POTASSIUM AND SODIUM EXTRACTION IN COCOPEAT FOR POTATO (*Solanum tuberosum* L.) MINITUBER PRODUCTION UNDER VARIED CALCIUM NITRATE SOAKING DURATIONS AND COCOPEAT-PUMICE MEDIA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been submitted or presented for examination in any other institution for the award of a degree

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Recommendation

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DEDICATION

This thesis is dedicated to my family, cohort III Transforming African Agricultural Universities to Meaningfully Contribute to Africa’s Growth and Development (TAGDev) students and TAGDev secretariat for their moral support and encouragement.

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ABSTRACT

The low potato productivity of 9-10 tonnes ha^{-1} in Kenya arose from the rampant use of uncertified seeds in unhealthy soils. The objectives of this study were to improve the cocopeat soilless medium through the extraction of high K and Na using calcium nitrate ($Ca(NO_3)_2$) and soaking duration and to evaluate cocopeat-pumice mixtures for potato minituber production. Three successive experiments were conducted in a greenhouse at the Climate and Water Smart Agriculture Centre of Egerton University, Kenya. The treatments for the first and second experiments were five soaking durations (12, 24, 36, 48, and 72 hours) and four levels of $Ca(NO_3)_2$ (0, 60, 100, and 150 g) levels mixed with 1.5 kg of cocopeat in 15 litres of water. Soil and untreated cocopeat were used as positive and negative controls, respectively. The third experiment comprised of six cocopeat-pumice mixtures (ratios), *viz* 100% cocopeat (T1), 75:25% (T2), 50:50% (T3), 25:75% (T4), 100% pumice (T5) and 100% soil (T6). The General Linear Model procedures were used for the Analysis of Variance at ($P \leq 0.05$) as well as regression analyses to develop nutrient-to-yield relationships. The result showed that K and Na in treated cocopeat were significantly ($P<0.05$) reduced by 78.44% and 92.00%, respectively when 1.5 kg of cocopeat was soaked for 36 hours with a concentration of 100 g $Ca(NO_3)_2$. In all the treatment combinations, after the cocopeat was washed, the EC was reduced from 1.55 to <1 mS cm^{-1} and pH from 5.83 to between 5.66-5.71. There were significant ($P \leq 0.05$) correlation and regression relationships between soaking duration of various $Ca(NO_3)_2$ concentrations with K, Na, N, Ca, EC and pH in both the leachate solution and the cocopeat filtrate. For the second experiment, the interaction of $Ca(NO_3)_2$ × soaking duration significantly ($P<0.001$) increased all the yield parameters. The highest growth and yield (464.67 g $plant^{-1}$) observations were obtained from the combination of 100 g of $Ca(NO_3)_2$ with a soaking duration of 36 hours. In the third experiment, the highest ($P \leq 0.05$) plant heights (67.57 cm and 63.87 cm) and minituber yields (402.68 g and 372.68 g $plant^{-1}$) were achieved with 100% cocopeat medium followed by the 50:50% cocopeat-pumice mixture, respectively. The highest minituber yields and economic returns were obtained with a 100% cocopeat medium. Seed potato producers using hydroponics systems can effectively optimize concentrations of K, Na; EC and pH levels in (cocopeat soil) media by soaking (ratios) of 1.5 kg untreated cocopeat in 100 g of $Ca(NO_3)_2$ for 36 hours.

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LIST OF ABBREVIATIONS AND ACRONYMS

ADC:	Agriculture Development Corporation
AFA-NOCD:	Agriculture and Food Authority-Nuts and Oil Crops
AFP:	Air-filled Porosity
ANOVA:	Analysis of Variance
ARCs:	Apical rooted cuttings
CEC:	Cation Exchange capacity
CRD:	Completely Randomized Design
EC:	Electrical conductivity
FAO:	Food and Agriculture Organization of the United Nations
FAOSTAT:	Food and Agriculture Organization Corporate Statistical Database
HSD:	Honestly Significant Difference
KARI/KALRO:	Kenya Agricultural Research Institute/ Kenya Agricultural and Livestock Research Organization.
KEPHIS:	Kenya Plant Health Inspectorate Service
KES:	Kenyan Shillings
M.A.S.L:	Metres above sea level
MSD:	Minimum Significant Difference
NARL:	National Agricultural Research Laboratory
NDVI:	Normalized Difference Vegetation Index
NPCK:	National Potato Council of Kenya
SSA:	Sub-Saharan Africa
TAGDev:	Transforming African Agricultural Universities to Meaningfully Contribute to Africa's Growth and Development
WHC	Water Holding Capacity

CHAPTER ONE

INTRODUCTION

1.1 Background information

Potato (*Solanum tuberosum* L.) is widely used as a food and cash crop in most parts of the world. It belongs to the family of *Solanaceae*, and it is the world's third-largest food crop after wheat and rice (Campos & Ortiz, 2020). Due to its demand in over 149 countries in temperate and tropical regions, its cultivation is estimated at 19 million hectares globally, with 378 million tonnes of productivity (Devaux *et al.,* 2020). In most developing countries worldwide, potato is considered an essential source of income, employment, and food. As of 2018, Kenya emerges as the fourth biggest potato producer in Africa, with a total production of 1.8 million tonnes cultivated on 217,315 ha (FAOSTAT, 2018). After maize (*Zea mays*), potato is considered the second most important food crop in Kenya (NPCK, 2019). Potato production in Kenya is dominant in three regions: Central, Rift valley, and Eastern, with 40 to 50 billion Kenyan Shillings year^{-1} (KEPHIS, 2016).

