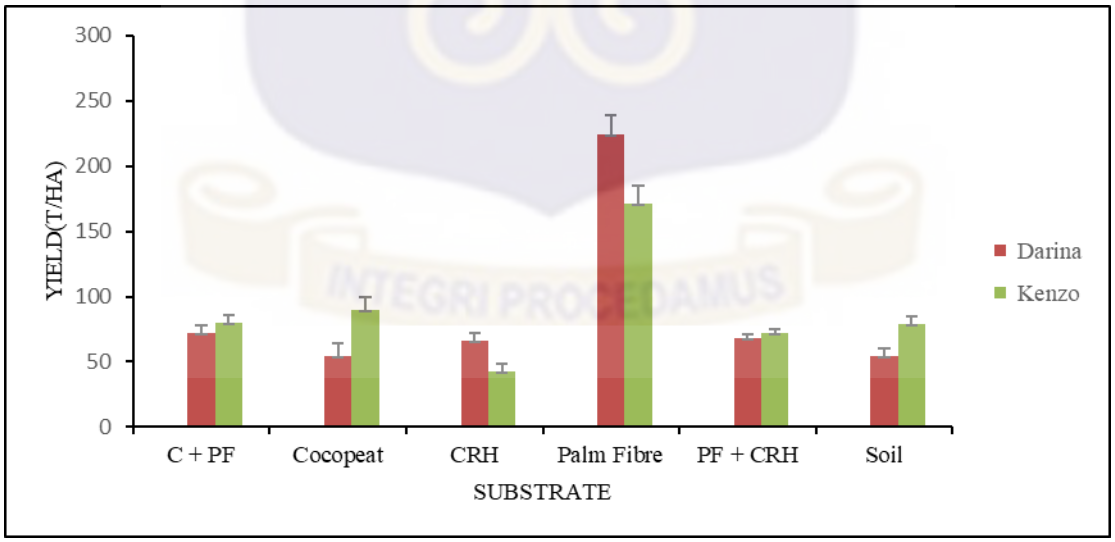

Figure 2: Mean Yield (t/ha) of different cucumber varieties in different substrate and their interaction (Experiment 2). **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture. Bar represent means ± SEM of 3 replicates.

4.6 Yield attributes of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction.

4.6.1 Mean fruit diameter of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction.

Mean fruit diameter of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction during experiment 1 and 2 are reported in Table 33 and 34 respectively.

Substrate Effect: Mean fruit diameter of different cucumber varieties was significantly ($p<0.001$) affected by the type of substrate used during experiment 1 and 2 (Table 33 and 34). From experiment 1, high fruit diameters were recorded in C+PF (15.23), PF (15.23) and C (14.67) whilst the lowest fruit diameter was recorded in So (12.13) substrates (Table 33).

Variety Effect: The results show that mean fruit diameter from Darina cucumber variety was significantly ($p<0.001$) higher than those from Kenzo cucumber variety during experiment 1 and significant ($p<0.05$) at experiment 2.

Interactive Effect: The interaction between substrate and variety was highly significant ($p<0.001$) during experiment 1 whilst experiment 2 was significant at 5%. The highest fruit diameter was recorded in Darina grown in PF (16.64) followed by Darina in C (16.36) whreas Darina and Kenzo interaction with So produced fruits with smallest diameters (11.85 and 12.41) (Table 33). During experiment 2, Darina grown in PF (16.69) and C (15.76) recorded fruits with biggest diameter whilst Darina in CRH (11.13) had the smallest diameter.

4.6.2 Mean fruit length of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction.

Table 33 and 34 signified Mean fruit length of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction for experiment 1 and 2 respectively.

Substrate Effect: Mean fruit length of two cucumber varieties (Kenzo and Darina) was significantly ($p<0.001$) affected by the type of substrate used during experiment 1 and 2. Highest fruit lengths was recorded by PF (18.00), C+PF (18.00) and C (17.33) during experiment 1 whilst So (14.34) produced fruits with the shortest length (Table 33). Experiment 2 results followed same trend as observed in experiment 1 (Table 33 and 34).

Variety Effect: The results show significant different in the fruit length as a result of variety effect and the mean fruit length of Darina cucumber variety was significantly longer than Kenzo cucumber variety during both experiments.

Interactive Effect: The interaction between substrate and variety during experiment 1 and 2 was significant ($p<0.001$). From experiment 1, it was observed that the longest fruit length was recorded in Darina grown in PF (19.67) but was not significantly different from Darina fruit from C (19.33) substrate. Both Kenzo and Darina interaction with So produced the fruits with the shortest lenght (Table 33). Data from experiment 2 indicated longest fruit in Darina grown in PF (18) and C (17) compared with the rest of the interactions. (Table 34).

Table 33: Mean fruit diameter and fruit length of different cucumber varieties in different substrate and their interaction (Experiment 1)

Yield Attributes	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
Fruit Diameter	Kenzo	12.97	13.82	12.97	12.69	15.23	12.41	**13.35**			
	Darina	16.36	16.64	13.54	13.54	15.23	11.85	**14.53**	0.92**	0.53**	1.31**
	Mean	**14.67**	**15.23**	**13.26**	**13.12**	**15.23**	**12.13**				
Fruit Length	Kenzo	15.33	16.33	15.33	15.00	18.00	14.67	**15.78**			
	Darina	19.33	19.67	16.00	16.00	18.00	14.00	**17.17**	1.09**	0.63**	1.54**
	Mean	**17.33**	**18.00**	**15.67**	**15.50**	**18.00**	**14.34**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 34: Mean fruit diameter and fruit length of different cucumber varieties in different substrate and their interaction (Experiment 2)

Yield Attributes	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S xV
Fruit Diameter	Kenzo	12.05	12.98	12.05	11.75	14.53	11.75	**12.52**			
	Darina	15.76	16.69	11.13	12.67	14.22	11.44	**13.65**	1.24**	0.72*	1.76*
	Mean	**13.91**	**14.84**	**11.59**	**12.21**	**14.38**	**11.60**				
Fruit Length	Kenzo	13.00	14.00	13.00	12.67	15.67	12.67	**13.50**			
	Darina	17.00	18.00	12.00	13.67	15.33	12.33	**14.72**	1.34**	0.77*	1.89*
	Mean	**15.00**	**16.00**	**12.50**	**13.17**	**15.50**	**12.50**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil,
LSD= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.7 Fruit quality of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction.

4.7.1 TSS (% Brix) of fruit from two cucumber varieties (Kenzo and Darina) in different substrate and their interaction.

Mean TSS (% Brix) of fruit from two cucumber varieties (Kenzo and Darina) in different substrate and their interaction for experiment 1 and 2 are presented in Table 35 and 36 respectively.

Substrate effect: Data from experiment 1 revealed that the highest TSS (% Brix) of fruit was recorded in C (4.42) followed by PF (4.18) even though there was no significant different between them. C and PF substrates however recorded significant ($p<0.05$) higher TSS values than the other substrates (Table 35).

Variety effect: The results show that mean TSS (% Brix) of fruit were not significantly ($p>0.05$) affected by the varieties in both experiments (Table 35 and 36).

Interactive effect: No significant interactions were found for TSS from experiment 1(Table 35). Significant ($p<0.001$) interactions were observed between the substrate and varieties during experiment 2. Kenzo fruits in C (4.80) recorded the highest TSS (% Brix) and was significantly ($p<0.001$) higher than Darina in PF (3.93) and Kenzo in PF (3.77). The lowest mean TSS (% Brix) of fruit was recorded in Kenzo and Darina grown in PF+CRH (2.43 and 2.80 respectively) (Table 36).

4.7.2 MC of fruit from two cucumber varieties (Kenzo and Darina) in different substrate and their interaction

The mean MC of fruit from two cucumber varieties (Kenzo and Darina) in different substrate and their interaction for experiment 1 and 2 are indicated in Table 35 and 36 respectively.

Substrate effects: The type of substrate significantly ($p<0.001$) affected mean MC of fruit. During both experiments, PF recorded highest MC of fruits followed by C+PF and C (Table 35 and 36).

Variety effects: The results show that mean MC of fruit from Darina cucumber variety was significantly ($p<0.001$) higher than fruits from Kenzo cucumber variety in both experiments (Table 35 and 36).

Interactive effect: The interaction between substrate and varieties was significant ($p<0.001$) during experiment 1 and 2 (Table 35 and 36). Result from experiment 1 revealed that Darina fruits grown in PF (323.15) recorded the highest mean MC of fruits followed by Kenzo grown in PF (270.93) whilst the Darina in So (145.90) recorded fruit with low MC (Table 35). Daina and PF interaction produced fruits with highest MC of 315.85) but the lowest mean MC of fruit was recorded by Darina grown in soil (140.85) (Table 36).

4.7.3 DM of fruit from two cucumber varieties (Kenzo and Darina) in different substrate and their interaction

The mean DM of fruit from two cucumber varieties (Kenzo and Darina) in different substrate and their interaction are presented in Table 35 and 36.

Substrate effects: Results in Table 35 shows that the highest mean DM of fruit was recorded by C (5.63) followed by PF (5.33) but were not significantly ($p>0.05$) different. The lowest mean DM of fruit was recorded by PF+CRH (4.06), however it was significantly same as CRH (4.18), C+PF (4.40) and So (4.61) (Table 35).

Variety effect: The cucumber varieties did not significantly ($p>0.05$) affected the DM content of the fruits during the first and second experiment (Table 35 and 36).

Interactive effect: Data in Table 36 indicates that substrate and variety interaction was significant ($p<0.001$) on the DM of fruit during experiment 2. Kenzo grown in C (6.12) recorded the highest mean DM of fruit followed by Darina and Kenzo in PF

(5.01 and 4.80 respectively). However significant difference was not observed between Darina and Kenzo in PF. The fruits produced by Kenzo in PF+CRH and CRH (3.10 and 3.61 respectively) recorded the lowest DM.

Table 35: Mean TSS of fruit, MC and DM of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction (Experiment 1)

Fruit Quality	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
TSS (% Brix)	Kenzo	4.93	4.20	3.10	2.97	3.40	3.60	**3.70**			
	Darina	3.90	4.17	3.47	3.40	3.50	3.63	**3.68**	0.49**	NS	NS
	Mean	**4.42**	**4.18**	**3.28**	**3.18**	**3.45**	**3.62**				
MC of Fruit	Kenzo	161.07	270.93	148.85	149.02	184.00	170.08	**180.66**			
	Darina	204.88	323.15	160.70	160.78	205.64	145.90	**200.18**	6.19**	3.58**	8.77**
	Mean	**182.98**	**297.04**	**154.78**	**154.90**	**194.82**	**157.99**				
Fruit DM	Kenzo	6.29	5.35	3.95	3.78	4.33	4.59	**4.71**			
	Darina	4.97	5.31	4.42	4.33	4.46	4.63	**4.69**	0.63*	NS	NS
	Mean	**5.63**	**5.33**	**4.18**	**4.06**	**4.40**	**4.61**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **TSS**= Total Soluble Solid, **MC**= Moisture Content, **DM**= Dry Matter, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

Table 36: Mean TSS of fruit, MC and DM of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction (Experiment 2)

Fruit Quality	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+ PF	So	Mean	S	V	S x V
TSS (% Brix)	Kenzo	4.80	3.77	2.83	2.43	3.20	3.27	**3.38**			
	Darina	3.60	3.93	3.27	2.80	3.30	3.30	**3.37**	0.28**	NS	0.40**
	Mean	**4.20**	**3.85**	**3.05**	**2.62**	**3.25**	**3.28**				
MC of Fruit	Kenzo	159.24	265.41	142.99	146.73	179.91	154.43	**174.79**			
	Darina	199.86	315.85	156.25	162.61	198.20	140.85	**195.60**	6.46**	3.73**	9.13**
	Mean	**179.55**	**290.63**	**149.62**	**154.67**	**189.06**	**147.64**				
Fruit DM	Kenzo	6.12	4.80	3.61	3.10	4.08	4.16	**4.31**			
	Darina	4.59	5.01	4.16	3.57	4.21	4.21	**4.29**	0.36**	NS	0.51**
	Mean	**5.35**	**4.91**	**3.89**	**3.33**	**4.14**	**4.18**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **TSS**= Total Soluble Solid, **MC**= Moisture Content, **DM**= Dry Matter, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

4.8 Economic analysis

4.8.1 Revenue

The mean revenue (GH) of cucumber fruit from two cucumber varieties (Kenzo and Darina) in different substrate and their interaction are presented in Table 37.

Substrate effects: Results in Table 37 shows that significantly higher revenue was recorded by PF (1,136,261.0 and the lowest revenue was recorded by CRH (325,157.0).

Variety effect: The cucumber varieties did not significantly ($p>0.05$) affect the revenue (Table 37).

Interactive effect: Darina grown in PF (1,275,201.0) recorded the highest revenue. This was followed by Kenzo and PF (997,321.0) interaction whilst Kenzo grown in CRH (225,131.0) recorded the lowest revenue.

4.8.2 Profit

The mean profit (GH) of cucumber fruit from two cucumber varieties (Kenzo and Darina) in different substrate and their interaction are tabulated in Table 37.

Substrate effects: The highest profitable substrate for cucumber production was recorded by PF (1,063,491.0). CRH (254,734.0) and C (199,389.5) had the lowest profit (Table 37).

Variety effect: The cucumber varieties did not significantly ($p>0.05$) affect the profit.

Interactive effect: Darina grown in PF (1,202,431.0) recorded the highest profit whilst Darina in C (145,437.0) and Kenzo grown in CRH (184,708.0) recorded the lowest profit (Table 37).

Table 37: Mean revenue and profit (GH) of two cucumber varieties (Kenzo and Darina) in different substrate and their interaction.

Economic Analysis	Variety (V)	Substrate (S)							LSD (0.05)		
		C	PF	CRH	PF+ CRH	C+PF	So	Mean	S	V	S x V
Revenue	Kenzo	492,778.0	997,321.0	255,131.0	441,718.0	523,775.0	515,445.0	**537,694.7**			
	Darina	384,874.0	1,275,201.0	395,183.0	439,201.0	489,773.0	359,454.0	**557,281.0**	95428.1**	NS	134955.7**
	Mean	**438,826.0**	**1,136,261.0**	**325,157.0**	**440,459.5**	**506,774.0**	**437,449.5**				
Profit	Kenzo	253,342.0	924,551.0	184,708.0	370,122.0	367,672.0	454,413.0	**425,801.3**			
	Darina	145,437.0	1,202,431.0	324,760.0	367,605.0	333,670.0	298,421.0	**445,387.3**	95428.1**	NS	134955.7**
	Mean	**199,389.5**	**1,063,491.0**	**254,734.0**	**368,863.5**	**350,671.0**	**376,417.0**				

C= Cocopeat, **PF**= Palm Fibre, **CRH**= Carbonated Rice Husk, **C+PF**= Cocopeat and Palm Fibre mixture, **PF+CRH**=Palm Fibre and Carbonated Rice Husk mixture, **So** = soil, **LSD**= Least Significant Difference; ***** = means significant at 5%, ****** = means significant at 1%, **NS** =means not significant at 5%.

CHAPTER FIVE

5 DISCUSSION

5.1 Characteristics of substrates

5.1.1 Physical characteristics of substrates

The physical properties of a substrate such as bulk density and water holding capacity are a vital component in plant performance therefore the bulk density and water holding capacity of substrate use for crop production must be within the acceptable range (Frantz *et al*. 2007). Bulk densities of substrates ranged between 0.14 gcm^{-3} and 1.17 gcm^{-3}. Differences in results obtained here is most likely due to the variation in particle-size distribution of the material (Richards, 1986). Variability in the physical properties of soilless media is common (Wiberg *et al*, 2005). Cocopeat had lower bulk density comparative to PF and within values between 0.1 and 0.3 g cm-3 which are considered acceptable for hydroponic seedlings and crop production (Kampf *et al*. 1999). The soil bulk density was higher than PF and the other substrates. The two lowest bulk densities were related to CRH (0.14) and Cocopeat (0.16). Mohammadi - Ghehsareh *et al.* (2011) and Borji *et al*. (2010) had similar results. Result obtained here is also consistent with result by Islam (2008) who found that the bulk density of carbonated rice husk was lower than the bulk density of cocopeat. The reduction in bulk density through addition of carbonated rice husk to PF confirm earlier studies by Rivenshield and Bassuk (2007) that soils, when amended with peat or food waste compost, had lower bulk density, and reduced potential root restriction.

The water holding capacity of the substrates ranged from 45% to 87.5%. The difference in water holding capacity among substrate could be due to differences between their total porosity and types of pores. This explanation agrees with Bunt, (1988) and Awang *et al*. (2009). PF+CRH mix substrate had the highest water holding capacity. This might be due to

the reduction in bulk density by the CRH, loosening of the PF thereby increasing amount of pore spaces and eventually increasing the water holding capacity confirming the findings of Nyle & Ray (1999).

5.1.2 Chemical characteristics of substrates

The pH and EC of the substrates are two important properties of any substrate as these parameters directly influenced the availability of nutrient in the media (Awang *et al.* (2009).

The substrates pH ranges from 6.08 to 6.94. The most favourable pH in the root zone of most crop species grown hydroponically range from 5.5 to 6.5 although values between 5.0 to 5.5 and 6.5 to 7.0 may not cause problems in most crops (Adams, 2002). For optimal growth, the optimum pH of the soilless media for good availability of essential elements is around 6.0 (Sonneveld and Voogt, 2009), in which cucurbit species require pH between 6.0 and 6.8 for optimal growth (Wancke, 2007). All the soilless and soil substrates fell within the above range except the Cocopeat- PF mix which recorded 6.94.

The highest and lowest EC of 1.26 dSm^{-1} and 0.13 dSm^{-1} were measured in Cocopeat and soil respectively. The EC values reflect the total inorganic ion concentration in the media extracts. The EC value which was less than 2 dS m^{-1} was in agreement with the conditions required for the growth of cucumber (Lian 1994; Tao 1995; Ge 2001).