Many potato varieties have been introduced in Kenya: *Shangi, Kenya Mpya, Tigoni, Asante, Dutch Robijn, Kenya Baraka, Sherekea, and Kenya Karibu,* amongst others (Kaguongo *et al.,* 2014). Regardless of Kenya being the fourth largest potato producer in Africa, there still exist significant production challenges in the potato sub-sector. The average national potato yield in Kenya is 9-10 tonnes ha^{-1}, compared to the global average potato productivity of 20-40 tonnes ha^{-1} attainable yield (Kiptoo *et al.,* 2016; VIB, 2019). This productivity gap is associated with poor quality potato minitubers, improper utilization of growth media, unbalanced crop mineral nutrition, and declining soil fertility, amongst other factors, especially in places like Nakuru, Kenya (Jane *et al.,* 2010). Only about 2% of the potato acreage in Kenya is planted with certified seeds from the formal seeds system (KEPHIS, 2016).

The use of appropriate growth media leads to high-quality seeds that are very important for higher yield. Increased shortage of certified planting materials has led to low yields, the spread of pests and diseases and poor-quality products (Demo *et al.,* 2015). Minitubers production, which is often done in a greenhouse, is one of the primary methods for potato seed production (Struik, 2007). Hence, the use of appropriate growth media systems can be an effective technique for producing quality minitubers. Soilless culture is a method of growing plants in a soilless medium that helps to reduce the problems of traditional crop cultivation related to soil (Murumkar *et al.,* 2012). Soilless cultivation is becoming a vital part of the world's agriculture. Using soil as growth media is associated with a low multiplication rate of tubers, higher disease prevalence and more laborious weed control (Darvishi *et al.,* 2012). In most developing countries, different growth media such as cocopeat, pumice, vermiculite, peat moss, and perlite mixtures have been used to produce potato minitubers. Commercial application of soilless culture has increased over the years since it is an alternative to soil disinfection, results in high productivity, and increases water use efficiency (Aydoğan *et al.,* 2009). The main challenges in the use of soilless media are related to the standardization of the media to provide the appropriate physical and chemical properties necessary for the effective growth of plants.

Soils are generally unsatisfactory for the production of plants in pot culture (Kamrani *et al.,* 2019). Aeration, water holding capacity, and drainage requirements are typically low in soil compared to commercially available media. Widespread adoption of soilless potting media in global food production has been reported as one of the technical solutions for problems including low productivity, root diseases, root zone oxygen deficiency, and fertility control which occurs in the soil system (Kamrani *et al.,* 2019). The merits of media systems over soil systems are better water and nutrient use efficiencies and higher productivity. Research has shown that different media, like cocopeat, pumice, perlite, vermiculite, and compost, amongst others, can be used to successfully grow seed potato plantlets in a greenhouse (Balali *et al.,* 2008).

Cocopeat is a planting media made from coconut husk. Cocopeat has a quickly absorbing and water-saving ability which contains pores that facilitate the exchange of air and the entry of sunlight (Putra *et al.,* 2019). Potassium, one of the dominant elements in cocopeat, can be attached to up to 40 cmol kg^{-1} of the total sites and Na at about 15 cmol kg^{-1} of the total sites (Halamba & Kuack, 2021). High K concentration levels have been reported in cocopeat, which leads to toxicity and affects crop production in a hydroponics production system (Awang *et al.,* 2009). For this reason, efforts are made to optimize K in cocopeat to about 4.87 cmol kg^{-1} before using it as a growing media (Kang *et al.,* 2014). Optimizing the high level of K in cocopeat reduces K toxicity in the media, stimulates root development, and effective growth of crops like potato (Shanmugasundaram *et al.,* 2014). Calcium nitrate reduces elements that are naturally bonded to the cation exchange complex of cocopeat; washing the cocopeat with water will merely allow the water-soluble elements to be removed (Halamba & Kuack, 2021; Marock, 2021; Wittman, 2020). The goal of treating cocopeat is to standardize the quantity of cation exchange capacity (CEC) sites that have K and Na attached.