5.2 Effect of different substrates on cucumber plant growth indices

The highest plant was recorded by PF followed by Cocopeat, PF+CRH and C+PF; however there was no significant difference among the heights. Sufficient conditions in the PF caused good supply of water and nutrient elements for plant and leading to good growth (Olympious 1992; Kumar and Goh 1999). According to Ahmed *et al*. (2013), physical properties such as total porosity, bulk density, moisture content, rate of drainage and chemical characteristics

like pH and electrical conductivity of the PF substrate were relatively positive for cucumber plant growth. A balanced rooting medium that contains an adequate supply of nutrients is essential for plants to attain maximum growth and development. Balanced rooting media greatly affects the plant height and availability of growing substrate with the supplement of essential nutrients is essential for attaining maximum plant height Ikram *et al*. (2012). Results showed that use of different potting media affect plant height differently. Maximum increase in plant height was attained in PF which might be due to maximum uptake of nutrients Turhan *et al*. (2007). High quantities of nitrogen, phosphorus and potassium in the C substrate might have favoured the growth and development. Increase in plant height in PF, C, PF+CRH and C+PF could be as a result of increased uptake of nutrients by plants in these media leading to enhanced carbohydrate synthesis thereby resulting in increased cell division and enlargement and therefore increase in plant height. Ghehsareh *et al.* (2012) recorded higher cucumber plant height in date-palm leafs, Mavrona *et al.*, (2001) founded longer plant height in cocopeat than in perlite. Same results showed on tulip and strawberry as well (Kahraman, 2006), however AL-Rawahy *et al* (2009) did not find differences with date palm leaf straw in height of cucumber plants. Significant same height of Kenzo and Darina cucumber varieties could be as a result of their similarity in genetic character that could not be changed by substrates or management.

The number of leaves was highest in PF followed by PF+CRH, S, C+PF and C although there was no significant different among them. This could be due to increased availability of nutrients for plant uptake which promoted cell division (Osodeke, 2001). High water holding capacity induced higher vegetative growth in hydroponics culture of ornamental plants like Oriental hybrid lily (*Liliumasiatic*) (Ryota *et al* 2002). Higher vegetative growth includes high number of leaves and this might result in these substrates producing more leaves.

In cucumber, number of leaves, in plants grown in pumice or perlite did not show any differences among the substrates (Abul-Soud *et al*, 2003). Nikrazm *et al*. (2011) in a study on lily flower reported that coco-peat medium was better than inorganic media in relation to leaf number. Mavrona *et al.*, (2001) found higher number of leaves in cocopeat than inperlite. The findings of a study by Sahinrokhsar *et al*. (2007) on the effect of substrate type on the vegetative characteristics of strawberry in hydroponic culture showed that leaf number was a function of substrate, which is consistent with the findings of the present study. They found that the highest leaf number belonged to coconut substrate. Samiei *et al.* (2005) found that organic substrates had a significant impact on growth indexes so much that the highest leaf number belonged to coco peat. The variability in leaf number produced between the varieties could be as a result of genetic differences.

Highest recorded stem girth was in plants grown in C but was not significantly higher than PF substrates at 2 and 4 WAT. Studies conducted by Gallardo *et al*. (2006), reflected that there was an increase in stem diameter on young plants and the slow growth was observed on mature plants. The result is in agreement to this as seen from 2 to 4 WAT. Sufficient conditions in the PF caused good supply of water and nutrient elements for plant and leading to good stem girth growth (Olympious 1992; Kumar and Goh 1999). Secondary, high quantities of nitrogen, phosphorus and potassium in the C substrate might have contributed to its high stem girth recorded. At 6 WAT, the analysis of variance in relation to the stem girth of the cucumber plants was not significant. This finding is in agreement with Borji *et al.* (2010) who suggested that Culture media including cocopeat and date palm had no significant effect on stem diameter of tomato plants.

The chlorophyll content of S was not significantly higher than PF at both vegetative and reproductive stages but was significantly higher than C and PF+CRH during experiment 1.

This could be attributed to the increased uptake of nutrient in the plants grown in PF leading to enhanced chlorophyll content and carbohydrate synthesis. N and other nutrients availability and uptake in the S and PF could have affected chlorophyll synthesis, interfering with the measurements of leaf greenness index by chlorophyll meters (Masoni *et al.*, 1996). Since differences existed in the bulk density and water holding capacities of the different growing media, this could have affect the soil and PF moisture relations, release and absorption of nutrients by the crop for various metabolic that could have impact on the chlorophyll content. The chlorophyll content of plants is regulated by many factors such as the genotype and the environment, where the genotype is a major component involved in the mechanisms regulating chlorophyll content Li *et al.* (2009). This might explain the significant higher content recorded by Kenzo compared to Darina variety.

Findings from both experiments show that there was no significance difference between the means of S, C and PF in relation to the leaf area of cucumber plants. Plant growth was significantly correlated with the water retention properties of substrates. High available water in S, C and PF might have contributed to their large leaf area. The availability of nutrients in growing substrate might have greatly affected the size of leaves. Best substrate having adequate supply of nutrients can be used to accomplish significant results. Maximum increase in size of leaves might be due to the fact that plants were able to adapt to the substrates. This result disagreed with Nikrazm *et al.* (2011) who reported that cocopeat medium was better than inorganic media in relation to leaf area of lily flower and Samiei *et al.* (2005) who suggested that Aglaonema (flower) leaf area in peat moss and date-palm peat substrates was similar but this index for coco peat substrate was higher.

Significant highest nodes observed in plants grown on PF substrates could be explain by increased uptake of plant nutrients in the PF substrate which might resulted in improved

vegetative structure development like length of vines. Balanced nutrition has been found to result in active cell division, cell elongation as well as development of meristematic tissues which consequently results in development of more nodes. Bilderback *et al.*, (2005) found that plant growth was significantly correlated with the water retention properties of substrates. Low water holding capacity as seen in CRH might have contributed to decreasing cell wall stretching, leaf area surface and photosynthesis leading to reduction of growth and subsequently the least number of nodes recorded.

PF+CRH, C+PF, C and PF produced the highest plant dry weight in decreasing other although there was no significant different among them. This might be due to high water holding capacity of PF+CRH which ensured good growth and development of plants translating to dry weight. Biomass production is primarily driven by photosynthesis, while its extent depends on light interception, which furthermore varies with leaf area (Heuvelink, 2005). High level of chlorophyll in plants grown in PF might have resulted in more photosynthates production thereby making it available for vegetative growth after satisfying respiratory requirements leading to high dry weight. According to Mylarapu and Zinati (2009), nitrogen is required to manufacture structural, genetic and metabolic materials in plant cells. C and C+PF substrates had highest and third highest nitrogen which might translate to their high plant dry weights. Also the decrease in bulk density, as seen in C improved water and nutrient uptake that resulted in the improved dry matter production observed in the C. Ghehsareh *et al*. (2012) revealed that higher amount of cucumber biomass weight obtained when date-palm leafs used as media compared to the conventional soil system.

From the results, the mean shoot dry weight of cucumber plants was highest in PF+CRH followed by C+PF, C and PF even though there was no significance difference among the

means. Increased shoot dry matter as a result of the substrates and nutrient application is attributed to balanced nutrient uptake by the plants which resulted in enhanced cell division and enlargement leading to the build–up of the shoot dry matter (Wange and Kale, 2004). The increased uptake of plant nutrients supplied by these substrates resulted in improved vegetative structure development (Suthar *et al*., 2005). It has been proven that the cocopeat (soilless) system offers better possibilities for an optimized fertigation regime and better nutrient availability than soil system leading to higher growth rates, and a higher total weight of stems (Pardossi *et al.*, 2011). Khayyat *et al.* (2007) reported shoot dry weights of pothos (*Epipremnum aureum* Lind) were higher in medium containing only coco peat.

Ghehsareh *et al.* (2012) and Khayyat *et al.* (2007) revealed that higher amount of root weight were obtained when date-palm leafs and coco peat was used. In this study, there was no significant different in the means in terms of cucumber dry root weight between PF and Cocopeat. However, C+PF substrate mix had significantly higher mean of dry cucumber root weight than Cocopeat and PF. Phosphorus assists in root development and cell division. This could contribute to the high root weight of C+PF and C since they had third and second highest phosphorus contents respectively.

SLA at the reproductive stage was not significantly different between S and PF whilst the lowest SLA was recorded by PF+CRH. This might imply that cucumber plants grown in S and PF had thinner but broad leaves. Low SLA observed by PF+CRH plants could be an indication of tick leaves and this is in agreement with Hunt (1978) who indicated SLA of thick leaves are low. PF+CRH recorded the highest mean LWR and this was followed by CRH and C+PF. LWR realistically involved dry matter partition to the leaves, therefore the highest water holding capacity recorded by PF+CRH might have provided optimum moisture for good growth and dry matter production. The decrease in LWR from the vegetative to

reproductive stage as observed in PF, C and C+PF could be as a result of the plants channelling of dry matter to flower and fruit formation. This is in agreement with Demural *et al*., (2005) who suggested that the decreasing values of LWR are associated with increasing distribution of dry matter to other plant organs as plants grow. The highest LAR was recorded in S and PF substrate. Leaf area ratio (LAR) is the ratio of total leaf area to whole plant dry weight and in the broad sense represents the ratio of photosynthesising to respiring material within the plant. Increased uptake of plant nutrients in the PF substrate which might result in improved vegetative structure could explain the high LAR in PF. LAR depended on many factors such as light intensity and nutrient solution concentration. LAR is the amount of LA per unit total plant mass and a function of the SLA and LWR (Lambers *et al*., 1989). Miranda *et al*., (2010) reported that the reduction of LAR was primarily caused by a decrease in the SLA, which played an important role in determining the RGR of the treated plants. The result of this experiment is in agreement with Miranda *et al*., (2010). NAR is a measure of the average photosynthetic efficiency of the leaves of plants or in a crop stand (Hunt, 1990; Lambers *et al*., 1989). NAR is the most important parameter explaining variation in RGR within plants of the same genus or species and even between closely related plant species (Hunt, 1982). Hunt (1978) has indicated that in general any departure from adequate supply of mineral nutrients and water will produce an adverse effect on RGR. The lowest RGR value recorded by S could be attributed to its high bulk density which might have impeded root growth, metabolism and thus reduced water and nutrient absorption. Bruggink and Heuvelink (1987) studied the effect of light on RGR, NAR and LAR of young tomato, cucumber and sweet pepper plants grown in the greenhouse. They reported that RGR for cucumber and tomato were about the same and that NAR was almost the same for all three species.

5.3 Effect of different substrates on cucumber yield and yield attributes

Highest fruit number/ plant were recorded in PF substrate whilst CRH produced the lowest fruit number per plant. The highest number of fruit recorded in PF might have been due to sufficient conditions with view to bulk density in which might have caused good supply of water and nutrient elements for plant leading to good growth that translated into number of fruits produced. According to Ahmed *et al*. (2013), physical properties such as total porosity, bulk density, moisture content, rate of drainage and chemical characteristics like pH and electrical conductivity of the PF substrate were relatively positive for cucumber fruit production. The results are in agreement with Alifar *et al*. (2010). PF plants also recorded significantly higher nodes that might translate into more flowers developing into fruits since parthenocarpic cucumber hybrids bear fruits at almost every node. Therefore, plants having more number of nodes are desired for getting higher yield. Strong relationship between number of node and cucumber yield have been found by researchers (Wehner and Cramer 1996 and Ghehsareh 2013). Plant height helps in light attraction therefore the taller the plant, the easier it intercept light for maximum photosynthesis. This could be attributed to PF yielding more fruit. This finding is in line with Ogbodo (2009) who revealed that tall plant has easy access to intercept light for photosynthesis. Large leaf area and higher number of leaves in plant grown in PF might have led to increased transpiration rate which accounts for more nutrient uptake and thereby enhancing fruit yield. A study conducted by Logendra *et al*. (2001) reported that an increase in the number of leaves elevated the photosynthetic reaction and increased carbohydrates. This carbohydrate might have favoured PF substrates to produce highest fruit number. The decrease in LWR from the vegetative to reproductive stage as observed in PF could be as a result of the plants channelling of dry matter to flower and fruit formation. This is in agreement with Demural *et al*., (2005) who suggested that the decreasing values of LWR are associated with increasing distribution of dry matter to other

plant organs as plants grow. The low number of fruits produced by CRH substrate could be attributed to the low chlorophyll content. Secondary, flowering and fruit setting are the most sensitive stages to water stress. In general, water stress impairs flower development and fruit setting and thus, reduces the number of fruit (Costa and Gianquinto; 2002. Nuruddin *et al.*, 2003). This might account for the lowest fruit number produce by CRH. The reduction of leaf area decreases the capacity of plants to intercept light. Less light interception will reduce plant growth, development and yield as seen in CRH (Hernández and Kubota 2015). Leaf number per plant corresponds to the quantum of photosynthate produced and subsequently the yield. Although higher number of leaves was recorded by Kenzo variety, their recorded number of fruits was not significantly higher than Darina. This could be as a result of Kenzo channelling more nutrients and moisture to its vegetative parts than the reproductive parts.

The highest mean yield (t/ha) during the experiment was produced in PF substrates and was significantly higher than the rest of the substrates whilst the lowest yield (t/ha) was recorded by CRH. Physiochemical characteristics of PF could account for good growth, development and high yield of the cucumber plants. According to Ahmed *et al*. (2013), physical properties such as total porosity, bulk density, moisture content, rate of drainage and chemical characteristics like pH and electrical conductivity of PF substrate were relatively positive for cucumber plant growth, development and fruit production of cucumber in the PF substrate. The tallest plants produced by PF substrates coupled with high chlorophyll content and high leaf area might account for the production of more photosynthate which could result in good growth and yield. Cucumber plants grown in PF produced high leaf dry weight which could store more photosynthate and hence, translocate to the reproductive parts leading to higher yield. Stem diameter is an important index for water uptake by plant which can determine plant transpiration rate. Stem diameter also influences stem cells, nutrition of mineral nutrients, photosynthesis, transpiration, transportation and metabolism of photosynthetic

products (Ilnitskaya *et al*., 1997). Therefore the high yield of PF in t/ha could be attributed to their high recorded stem girth. The supply of nutrient to a plant is directly related to water movement into roots, and when such movement ceases because of lowered soil moisture, roots are limited to those nutrients within the range of diffusion (Crafts, 1968). This might explained the low yield (t/ha) recorded by CRH since it recorded the lowest moisture holding capacity. The soilless cultivation is one of the most efficient alternatives to soil fumigation since it provides a pathogen-free root environment at planting, while promoting higher yields (Savvas, 2009). The result is in agreement with Ghehsareh *et al*. (2012) who revealed that higher amount of cucumber yield was produced in date-palm leaves compared to the conventional soil system.

Highest fruit lengths was recorded in PF, C+PF and C during experiment 1 but were not significantly different whereas S produced fruits with the shortest length. Higher accumulation of root dry weight in PF cucumber plants could mean their roots systems are more developed and tend to explore greater volume of substrate leading to greater absorption of water and nutrients and thus perform better with respect to fruit length (Carvalho *et al*, 2008). Also, increase in shoot root ratio as seen in C and PF might indicate that shoots have a higher priority for photosynthate accumulation than roots and are able to translocate to fruits for development hence longer fruits produced (Fageria *et al*., 2006). The least growth in field soil (control) may be due to reduced number of leaves and shoots that may have decrease the rate of photosynthesis, thereby reducing plant growth leading to short fruits. Peyvast *et al* (2008), found no significant effects on fruit length in cucumber grown in peat or perlite substrates. Different hybrids had significant influence on fruit length. Significantly longer fruits produced by Darina could basically be due to its genetic character that is slightly changed by substrate and management. Also higher leaf area produced by Darina cucumber plants could have increase phothosynthate production leading to longer fruit development.

High fruit diameter was recorded in PF and C+PF substrates whilst the lowest fruit diameter was recorded in S and CRH substrates. Biomass production is primarily driven by photosynthesis, while its extent depends on light interception which furthermore varies with leaf area (Heuvelink, 2005). PF recorded high chlorophyll content, tallest plants as well as largest leaf area. A high biomass production of transplants in PF might have contributed to high yield, and later the fruit diameter development. Sufficient conditions with a view to bulk density and porosity in palm media caused good supply of water and nutrient to plant and this might have resulted in good growth and fruit diameter development. Medany *et al*. (1995), in Egypt, produced a larger cucumber crop in cheap local date palm fibres. The findings disagreed with the results of Alifar *et al.* (2010) who indicated that large cucumber fruit diameter was obtained from Cocopeat media. Minimum fruit diameter of fruits produced by S could be attributed to its higher bulk density which might have lowered aeration, reduced root metabolism and absorption of nutrients for fruit development. Superior diameter of Darina cucumber fruits over Kenzo variety could be attributed to less leaves produced by Darina plants which might have accounted for sufficient moisture and nutrient distribution to the developing fruits thereby improving their diameter. This could also be explained by the fact that genetic variation exist between the varieties confirming Afangideh and Uyoh (2007) who reported the existence of genetic variation among cucumber genotypes.

5.4 Effect of different substrates on cucumber fruit quality.

Cocopeat and PF produced cucumber fruit with the highest sugar concentration. The taste as a quality attribute of produce is determined by the amount of soluble solids and organic acids contained in the produce (Kader, 2002; Cantwell *et al*., 2007). Ghehsareh *et al.* (2012) revealed that higher amount of cucumber fruit Total Soluble Solids (TSS) were obtained when date-palm leaves were used used as media values compared to the conventional soil

system values. The results of Inden and Torres (2004) on tomato showed highest amount of TSS value related to the use of cocopeat substrate. High TSS recorded by Cocopeat and PF compared to soil confirms the findings of Massantini *et al*. (1988). Plant nutrients are believed to have high influence on fruit quality and according to Paiva *et al.* (1998), the function of nutrients on plants metabolism influences the effect of nutrient on growth, yield and quality. Potassium (K) is the nutrient having the strongest influence on quality attributes that determine fruit marketability (Al-Moshileh, 2003; Lester *et al*. 2007). This may be explained that the high sugar content of the fruit is due to optimal potassium content of the cocopeat substrate. Voogt and Sonneveld (1997), reported that increase in potassium content of growth media leads to increase in TSS of fruits produced from the medium. Secondly, this may be due to the fact that those fruits were able to convert all their organic acids and starch contents into sugar during maturity. Total biomass production, biomass partitioning influences product quality (Jankauskiene *et al*., 2013). Highest biomass produced by PF coupled with carbohydrate metabolism might have played an important role in the quality of cucumber fruit (Ho, 1988).