Pumice is a well-known glassy igneous rock of volcanic sources, having low density and high porosity (Rashad, 2021). It is a naturally lightweight material that is formed due to the speedy cooling of molten volcanic ash (Caso *et al.,* 2009). Like cocopeat, pumice has a relatively low bulk density which is essential for crop production. Pumice has been largely used as a plant growth medium; it lightens the soil when mixed and improves soil aeration and water-holding capacity. Pumice mixed with soil in certain quantities improves water conductivity and soil air and decreases the negative effects of saturation, crusting, shrink-swelling, and cracking (Sahin *et al.,* 2002). Pumice can also be used for an extended period because of its stable physical and chemical properties. It can be easily accessed since there are many pumice deposits distributed around the world. Growing healthy and the best quality minitubers is an essential issue in potato production. This is possible when suitable growing media is used. Despite the previous research done to enhance potato productivity in Kenya, more have focused on pest and disease control. Less attention has been paid to soilless media for quality potato minitubers production using apical rooted cuttings. Hence, this research objective was to find out the best soaking duration and $Ca(NO_3)_2$ concentration for extracting K and Na in cocopeat media and finding the best mixture of cocopeat and pumice for seed potato production in Kenya.

1.2 Statement of the problem

Currently, only about 2% of the potato growing areas in Kenya is planted with certified seeds while 98% is planted with seeds from the informal system (uncertified). Despite the importance of potato in the country, its yields per hectare have declined way below the potential with poor quality seed being one of the significant factors responsible. The estimated potato yield in Kenya is 9-10 tonnes ha^{-1}, while the potential global productivity is estimated at 20-40 tonnes ha^{-1}. To produce certified seeds, minituber production is one of the most critical approaches. Further, most farmers in Kenya are using soil for the production of minitubers. Soil is prone to infection by soil pests and diseases, leading to low yields. Because cocopeat is readily available, some farmers are using it with limited knowledge of its high K, Na, and EC levels. Using cocopeat without reducing its K, Na, and EC content results in low minituber production due to its toxicity. This study aimed to reduce the K, Na and EC levels in cocopeat media using different $Ca(NO_3)_2$ levels and soaking durations for its subsequent use in production of potato minitubers.

1.3 Objectives

1.3.1 General objective

To contribute to food security amongst potato consumers by enhancing the productivity of potato minitubers through standardized soilless media in Kenya.

1.3.2 Specific objectives

i. To determine the effect of calcium nitrate levels and soaking durations on chemical properties of untreated cocopeat.

ii. To determine the effect of calcium nitrate levels and soaking durations in ccocopeat on growth, yield and nutrient uptake of potato.

iii. To determine the effect of treated cocopeat-pumice mixture on media physical properties, nutrient uptake, growth and yield of potato.

1.4 Hypotheses

i. There is no significant effect of calcium nitrate levels and soaking durations on the chemical properties of untreated cocopeat.

ii. There is no significant effect of calcium nitrate levels and soaking durations in cocopeat on growth, yield and nutrient uptake of potato.

iii. There is no significant effect of treated cocopeat-pumice mixture on media physical properties, nutrient uptake, growth and yield of potato.

1.5 Justification of the study

The importance of the study arises from the rampant use of poor quality seed and soil (media) for minituber production which has led to low and poor potato productivity in Kenya (Darvishi *et al.,* 2012). The findings of this study will benefit potato producers (small and large scale farmers) and will contribute to the Agricultural Development Cooperation, Kenya. Potato is considered the second most important food crop, with over 800,000 smallholder potato farmers, constituting 83% of the total farmers in Kenya (KEPHIS, 2016). Increased production of potato in Kenya is likely to impact the food security situation positively. The findings of this research will therefore contribute to achieving higher potato productivity, food security and reducing environmental pollution resulting from coconut husks. The availability of quality seed potato leads to a higher production rate and minimizes the cost of production (Janssens *et al.,* 2013). It is envisaged that with quality seed, Kenya can close the productivity gap of 9-10 tonnes ha^{-1} to 20-40 tonnes ha^{-1}. One way to solve this problem is by producing quality minitubers using soilless technology, like cocopeat as a growth medium. This research determined an optimal cocopeat K, Na and EC content and $Ca(NO_3)_2$ concentration with the soaking duration for potato minitubers production.

1.6 Thesis layout

This thesis comprises of six chapters where chapters one and two are background information and literature review, respectively. Chapter three, four and five results from related objectives 1, 2, and 3 are presented and discussed. Each of these three chapters comprises an abstract, introduction, materials and methods, results, discussions, and conclusions. A general discussion is presented in chapter six and includes the overall conclusions and recommendations. The references for all chapters are given together in one list, followed by appendices.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution of potato

Potato belongs to the family *Solanaceae* associated with crops such as pepper (*Capsicum annuum*), eggplant (*Solanum melogena*), tobacco (*Nicotiana tabacum*), and tomato (*Lycopersicon esculentum*) (Campos & Ortiz, 2020). It is classified as an annual plant that produces starchy tubers, which are highly nutritious. Its origin is traced to the Andean regions of Bolivia and Peru. It was introduced into Spain from South America in the latter half of the sixteenth century. From Spain, the potato was introduced to adjacent countries and within 100 years was being grown extensively in many regions of Europe. Distribution beyond Europe soon occurred with the introduction into India in the seventeenth century and China and Japan in the eighteenth century (Campos & Ortiz, 2020). It was introduced in Africa at the end of the 17th century by Christian missionaries through small plantations (Lim, 2016). Potato has been used for food for over 10,000 years. It was domesticated during pre-Columbian times over 8,000 years ago because it is an essential food for most developing countries' rural and urban populations (Louderback & Pavlik, 2017).