High moisture content of fruits in C and C+PF could be due to high potassium content which reduces water loss thereby aided translocation of water to the fruits in C and C+PF. Acquaah (2005) stated that in the event of water stress, fruit crops like tomato and cucumber leaves draw water from the fruit and this might result in low MC of fruits obtained from CRH since the substrate has low moisture holding capacity. The findings support Hector *et al.* (1993) and Albert (2009) who suggested that cucumber contains about 95% water. The more moisture content of fruit recorded by Darina than Kenzo varieties could be due to the fact that Kenzo has more leaves and has to channel more moisture to the vegetative parts thereby reducing the moisture content in their fruits.

With regard to dry matter content of cucumber fruits, there was no significant difference between cocopeat and PF even though higher dry matter content was recorded in cocopeat. Colla *et al* (2003) revealed no significant differences in fruit quality between cucumbers grown in rockwool, perlite and coir.

5.5 Cost benefit analysis of substrates

The highest revenue and the most profitable substrate for cucumber production were recorded by PF whereas CRH and C had the lowest profit. This result could be attributed to the highest yield (t/ha) recorded by PF substrate translating to high revenue. Waste materials may cost less to purchase per unit volume than primary materials like cocopeat (Raviv, 2013). The availability and low cost of PF might have contributed to the high profit obtained in the PF. This confirms Acuna *et al.,* (2005) who reported that the cost of production of soilless media can be reduced especially when local materials are used. Rozman *et al*. (2000) reported that PF is used as a substrate for vegetable production because of its availability and low cost. The low profit obtained in C and CRH might have been due to the high cost of C and low yield produced in CRH. Results proved that palm fibers can be use in place of imported cocopeat or locally processed cocopeat which are expensive. Shabani *et al*. (2011) recommended palm fiber as a whole or mixed as a replacement for peat medium in sweet pepper soilless system.

CHAPTER SIX

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusions

This study has demonstrated that a range of agricultural wastes which are soilless substrates can be used to successfully produce cucumbers under greenhouse conditions and PF, C and PF + CRH significantly had higher growth, yield and fruit quality of cucumber grown under greenhouse conditions. This study also revealed that CRH substrate resulted in poor growth, yield as well as quality of cucumber. However, CRH mixed with PF improved their physical and chemical properties thereby promoting good growth, yield and quality of cucumber fruits.

Based on the objectives of the study, the following conclusions were made.

- PF, C and PF+CRH results in good growth of greenhouse cucumber plants compared to CRH substrate.
- The soilless substrates that produced the best yield of greenhouse grown cucumber are PF (227.25 t/ha), C+PF (101.40 t/ha) and PF+CRH (88.05 t/ha).
- The soilless substrates that produced best cucumber fruits quality in terms of TSS, DM and MC are C, PF and C+PF.
- The production of darina cucumber in PF under greenhouse conditions gave highest profit of GHC 1,202,431.0

6.2 Recommendations

Based on the results from the work conducted, it is recommended that;

- The optimum soilless substrate or their combination that cucumber growers in Ghana can use as an alternative growth media to soil in greenhouse are PF, C, PF + CRH and C+PF substrates due to their relative high performance in terms of growth, yield, quality and profitability as observed in the study.

- Different volumes of trough should be used for these substrates in order to determine their effect on cucumber as well as their cost effectiveness.

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APPENDICES

Appendix 1a: Analysis of variance for plant height (cm) at 2 WAT (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	910.1	455.05	11.28	
Substrate	5	1630.44	326.09	8.08	<.001
Variety	1	300.21	300.21	7.44	0.012
Substrate.Variety	5	133.2	26.64	0.66	0.657
Residual	22	887.82	40.36		
Total	35	3861.78			

Appendix 1b: Analysis of variance for plant height (cm) at 2 WAT (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	849.52	424.76	12.27	
Substrate	5	1551.01	310.2	8.96	<.001
Variety	1	64.8	64.8	1.87	0.185
Substrate.Variety	5	194.44	38.89	1.12	0.377
Residual	22	761.5	34.61		
Total	35	3421.28			

Appendix 2a: Analysis of variance for plant height (cm) at 4 WAT (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	736.5	368.2	3.18	
Substrate	5	5411.6	1082.3	9.35	<.001
Variety	1	6.1	6.1	0.05	0.821
Substrate.Variety	5	885.2	177	1.53	0.221
Residual	22	2545.9	115.7		
Total	35	9585.3			

Appendix 2b: Analysis of variance for plant height (cm) at 4 WAT (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	464.8	232.4	2.43	
Substrate	5	6628.15	1325.63	13.87	<.001
Variety	1	409.39	409.39	4.28	0.05
Substrate.Variety	5	1232.39	246.48	2.58	0.056
Residual	22	2102.77	95.58		
Total	35	10837.51			

Appendix 3a: Analysis of variance for plant height (cm) at 6 WAT (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	1473.7	736.9	3.34	
Substrate	5	9935.3	1987.1	9.01	<.001
Variety	1	758.1	758.1	3.44	0.077
Substrate.Variety	5	379.7	75.9	0.34	0.88
Residual	22	4849.2	220.4		
Total	35	17395.9			

Appendix 3b: Analysis of variance for plant height (cm) at 6 WAT (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	1768.1	884.1	3.49	
Substrate	5	8153.6	1630.7	6.44	<.001
Variety	1	15.6	15.6	0.06	0.806
Substrate.Variety	5	3544.5	708.9	2.8	0.042
Residual	22	5567.5	253.1		
Total	35	19049.2			

Appendix 4a: Analysis of variance for number of leaves/ plant at 2 WAT (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.4822	0.2411	0.65	
Substrate	5	7.8622	1.5724	4.24	0.008
Variety	1	8.2178	8.2178	22.16	<.001
Substrate.Variety	5	2.9422	0.5884	1.59	0.205
Residual	22	8.1578	0.3708		
Total	35	27.6622			

Appendix 4b: Analysis of variance for number of leaves/ plant at 2 WAT (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.5956	0.2978	1.49	
Substrate	5	9.4322	1.8864	9.45	<.001
Variety	1	3.3611	3.3611	16.84	<.001
Substrate.Variety	5	1.8589	0.3718	1.86	0.142
Residual	22	4.3911	0.1996		
Total	35	19.6389			

Appendix 5a: Analysis of variance for number of leaves/ plant at 4 WAT (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	8.6667	4.3333	8.94	
Substrate	5	21.3333	4.2667	8.8	<.001
Variety	1	44.4444	44.4444	91.67	<.001
Substrate.Variety	5	8.8889	1.7778	3.67	0.015
Residual	22	10.6667	0.4848		
Total	35	94			

Appendix 5b: Analysis of variance for number of leaves/ plant at 4 WAT (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	4.916	2.458	2.45	
Substrate	5	44.272	8.854	8.82	<.001
Variety	1	56.25	56.25	56	<.001
Substrate.Variety	5	7.01	1.402	1.4	0.264
Residual	22	22.098	1.004		
Total	35	134.546			

Appendix 6a: Analysis of variance for number of leaves/ plant at 6 WAT (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	5.167	2.583	0.68	
Substrate	5	55.583	11.117	2.93	0.036
Variety	1	34.028	34.028	8.97	0.007
Substrate.Variety	5	22.472	4.494	1.18	0.349
Residual	22	83.5	3.795		
Total	35	200.75			

Appendix 6b: Analysis of variance for number of leaves/ plant at 6 WAT (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	9.722	4.861	1.43	
Substrate	5	75.139	15.028	4.41	0.006
Variety	1	61.361	61.361	18.01	<.001
Substrate.Variety	5	21.139	4.228	1.24	0.324
Residual	22	74.944	3.407		
Total	35	242.306			

Appendix 7a: Analysis of variance for stem girth at 2 WAT (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.004539	0.002269	2.74	
Substrate	5	0.024214	0.004843	5.86	0.001
Variety	1	0.000625	0.000625	0.76	0.394
Substrate.Variety	5	0.005992	0.001198	1.45	0.246
Residual	22	0.018194	0.000827		
Total	35	0.053564			

Appendix 7b: Analysis of variance for stem girth at 2 WAT (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.001622	0.000811	1.75	
Substrate	5	0.020614	0.004123	8.91	<.001
Variety	1	0.000336	0.000336	0.73	0.403
Substrate.Variety	5	0.004281	0.000856	1.85	0.144
Residual	22	0.010178	0.000463		
Total	35	0.037031			