2.2 Global potato production

Currently, Potato is consumed almost daily by more than a billion people and it is grown in more than 149 countries, while hundreds of millions of people in developing countries depend on potato (Kaguongo *et al.*, 2013). Globally, China and India, respectively, stand as the leading producers of potato (Campos & Ortiz, 2020). Sub-Saharan Africa produces more than 7 million tonnes of potato annually, about 5% of global production. The potato growth rate has also been vital in Africa, with Egypt, Malawi, South Africa, Algeria, and Morocco producing more than two-thirds of the total potato in the region (Campos & Ortiz, 2020).

2.3 Economic importance of potato

Potato is the second most important food crop in Kenya in productivity; it is an important staple and cash crop for smallholder farmers with over 800,000 (Gildemacher *et al.*, 2011). In terms of monetary value, potato contributes KES (Kenyan shillings) of about 30 to 40 billion year^{-1} in Kenya (Janssens *et al.,* 2013). Potato is ranked as the fourth world crop with a rate of nearly 378 million tonnes of annual production (Nagib *et al.,* 2003). This crop has been the key factor in terms of food security, nutrition, population growth and urbanization in many regions. In recent decades, the potato has become a dominant crop in countries such as China and India, and its cropping area and production have increased more than those of any other food crop in Africa (Sapkota *et al.,* 2019). Global potato production has increased by about 20% since 1990, but its production is still 50% below wheat, maize, and rice (FAO, 2019).

2.4 General requirements for potato production

Potato perform well in cool climatic conditions and the optimum temperature range is 15- 20°C. It prefers day temperatures of 20°C and night temperatures below 20°C (Lim, 2016). Such temperature conditions are conducive for growth and tuberization. Potato should be grown at an altitude of 1500-2800 metres above sea level (m.a.s.l) (Kaguongo *et al.,* 2013). However, the average temperature during the growing season is the primary determinant factor for final dry matter concentration at harvest: low temperatures lead to high dry matter concentrations and vice versa (MacKerron & Haverkort, 2004). The suitability of growing conditions highly contributes to higher productivity. Potato prefers slightly acidic sandy or silty soil with a pH ranging from 5-6.5. At the same time, potato is a highly fertilizer-requiring crop (Sapkota *et al.,* 2019). For maximum potato production, rainfall between 850-1200 mm is recommended (JIAC *et al.,* 2019).

Due to the high prevalence of this disease, a strict rotation programme is required in potato production. Despite this requirement, only a few farmers in the potato-growing areas of Kenya can afford to maintain the recommended one-and-a-half years rotational programme due to the scarcity of land (Riungu, 2011). Currently, the public bodies involved in seed potato production include KALRO, Universities, KEPHIS, Agricultural Development Corporation (A.D.C) and the Ministry of Agriculture, Livestock and Fisheries. Seed potato grows well at altitudes between 1,500 to 3,000 m.a.s.l with an optimum soil temperature of 15-20 ºC and an optimum pH of 5.5 to 7.0 (NPCK, 2019).

2.5 Effects of sodium in potato production

Among abiotic stresses, salinity is a major global threat to agriculture, causing severe damage to crop like potato production and productivity. Salinity stress is primarily sensed by the roots, and particularly root meristem (Richardson *et al*., 2001). As the concentration of salts (particularly Na^{+} and Mg^{2+} ions) increases, there is a decline in root number, root diameter, and root length (Murshed *et al*., 2018). Excessive Na concentration leads to a drastic reduction of crop yield and quality. The initial symptoms of sodium toxicity are observed in the root system, where the reduction in root growth was severely impaired due to excessive Na (Jbir-Koubaa *et al*., 2015). In addition to changing climatic scenarios, soil salinization has become a global problem. Potato is a very versatile crop that can be grown in different kinds of soil. However, its growth and yield are severely affected due to salinity stress (Zhang *et al*., 2020). High concentrations of Na^{+} is a limiting factor for growth under salt stress. Sodium interferes with K^{+} along with reduction in the photosynthetic capacity due to chlorophyll degradation. These ions also impair biochemical function, such as the synthesis of protein and inactivation of enzymes. Damage to chloroplasts and other organelles occurs under extreme Na^{+} conditions (Zhang *et al*., 2020). Plant species maintain their standard metabolic mechanism like water use efficiency (WUE) under salt stress conditions. Based on the response to the salinity, plant species have been classified into two groups, namely, salt-tolerant (≤4 dsm−1 or ≤40 mM NaCl), and salt-sensitive (≥2 dsm−1 or up to 20 mM NaCl) (Hirasawa *et al*., 2017).