Appendix 8a: Analysis of variance for stem girth at 4 WAT (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.016372	0.008186	5.89	
Substrate	5	0.017722	0.003544	2.55	0.058
Variety	1	0.0016	0.0016	1.15	0.295
Substrate.Variety	5	0.000767	0.000153	0.11	0.989
Residual	22	0.030561	0.001389		
Total	35	0.067022			

Appendix 8b: Analysis of variance for stem girth at 4 WAT (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.006817	0.003408	3.57	
Substrate	5	0.017658	0.003532	3.7	0.014
Variety	1	0.002336	0.002336	2.45	0.132
Substrate.Variety	5	0.006281	0.001256	1.32	0.293
Residual	22	0.020983	0.000954		
Total	35	0.054075			

Appendix 9a: Analysis of variance for stem girth at 6 WAT (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.021272	0.010636	9.17	
Substrate	5	0.010614	0.002123	1.83	0.149
Variety	1	0.007803	0.007803	6.72	0.017
Substrate.Variety	5	0.006547	0.001309	1.13	0.375
Residual	22	0.025528	0.00116		
Total	35	0.071764			

Appendix 9b: Analysis of variance for stem girth at 6 WAT (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.014172	0.007086	6.75	
Substrate	5	0.009456	0.001891	1.8	0.154
Variety	1	0.017778	0.017778	16.94	<.001
Substrate.Variety	5	0.005789	0.001158	1.1	0.387
Residual	22	0.023094	0.00105		
Total	35	0.070289			

Appendix 10a: Analysis of variance for chlorophyll content at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	211.947	105.974	19.06	
Substrate	5	265.08	53.016	9.54	<.001
Variety	1	176.181	176.181	31.69	<.001
Substrate.Variety	5	104.317	20.863	3.75	0.013
Residual	22	122.313	5.56		
Total	35	879.839			

Appendix 10b: Analysis of variance for chlorophyll content at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	190.84	95.42	13.37	
Substrate	5	366.262	73.252	10.26	<.001
Variety	1	143.76	143.76	20.14	<.001
Substrate.Variety	5	9.463	1.893	0.27	0.927
Residual	22	157.013	7.137		
Total	35	867.339			

Appendix 11a: Analysis of variance for chlorophyll content at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	539.22	269.61	13.74	
Substrate	5	383.12	76.62	3.91	0.011
Variety	1	493.95	493.95	25.18	<.001
Substrate.Variety	5	16.59	3.32	0.17	0.971
Residual	22	431.59	19.62		
Total	35	1864.47			

Appendix 11b: Analysis of variance for chlorophyll content at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	421.92	210.96	7.15	
Substrate	5	298.27	59.65	2.02	0.115
Variety	1	162.86	162.86	5.52	0.028
Substrate.Variety	5	161.37	32.27	1.09	0.392
Residual	22	648.99	29.5		
Total	35	1693.42			

Appendix 12a: Analysis of variance for leaf area at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	1096.3	548.1	1.13	
Substrate	5	7552.9	1510.6	3.1	0.029
Variety	1	2402	2402	4.93	0.037
Substrate.Variety	5	462.8	92.6	0.19	0.963
Residual	22	10714.5	487		
Total	35	22228.4			

Appendix 12b: Analysis of variance for leaf area at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	1478	739	0.25	
Substrate	5	19128	3826	1.28	0.309
Variety	1	9816	9816	3.28	0.084
Substrate.Variety	5	26549	5310	1.77	0.16
Residual	22	65936	2997		
Total	35	122908			

Appendix 13a: Analysis of variance for leaf area at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	4276	2138	1.96	
Substrate	5	27713	5543	5.08	0.003
Variety	1	7606	7606	6.98	0.015
Substrate.Variety	5	31272	6254	5.74	0.002
Residual	22	23988	1090		
Total	35	94855			

Appendix 13b: Analysis of variance for leaf area at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	6724	3362	1.9	
Substrate	5	41513	8303	4.7	0.005
Variety	1	5419	5419	3.07	0.094
Substrate.Variety	5	15168	3034	1.72	0.172
Residual	22	38836	1765		
Total	35	107660			

Appendix 14a: Analysis of variance for longest root length at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	96.847	48.424	11.16	
Substrate	5	26.118	5.224	1.2	0.34
Variety	1	12.84	12.84	2.96	0.099
Substrate.Variety	5	18.951	3.79	0.87	0.515
Residual	22	95.486	4.34		
Total	35	250.243			

Appendix 14b: Analysis of variance for longest root length at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.389	0.194	0.03	
Substrate	5	49.785	9.957	1.52	0.224
Variety	1	8.507	8.507	1.3	0.267
Substrate.Variety	5	40.118	8.024	1.22	0.331
Residual	22	144.111	6.551		
Total	35	242.91			

Appendix 15a: Analysis of variance for longest root length at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	141.85	70.92	1.08	
Substrate	5	686.87	137.37	2.09	0.105
Variety	1	65.34	65.34	0.99	0.329
Substrate.Variety	5	120.53	24.11	0.37	0.866
Residual	22	1445.15	65.69		
Total	35	2459.74			

Appendix 15b: Analysis of variance for longest root length at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	91.08	45.54	0.95	
Substrate	5	602.82	120.56	2.51	0.061
Variety	1	5.92	5.92	0.12	0.729
Substrate.Variety	5	52.99	10.6	0.22	0.95
Residual	22	1058.49	48.11		
Total	35	1811.31			

Appendix 16a: Analysis of variance for plant dry weight at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	3.95181	1.9759	28.76	
Substrate	5	4.70618	0.94124	13.7	<.001
Variety	1	0.00063	0.00063	0.01	0.925
Substrate.Variety	5	1.03396	0.20679	3.01	0.032
Residual	22	1.51153	0.06871		
Total	35	11.2041			

Appendix 16b: Analysis of variance for plant dry weight at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	1.7662	0.8831	4.87	
Substrate	5	5.854	1.1708	6.46	<.001
Variety	1	0.0084	0.0084	0.05	0.832
Substrate.Variety	5	0.8295	0.1659	0.92	0.49
Residual	22	3.9888	0.1813		
Total	35	12.4469			

Appendix 17a: Analysis of variance for plant dry weight at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	31.39	15.69	1.29	
Substrate	5	75.07	15.01	1.24	0.325
Variety	1	16.57	16.57	1.37	0.255
Substrate.Variety	5	99.31	19.86	1.64	0.192
Residual	22	266.75	12.13		
Total	35	489.09			

Appendix 17b: Analysis of variance for plant dry weight at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	13.22	6.61	0.57	
Substrate	5	220.52	44.1	3.77	0.013
Variety	1	0.32	0.32	0.03	0.871
Substrate.Variety	5	74.17	14.83	1.27	0.313
Residual	22	257.32	11.7		
Total	35	565.55			

Appendix 18a: Analysis of variance for shoot dry weight at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	3.89764	1.94882	29.42	
Substrate	5	4.89889	0.97978	14.79	<.001
Variety	1	0.00444	0.00444	0.07	0.798
Substrate.Variety	5	1.11222	0.22244	3.36	0.021
Residual	22	1.45736	0.06624		
Total	35	11.37056			

Appendix 18b: Analysis of variance for shoot dry weight at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	2.1652	1.0826	6.41	
Substrate	5	5.409	1.0818	6.4	<.001
Variety	1	0.0125	0.0125	0.07	0.788
Substrate.Variety	5	0.7525	0.1505	0.89	0.504
Residual	22	3.7167	0.1689		
Total	35	12.0559			

Appendix 19a: Analysis of variance for shoot dry weight at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	28.95	14.47	1.22	
Substrate	5	73.04	14.61	1.23	0.327
Variety	1	17.31	17.31	1.46	0.239
Substrate.Variety	5	93.55	18.71	1.58	0.207
Residual	22	260.32	11.83		
Total	35	473.16			

Appendix 19b: Analysis of variance for shoot dry weight at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	12.06	6.03	0.52	
Substrate	5	227.87	45.57	3.89	0.011
Variety	1	0.53	0.53	0.05	0.834
Substrate.Variety	5	75.02	15	1.28	0.307
Residual	22	257.6	11.71		
Total	35	573.08			

Appendix 20a: Analysis of variance for dry leaf weight at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	1.30722	0.65361	24.46	
Substrate	5	1.43556	0.28711	10.75	<.001
Variety	1	0.01361	0.01361	0.51	0.483
Substrate.Variety	5	0.31389	0.06278	2.35	0.075
Residual	22	0.58778	0.02672		
Total	35	3.65806			

Appendix 20b: Analysis of variance for dry leaf weight at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.71375	0.35687	5.49	
Substrate	5	1.80312	0.36062	5.55	0.002
Variety	1	0.00562	0.00562	0.09	0.771
Substrate.Variety	5	0.20979	0.04196	0.65	0.668
Residual	22	1.42958	0.06498		
Total	35	4.16187			

Appendix 21a: Analysis of variance for dry leaf weight at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	10.994	5.497	1.31	
Substrate	5	11.74	2.348	0.56	0.729
Variety	1	16.219	16.219	3.87	0.062
Substrate.Variety	5	29.703	5.941	1.42	0.257
Residual	22	92.16	4.189		
Total	35	160.817			