2.6 Importance of treating cocopeat for minituber production

Coconut coir dust, commercially known as coco-peat, is an easily affordable growth medium for raising seedlings in nurseries, especially for vegetable crops in the tropics. Approximately 12 million tonnes of cocopeat are produced annually around the world (Nichols, 2013). Cocopeat is an agricultural by-product obtained after extracting fibre from the coconut husk, which has a quickly absorbing and saving water attribute (Abad *et al.,* 2002). Cocopeat also has pores that facilitate the exchange of air and the entry of sunlight. It has a salt content or EC level of 6 to 12 mS cm^{-1}, too high for a growing medium. High-quality cocopeat should be washed thoroughly until an EC of below 1 mS cm^{-1} is reached. After soaking, there will still be some K and Na in the peat complex, which can only be removed through buffering (Marock, 2021). Cocopeat is a suitable growing media with acceptable physical and chemical attributes such as K, pH, electrical conductivity, bulk density and other attributes (Abad *et al.,* 2002). Awang *et al.* (2009) indicated that the E.C of treated cocopeat is 0.16 mS cm^{-1} while the bulk density is 0.16g per cm^{3}, but when mixed with other soilless media (perlite, kenaf core fibre) its bulk density tends to reduce.

According to Sahin *et al.* (2002), a mixture of peat moss: and perlite at the ratio of 60:40 and 80:20 will reduce the bulk density to 0.09 g per cm^3. Subramani *et al.* (2020) reported that the mixture of cocopeat and saw dust (1:1 v/v) was economically and environmentally sustainable for the soilless cultivation of tomatoes.

2.7 Seed potato production in a hydroponics system

Hydroponics is the system of growing plants using nutrient solutions dissolved in water without the use of soilless as a growing medium. Soilless culture is characterized as plant cultivation *in situ* systems without soil (Savvas & Gruda, 2018). In this system, plants can take all the required nutrients directly through their roots by fertigation (Tessema & Dagne, 2018). The word hydroponics is derived from Greek phrases *hydro*, meaning water and *ponos*, which means labour. It is the technique that involves growing plants in water mixed with all the necessary plant nutrients or in an inert medium such as gravel, block or cockpit. The technology is well suited to locations and situations where land is scarce, the soil is poor in quality, and population pressure is the challenge to expand the farming lands.

In hydroponics technology, one could harvest the same output only in 20% of land compared to soil gardens. Hydroponics crop production has significantly increased in recent years worldwide, as it allows more efficient use of water and fertilizers as well as better control of climate change-related pests. Soilless propagation techniques provide unprecedented opportunities for producing seed potatoes at enhanced rates in a controlled environment with a minimal incidence of pests and diseases. According to Roy (2014), seeds have become the most critical concern to ensure the harvest with acceptable quality and to capacitate productivity by 15-25%. Therefore, improving seed potato quality and availability is one way of improving the productivity of potato. Furthermore, the conventional propagation method is one of the slowest methods of seed multiplication for potato due to its low multiplication rate unless some of the accelerated seed potato multiplication systems are implemented (Otazu, 2010; Tessema & Dagne, 2018).

2.8 Utilization of pumice for potato production

Pumice, like perlite, is a siliceous material of volcanic origin. It has basically the same properties as perlite, but it is quite heavier and does not absorb much water as readily since it has not been hydrated. It is used in mixtures of peat and sand for the growing of potted plants (Resh, 2013). Essentially, pumice contains trace amounts of nutrients such as Phosphorus, Potassium, Calcium, Magnesium, Sodium, Copper, Iron, and Manganese (FAO, 2018). Pumice is one of the most common solid materials used in hydroponics systems for seed potato production. Other materials such as expanded clay pebbles, rock wool, vermiculite, perlite, and gravel are essential mixtures with other soilless media for seed potato production (Resh, 2013). Most commonly, pumice, which costs less, may be substituted for perlite in most mixes (25:75, 50:50, 75:25%, and vice versa). Perlite, vermiculite, and pumice break down with constant use, resulting in the compaction of the medium. For this reason, peat mixtures are generally mixed between crops for effective productivity (Resh, 2013). Awang *et al.* (2009), found that the pH in 100% cocopeat and 70% cocopeat: 30% kenaf core fibre was higher than the mixture of 70% cocopeat: 30% burnt rice hull, 70% cocopeat: 30% perlite, and 40% cocopeat: 60% kenaf core fibre. Trivedi and Joshi (2014) reported a higher seed germination rate at 68% in pure cocopeat than in the mixture of cocopeat with sand and cocopeat with soil.

2.9 Effects of soil on crop production

The low number of seed potato in soil culture compared with soilless culture have been reported by Mobini *et al.* (2009). The more significant number of seed potatoes in soilless culture was attributed to the availability of nutrients and lower pH range than soil media. Some of the disadvantages of using soil for seed production include disease prevalence, low tubers' multiplication rate, and intense laborious weed controlling (Darvishi *et al.,* 2012). Growth media containing soil has a higher bulk density compared to other media. Daniels-Lake *et al.* (2005) reported a greater tuber fresh weight and dry weight and leaf area index in soilless culture than in soil culture. Similarly, a low number of seed potato in soil culture has been reported compared with soilless culture (Corrêa *et al.,* 2008).

CHAPTER THREE

EFFECTS OF CALCIUM NITRATE LEVELS AND SOAKING DURATIONS ON CHEMICAL PROPERTIES OF UNTREATED COCOPEAT

Abstract

Methods for extracting potassium (K), sodium (Na) and lowering electrical conductivity (EC) are yet to be standardized for the production of seed-potato minitubers. This study was therefore conducted to investigate and optimize the extraction of K and Na elements in untreated cocopeat. A greenhouse pot experiment was carried out at the Climate and Water Smart Agriculture Centre of Egerton University, Kenya. Five soaking durations *viz,* 12, 24, 36, 48, and 72 hours and four calcium nitrate ($Ca(NO_3)_2$) levels *viz,* 0, 60, 100, and 150 g were used. The General Linear Model procedures were used for the Analysis of Variance at ($P \leq 0.05$). The result showed that there was no significant ($P > 0.05$) interaction effect of $Ca(NO_3)_2$ × soaking duration for the extraction of K, Na, and EC in cocopeat. The addition of 100 g $Ca(NO_3)_2$ extracted significantly more K and Na in the leachate than the control (0.0 g) and 60 g $Ca(NO_3)_2$, respectively. The EC levels in the leachate increased with the $Ca(NO_3)_2$ application levels while the pH levels were declining from 6.36 to 5.88. In the treated cocopeat, soaking for 36 hours with 100 g $Ca(NO_3)_2$ significantly reduced K and Na by 78.44% and 92%, respectively. Exchangeable calcium (Ca) and total nitrogen (N) were observed to increase with a commensurate decline in K and Na concentrations. Subsequent washing of all treated cocopeat resulted in the decline of EC (<1 mS cm^{-1}) and pH (5.5-6.5) values to within acceptable ranges for optimal growth and yield of potato apical rooted cuttings. There was an inverse correlation between Ca and Na; Ca and K, and Na and EC. However, there was a significant positive correlation between exchangeable Ca and N and between Ca and EC observed. Growers are therefore encouraged to treat 1.5 kg of untreated cocopeat for 36 hours with 100 g of $Ca(NO_3)_2$ in 15 litres of water for minimal reduction of K and Na in cocopeat for hydroponics uses.

Key words: Hydroponics, leachate, potassium, potato, sodium.

3.1 Introduction

Cocopeat, also known as coconut (C*ocos nucifera* L.) fibre, coir, coir pith, or coir dust, is an organic planting media made from coconut husk that surrounds the shell of the coconut (Kimbonguila *et al.,* 2019; Putra *et al.,* 2019). Generally, cocopeat contains high K, Na, and EC levels, which vary with the source (Abad *et al.,* 2002). The husks are used to produce various types of growing substrates, including cocopeat, chips, and chunks. Out of the total annual global production of coconut 62.8 million tonnes, only 10% of the coconut husks are used for cocopeat extraction, amounting to an estimated 1.5 million metric tonnes (AFA-NOCD, 2020; FAOSTAT, 2020). The importance of cocopeat as a soilless media cannot be overemphasized; it has an ideal pH, holds more than 22% air, and has excellent drainage properties. Its anti-fungicidal properties help plants get rid of soil-borne diseases, and it is 100% renewable, easy to hydrate, has little or no weed, and is environmentally friendly (Marock, 2021; Schell, 2021). In Kenya, the total area covered by coconut was estimated at 82,921 and 84, 824 hectares in 2018 and 2019, respectively, and this was mainly in the coastal regions (AFA-NOCD, 2020; FAOSTAT, 2020).

Soilless culture has become one of the prominent means to achieve higher crop productivity around the globe. Despite cocopeat's importance as a media, its use faces some challenges related to its chemical composition. The cocopeat's cation exchange capacity (CEC) is between 40-100 cmol kg^{-1} (Marock, 2021). This means that cocopeat can hold onto nutrients, but it can also lock certain nutrients out, leading to deficiencies in the plants. Cocopeat's initial cation exchange sites are naturally saturated with K and Na with little or no calcium (Ca) (Halamba & Kuack, 2021; Sachin *et al.,* 2020; Wittman, 2020). Potassium, the dominant element in cocopeat, can be attached up to between 38.5-40 cmol kg^{-1} of the total sites and Na at 13.04-15 cmol kg^{-1} of the total sites (Wittman, 2020). Through cation exchange, in the presence of Ca, the sites will release their Na and K cations and lock onto Ca. Coconut trees have a naturally high tolerance for sodium chloride (Marock, 2021). Most coconuts are produced along the coast or on highly saline soils. The origin of cocopeat has an impact on its nutrient content as those produced away from the ocean may not accumulate as much Na and K compared to those grown along the coast (Poulter, 2014). The EC of an untreated cocopeat is usually >1.0 milli-Siemens per centimetre (mS cm^{-1}). For hydroponics purposes, it is advisable to maintain EC <1.0 mS cm^{-1} (Halamba & Kuack, 2021). For maximum utilization of cocopeat for crop production, efforts must be made to reduce the high level of K and Na in cocopeat. Reducing the high level of K in cocopeat reduces K toxicity, enhances Ca uptake by the plant, and stimulates crop root development leading to higher productivity of crops (Shanmugasundaram *et al.*, 2014).