Appendix 21b: Analysis of variance for dry leaf weight at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	4.777	2.388	0.49	
Substrate	5	58.297	11.659	2.39	0.071
Variety	1	0.311	0.311	0.06	0.803
Substrate.Variety	5	12.966	2.593	0.53	0.749
Residual	22	107.164	4.871		
Total	35	183.515			

Appendix 22a: Analysis of variance for root dry weight at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.002917	0.001458	0.64	
Substrate	5	0.010833	0.002167	0.95	0.472
Variety	1	0.001111	0.001111	0.48	0.494
Substrate.Variety	5	0.002222	0.000444	0.19	0.962
Residual	22	0.050417	0.002292		
Total	35	0.0675			

Appendix 22b: Analysis of variance for root dry weight at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.001689	0.000844	1.22	
Substrate	5	0.012014	0.002403	3.47	0.018
Variety	1	0.005136	0.005136	7.41	0.012
Substrate.Variety	5	0.014014	0.002803	4.04	0.009
Residual	22	0.015244	0.000693		
Total	35	0.048097			

Appendix 23a: Analysis of variance for root dry weight at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.91479	0.45739	5.35	
Substrate	5	2.10733	0.42147	4.93	0.004
Variety	1	0.0141	0.0141	0.17	0.688
Substrate.Variety	5	0.1671	0.03342	0.39	0.849
Residual	22	1.87925	0.08542		
Total	35	5.08257			

Appendix 23b: Analysis of variance for root dry weight at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.75769	0.37885	9.32	
Substrate	5	0.5045	0.1009	2.48	0.063
Variety	1	0.04217	0.04217	1.04	0.32
Substrate.Variety	5	0.29641	0.05928	1.46	0.243
Residual	22	0.8943	0.04065		
Total	35	2.49507			

Appendix 24a: Analysis of variance for shoot: root ratio at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	556.2	278.1	1.93	
Substrate	5	1706.6	341.3	2.37	0.072
Variety	1	271.7	271.7	1.89	0.183
Substrate.Variety	5	538.2	107.6	0.75	0.596
Residual	22	3163.7	143.8		
Total	35	6236.3			

Appendix 24b: Analysis of variance for shoot: root ratio at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	70.2	35.1	0.22	
Substrate	5	3276	655.2	4.17	0.008
Variety	1	85	85	0.54	0.47
Substrate.Variety	5	973.1	194.6	1.24	0.325
Residual	22	3454.3	157		
Total	35	7858.6			

Appendix 25a: Analysis of variance for shoot: root ratio at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	102.05	51.02	1.58	
Substrate	5	845.82	169.16	5.24	0.003
Variety	1	135.3	135.3	4.19	0.053
Substrate.Variety	5	203.23	40.65	1.26	0.317
Residual	22	710.43	32.29		
Total	35	1996.83			

Appendix 25b: Analysis of variance for shoot: root ratio at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	96.49	48.25	3.05	
Substrate	5	266.51	53.3	3.37	0.021
Variety	1	2.5	2.5	0.16	0.695
Substrate.Variety	5	177.59	35.52	2.25	0.086
Residual	22	347.91	15.81		
Total	35	891.01			

Appendix 26a: Analysis of variance for LAR at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	2192.3	1096.2	5.31	
Substrate	5	3836.4	767.3	3.72	0.014
Variety	1	1751.7	1751.7	8.49	0.008
Substrate.Variety	5	2546.2	509.2	2.47	0.064
Residual	22	4540.9	206.4		
Total	35	14867.6			

Appendix 26b: Analysis of variance for LAR at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	30245	15122	2.34	
Substrate	5	102570	20514	3.18	0.026
Variety	1	15029	15029	2.33	0.141
Substrate.Variety	5	37498	7500	1.16	0.359
Residual	22	142120	6460		
Total	35	327462			

Appendix 27a: Analysis of variance for LAR at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	35.28	17.64	0.87	
Substrate	5	669.77	133.95	6.61	<.001
Variety	1	249.93	249.93	12.33	0.002
Substrate.Variety	5	373.75	74.75	3.69	0.014
Residual	22	446.08	20.28		
Total	35	1774.81			

Appendix 27b: Analysis of variance for LAR at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	142.99	71.49	3.31	
Substrate	5	942	188.4	8.71	<.001
Variety	1	31.66	31.66	1.46	0.239
Substrate.Variety	5	115.87	23.17	1.07	0.403
Residual	22	475.68	21.62		
Total	35	1708.2			

Appendix 28a: Analysis of variance for LWR at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.001187	0.000593	0.31	
Substrate	5	0.014695	0.002939	1.52	0.225
Variety	1	0.001916	0.001916	0.99	0.331
Substrate.Variety	5	0.010606	0.002121	1.1	0.391
Residual	22	0.042609	0.001937		
Total	35	0.071013			

Appendix 28b: Analysis of variance for LWR at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.017328	0.008664	1.85	
Substrate	5	0.021018	0.004204	0.9	0.499
Variety	1	0.000244	0.000244	0.05	0.821
Substrate.Variety	5	0.013787	0.002757	0.59	0.708
Residual	22	0.102888	0.004677		
Total	35	0.155265			

Appendix 29a: Analysis of variance for LWR at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.022191	0.011095	1.88	
Substrate	5	0.19934	0.039868	6.74	<.001
Variety	1	0.02761	0.02761	4.67	0.042
Substrate.Variety	5	0.04452	0.008904	1.51	0.229
Residual	22	0.130106	0.005914		
Total	35	0.423767			

Appendix 29b: Analysis of variance for LWR at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.002616	0.001308	0.23	
Substrate	5	0.026826	0.005365	0.95	0.47
Variety	1	0.005217	0.005217	0.92	0.347
Substrate.Variety	5	0.021077	0.004215	0.75	0.598
Residual	22	0.124432	0.005656		
Total	35	0.180168			

Appendix 30a: Analysis of variance for SLA at vegetative stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	6828.2	3414.1	3.69	
Substrate	5	11261.1	2252.2	2.43	0.067
Variety	1	4881.3	4881.3	5.28	0.032
Substrate.Variety	5	9776	1955.2	2.11	0.102
Residual	22	20352	925.1		
Total	35	53098.5			

Appendix 30b: Analysis of variance for SLA at vegetative stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	30245	15122	2.34	
Substrate	5	102570	20514	3.18	0.026
Variety	1	15029	15029	2.33	0.141
Substrate.Variety	5	37498	7500	1.16	0.359
Residual	22	142120	6460		
Total	35	327462			

Appendix 31a: Analysis of variance for SLA at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	32.42	16.21	0.24	
Substrate	5	1925.39	385.08	5.67	0.002
Variety	1	1295.09	1295.09	19.08	<.001
Substrate.Variety	5	1009.32	201.86	2.97	0.034
Residual	22	1493.62	67.89		
Total	35	5755.84			

Appendix 31b: Analysis of variance for SLA at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	514.8	257.4	3.8	
Substrate	5	2159.77	431.95	6.38	<.001
Variety	1	69.1	69.1	1.02	0.323
Substrate.Variety	5	455.68	91.14	1.35	0.282
Residual	22	1489.59	67.71		
Total	35	4688.95			

Appendix 32a: Analysis of variance for RGR at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	2.78E-05	1.39E-05	3.76	
Substrate	5	6.17E-05	1.24E-05	3.34	0.021
Variety	1	4.15E-06	4.15E-06	1.12	0.301
Substrate.Variety	5	3.10E-05	6.20E-06	1.68	0.182
Residual	22	8.13E-05	3.70E-06		
Total	35	2.06E-04			

Appendix 32b: Analysis of variance for RGR at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	1.69E-06	8.44E-07	0.15	
Substrate	5	9.04E-05	1.81E-05	3.22	0.025
Variety	1	5.55E-06	5.55E-06	0.99	0.331
Substrate.Variety	5	4.25E-05	8.51E-06	1.51	0.226
Residual	22	1.24E-04	5.62E-06		
Total	35	2.64E-04			

Appendix 33a: Analysis of variance for NAR at reproductive stage (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	1.38E-06	6.91E-07	0.88	
Substrate	5	6.23E-06	1.25E-06	1.58	0.206
Variety	1	3.33E-06	3.33E-06	4.23	0.052
Substrate.Variety	5	2.98E-06	5.96E-07	0.76	0.59
Residual	22	1.73E-05	7.87E-07		
Total	35	3.12E-05			

Appendix 33b: Analysis of variance for NAR at reproductive stage (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2.52E-06	1.26E-06	1.3	
SUBSTRATE	5	2.42E-05	4.83E-06	4.98	0.003
VARIETY	1	8.70E-07	8.70E-07	0.9	0.354
SUBSTRATE.VARIETY	5	6.67E-06	1.33E-06	1.37	0.272
Residual	22	2.14E-05	9.71E-07		
Total	35	5.56E-05			

Appendix 34a: Analysis of variance for number of nodes/ plant (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	4.667	2.333	0.53	
Substrate	5	362.667	72.533	16.51	<.001
Variety	1	16	16	3.64	0.069
Substrate.Variety	5	113	22.6	5.14	0.003
Residual	22	96.667	4.394		
Total	35	593			

Appendix 34b: Analysis of variance for number of nodes/ plant (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	3.5	1.75	0.47	
Substrate	5	335.667	67.133	18.2	<.001
Variety	1	28.444	28.444	7.71	0.011
Substrate.Variety	5	136.222	27.244	7.38	<.001
Residual	22	81.167	3.689		
Total	35	585			

Appendix 35a: Analysis of variance for number of fruit/ plant (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	4.667	2.333	0.53	
Substrate	5	362.667	72.533	16.51	<.001
Variety	1	16	16	3.64	0.069
Substrate.Variety	5	113	22.6	5.14	0.003
Residual	22	96.667	4.394		
Total	35	593			

Appendix 35b: Analysis of variance for number of fruit/ plant (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	3.5	1.75	0.47	
Substrate	5	335.667	67.133	18.2	<.001
Variety	1	28.444	28.444	7.71	0.011
Substrate.Variety	5	136.222	27.244	7.38	<.001
Residual	22	81.167	3.689		
Total	35	585			

Appendix 36a: Analysis of variance for fruit weight (g) (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	349.89	174.94	6.41	
Substrate	5	91411.74	18282.35	669.54	<.001
Variety	1	3418.74	3418.74	125.2	<.001
Substrate.Variety	5	5414.58	1082.92	39.66	<.001
Residual	22	600.72	27.31		
Total	35	101195.7			

Appendix 36b: Analysis of variance for fruit weight (g) (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	355.01	177.51	6.01	
Substrate	5	89913.17	17982.63	609.26	<.001
Variety	1	3892.51	3892.51	131.88	<.001
Substrate.Variety	5	3718.89	743.78	25.2	<.001
Residual	22	649.34	29.52		
Total	35	98528.92			

Appendix 37a: Analysis of variance for fruit weight (Kg) (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	0.00035	0.000175	6.41	
Substrate	5	0.091412	0.018282	669.54	<.001
Variety	1	0.003419	0.003419	125.2	<.001
Substrate.Variety	5	0.005415	0.001083	39.66	<.001
Residual	22	0.000601	2.73E-05		
Total	35	0.101196			

Appendix 37b: Analysis of variance for fruit weight (Kg) (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	0.000355	0.000178	6.01	
Substrate	5	0.089913	0.017983	609.26	<.001
Variety	1	0.003893	0.003893	131.88	<.001
Substrate.Variety	5	0.003719	0.000744	25.2	<.001
Residual	22	0.000649	2.95E-05		
Total	35	0.098529			

Appendix 38a: Analysis of variance for fruit yield in t/ha (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	131.5	65.8	0.26	
Substrate	5	103947.2	20789.4	81.82	<.001
Variety	1	138.1	138.1	0.54	0.469
Substrate.Variety	5	7900.2	1580	6.22	<.001
Residual	22	5589.7	254.1		
Total	35	117706.7			

Appendix 38b: Analysis of variance for fruit yield in t/ha (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	172.6	86.3	0.49	
Substrate	5	85947.1	17189.4	96.79	<.001
Variety	1	7.8	7.8	0.04	0.836
Substrate.Variety	5	7998.3	1599.7	9.01	<.001
Residual	22	3906.9	177.6		
Total	35	98032.7			

Appendix 39a: Analysis of variance for fruit yield in Kg/m2 (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	1.156	0.578	0.26	
Substrate	5	913.616	182.723	81.82	<.001
Variety	1	1.214	1.214	0.54	0.469
Substrate.Variety	5	69.437	13.887	6.22	<.001
Residual	22	49.13	2.233		
Total	35	1034.552			

Appendix 39b: Analysis of variance for fruit yield in Kg/m2 (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	1.517	0.759	0.49	
Substrate	5	755.409	151.082	96.79	<.001
Variety	1	0.068	0.068	0.04	0.836
Substrate.Variety	5	70.299	14.06	9.01	<.001
Residual	22	34.339	1.561		
Total	35	861.633			

Appendix 40a: Analysis of variance for fruit yield in Kg/Plant (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	0.1184	0.0592	0.26	
Substrate	5	93.5543	18.7109	81.82	<.001
Variety	1	0.1243	0.1243	0.54	0.469
Substrate.Variety	5	7.1103	1.4221	6.22	<.001
Residual	22	5.0309	0.2287		
Total	35	105.9382			

Appendix 40b: Analysis of variance for fruit yield in Kg/Plant (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	0.1554	0.0777	0.49	
Substrate	5	77.3539	15.4708	96.79	<.001
Variety	1	0.007	0.007	0.04	0.836
Substrate.Variety	5	7.1986	1.4397	9.01	<.001
Residual	22	3.5163	0.1598		
Total	35	88.2312			

Appendix 41a: Analysis of variance for fruit diameter (cm) (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	1.2331	0.6165	1.04	
Substrate	5	49.7405	9.9481	16.72	<.001
Variety	1	12.4301	12.4301	20.9	<.001
Substrate.Variety	5	18.7148	3.743	6.29	<.001
Residual	22	13.0865	0.5948		
Total	35	95.205			

Appendix 41b: Analysis of variance for fruit diameter (mm) (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	0.334	0.167	0.15	
Substrate	5	63.819	12.764	11.83	<.001
Variety	1	11.56	11.56	10.71	0.003
Substrate.Variety	5	32.578	6.516	6.04	0.001
Residual	22	23.741	1.079		
Total	35	132.032			

Appendix 42a: Analysis of variance for fruit length (cm) (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	1.7222	0.8611	1.04	
Substrate	5	69.4722	13.8944	16.72	<.001
Variety	1	17.3611	17.3611	20.9	<.001
Substrate.Variety	5	26.1389	5.2278	6.29	<.001
Residual	22	18.2778	0.8308		
Total	35	132.9722			

Appendix 42b: Analysis of variance for fruit length (cm) (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.389	0.194	0.15	
Substrate	5	74.222	14.844	11.83	<.001
Variety	1	13.444	13.444	10.71	0.003
Substrate.Variety	5	37.889	7.578	6.04	0.001
Residual	22	27.611	1.255		
Total	35	153.556			

Appendix 43a: Analysis of variance for TSS of fruit (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	0.8956	0.4478	2.66	
Substrate	5	7.5389	1.5078	8.97	<.001
Variety	1	0.0044	0.0044	0.03	0.872
Substrate.Variety	5	2.0989	0.4198	2.5	0.062
Residual	22	3.6978	0.1681		
Total	35	14.2356			

Appendix 43b: Analysis of variance for TSS of fruit (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP Stratum	2	0.395	0.1975	3.49	
Substrate	5	9.66583	1.93317	34.16	<.001
Variety	1	0.0025	0.0025	0.04	0.835
Substrate.Variety	5	2.69917	0.53983	9.54	<.001
Residual	22	1.245	0.05659		
Total	35	14.0075			

Appendix 44a: Analysis of variance for MC of fruit (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	306.4	153.2	5.72	
Substrate	5	90160.95	18032.19	672.91	<.001
Variety	1	3428.68	3428.68	127.95	<.001
Substrate.Variety	5	5539.65	1107.93	41.34	<.001
Residual	22	589.54	26.8		
Total	35	100025.2			

Appendix 44b: Analysis of variance for MC of fruit (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	326.93	163.46	5.62	
Substrate	5	88626.93	17725.39	609.28	<.001
Variety	1	3900.47	3900.47	134.07	<.001
Substrate.Variety	5	3811.28	762.26	26.2	<.001
Residual	22	640.03	29.09		
Total	35	97305.63			

Appendix 45a: Analysis of variance for DM of fruit (Experiment 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	1.454	0.727	2.66	
Substrate	5	12.2399	2.448	8.97	<.001
Variety	1	0.0072	0.0072	0.03	0.872
Substrate.Variety	5	3.4077	0.6815	2.5	0.062
Residual	22	6.0036	0.2729		
Total	35	23.1124			

Appendix 45b: Analysis of variance for DM of fruit (Experiment 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	0.64131	0.32065	3.49	
Substrate	5	15.69315	3.13863	34.16	<.001
Variety	1	0.00406	0.00406	0.04	0.835
Substrate.Variety	5	4.38228	0.87646	9.54	<.001
Residual	22	2.02134	0.09188		
Total	35	22.74215			

Appendix 46a: Analysis of variance for revenue

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	3.29E+09	1.64E+09	0.26	
Substrate	5	2.60E+12	5.20E+11	81.82	<.001
Variety	1	3.45E+09	3.45E+09	0.54	0.469
Substrate.Variety	5	1.98E+11	3.95E+10	6.22	<.001
Residual	22	1.40E+11	6.35E+09		
Total	35	2.94E+12			

Appendix 46b: Analysis of variance for profit

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep Stratum	2	3.29E+09	1.64E+09	0.26	
Substrate	5	2.99E+12	5.98E+11	94.07	<.001
Variety	1	3.45E+09	3.45E+09	0.54	0.469
Substrate.Variety	5	1.98E+11	3.95E+10	6.22	<.001
Residual	22	1.40E+11	6.35E+09		
Total	35	3.33E+12			