Several methods are used to treat cocopeat for K and Na optimization: water, with and without $Ca(NO_3)_2$, magnesium nitrate, and barium chloride (Poulter, 2014; Verhagen, 1999; Wittman, 2020). The use of $Ca(NO_3)_2$ reduces elements that are naturally bonded to the cation exchange complex of cocopeat (Marock, 2021; Wittman, 2020). The main goal of treating cocopeat is to reduce the quantity of K and Na and supplement with Ca and N. Using untreated cocopeat to grow crops creates an unsuitable growth medium for many horticultural plants. When the untreated cocopeat is used for crop production, K and Na develop a stronger attraction to the peat's complex, causing nutrient lockout for other elements. This causes K and Na to be displaced into the solution and be taken up by the plants instead of Ca. The objective of this study was to determine the ratio of $Ca(NO_3)_2$ to cocopeat and soaking duration suitable for K, Na, and EC minimization while supplementing Ca and N in cocopeat.

3.2 Materials and methods

3.2.1 Determination of chemical properties of cocopeat and water used

Initially, the untreated cocopeat sourced from Cocoponics Africa Limited and the water that was used to soak the cocopeat were analysed at the Kenya National Agricultural Research Laboratory (NARL)-Kabete for K Na, Ca, N, EC, and pH. The water quality was evaluated because it affects the exchange reactions of K, Na and Ca on the adsorption complex of cocopeat (Verhagen, 1999). The pH and EC were determined using a 1:2 (w/v) ratio of media to water suspension using a pH metre and conductivity metre for EC (Cheng *et al.* 2006). Using the Kjeldahl digestion method as in Okalebo *et al.* (2002) for total N determination, samples of the substrates were dried in an oven at 70 ˚C and oxidized with hydrogen peroxide 30% at a relatively low temperature (100 ˚C). After decomposition of the excess H_2O_2 and water evaporation, digestion was completed with a concentrated 96% sulphuric acid (H_2SO_4) at elevated temperature (330 ˚C) under the influence of selenium powder as the catalyst. After the digested samples were cooled overnight, the exchangeable Ca was determined using an Atomic Absorption Spectrophotometer (AAS) at a wavelength (λ) of 422.7 nm, while exchangeable K and Na were determined using a flame photometer at λ of 766 nm and 589 nm, respectively (Walinga *et al.,* 1989) (Table 3.1).

Table 3.1: Chemical properties of the untreated cocopeat and water used

Properties	K	Na	Ca	Nitrogen	EC	pH
	(cmol kg^{-1})			(g kg^{-1})	(mS cm^{-1})	
Untreated cocopeat	33.33	13.90	3.51	5.30	1.55	5.83
Water	0.03	0.09	0.003	0.00	0.52	7.7

3.2.2 Experimental procedure and treatments

A greenhouse pot experiment, each with a height of 30 cm, base diameter of 28 cm, and top diameter of 28 cm, was conducted at the Climate and Water Smart Agriculture Centre of Egerton University, Nakuru County, Kenya. The study site is situated at 0° 22'S, 35°36'E at an altitude of 2267 m.a.s.l. The experimental site is in agro-ecological zone III (medium potential) with annual rainfall between 950 and 1500 mm (Jaetzold *et al*., 2006). At the experimental site, the average maximum and minimum ambient and greenhouse temperatures recorded were: 22.0 ^oC, 10.0 ^oC, 30.0 ^oC, and 15.1 ^oC, respectively. The experiment was laid in a 5×4 factorial in a Completely Randomized Design (CRD) with 20 treatments and three replicates. Each replicate had 40 soaking pots (two pots treatment^{-1}). The treatments were five soaking durations (12, 24, 36, 48, and 72 hours) and four levels of $Ca(NO_3)_2$ (0, 60, 100, and 150 g) mixed with 1.5 kg of cocopeat in 15. L of water (Table 3.2).

The mixtures were then soaked for their respective soaking durations. After every six hours, each treatment was mixed, and the leachate was collected after the respective soaking durations. Cocopeat media was then well rinsed using hydrogen peroxide (H_2O_2) (0.5 ml into one litre of tap water) as means of eliminating any harmful pest (Schmidt *et al.*, 2006). Each treatment was rinsed using ten litres of the H_2O_2 solution. A second rinsing was done with five litres of tap water (without H_2O_2) for each treatment, and the media was left standing for 24 hours to drain the remaining water. Samples of the treated media in each treatment were taken for laboratory analyses.

Table 3.2: Treatments combination for the leachate and treated cocopeat experiment

Treatments	$Ca(NO_3)_2$ g pot^{-1}	Soaking durations (hours)
C0D1	0	12
C0D2	0	24
C0D3	0	36
C0D4	0	48
C0D5	0	72
C1D1	60	12
C1D2	60	24
C1D3	60	36
C1D4	60	48
C1D5	60	72
C2D1	100	12
C2D2	100	24
C2D3	100	36
C2D4	100	48
C2D5	100	72
C3D1	150	12
C3D2	150	24
C3D3	150	36
C3D4	150	48
C3D5	150	72

Note: C0, C1, C2, C3: calcium nitrate 0, 60, 100, and 150g, respectively. D1, D2, D3, D4, and D5: soaking durations 12, 24, 36, 48 and 72 hours, respectively

3.2.3 Data collection

After the respective soaking durations, the leachate for each treatment was collected and analysed for K, Na, EC, and pH levels. To determine the nutrient content in the treated cocopeat, samples of the treated cocopeat were also collected from each treatment and analysed for K, Ca, Na, total N, EC, and pH levels.

3.2.4 Data analyses

The data collected were subjected to the Shapiro-Wilk normality test to check for conformation to ANOVA assumptions. General Linear Model (GLM) procedures of the statistical analysis system (SAS), version 9.0 was used for ANOVA at $P \leq 0.05$ (SAS Institute Inc., 2002). Treatment means for the main effects of soaking duration and $Ca(NO_3)_2$ were separated using Tukey's Honestly Significant Difference (HSD) test at a 0.05 level of significance. Pearson's Correlation test at $P \leq 0.05$ was also performed between treated cocopeat elements extracted by the main effects of soaking duration and $Ca(NO_3)_2$. Microsoft Excel 2015 was used to develop graphs.

Statistical model (5×4 Factorial randomized completely block design)

$$Y_{ijk} = \mu + C_i + D_j + CD_{ij} + \varepsilon_{ijk}$$

where:

Y_{ijkl} =Overall observations,

μ = Overall mean,

C_i= Effect of i^{th} calcium nitrate i^{th} =1,2,3,4

D_j= Effect of j^{th}, soaking duration j^{th} = 1,2,3,4,5

CD_{ij}= Effect of i^{th} calcium nitrate and j^{th} soaking duration,

ε_{ijk}= Random error.

3.3 Results

3.3.1 Initial analyses for the untreated cocopeat and water

The results showed that the untreated cocopeat had excessive concentrations of K (33.33 cmol kg^{-1}) and Na (13.90 cmol kg^{-1}). The concentrations of Ca and total N were low while the EC was above the threshold of 1 mS cm^{-1}, and the pH value was found to be in the suitable range of 5.5-6.5 (Table 3.1). The critical nutrients in water were ideal for the soaking of cocopeat as none was excessive. The EC of the untreated cocopeat was above the threshold for hydroponics system production due to the high level of Na and K. The untreated cocopeat pH was in a suitable range for hydroponics crops (5.5-6.5) (Mohammed & Marzooqi, 2020; Schell, 2021). Therefore, K, Na and EC were the major problems in the untreated cocopeat examined. Generally, the untreated cocopeat had high K and Na with low N and Ca (Gohil, 2018; Halamba & Kuack, 2021; Sachin *et al.*, 2020; Wittman, 2020). The water used was suitable for treating cocopeat as it had low K, Na, and EC while the pH was basic.

3.3.2 Effects of calcium nitrate levels and soaking durations on the chemical properties of cocopeat leachate

Other than Na, no significant ($P>0.05$) interaction effect between $Ca(NO_3)_2$ and soaking duration was observed for K, EC, and pH in the cocopeat lactate (Appendix A.1). The results showed that $Ca(NO_3)_2$ 100 g significantly increased K in the leachate by 15.5%, compared to $Ca(NO_3)_2$ (0.0 g). Electrical conductivity levels increase with an increase in the application levels of the $Ca(NO_3)_2$. The highest rate of $Ca(NO_3)_2$ (150g) increased the EC by 56.28% compared to the treatment with no $Ca(NO3)_2$ application. On the other hand, pH was inversely proportional to the concentrations of $Ca(NO_3)_2$ and EC in the leachate. As the $Ca(NO_3)_2$ concentration increased, the pH values became more acidic to pH 5.88 for the highest level of $Ca(NO_3)_2$ application (Table 3.3). Soaking duration did not significantly ($P>0.05$) influence K, EC, and pH, but significant differences ($P<0.05$) were observed for Na.

Table 3.3: Means separation for the effects of soaking duration and calcium nitrate on K, EC and pH in the leachate

Soaking durations (hours)	K (cmol kg^1)	EC (mS cm^{-1})	pH
12	10.64 ^{a}	7.76 ^{a}	6.13^{a}
24	11.18 ^{a}	7.87 ^{a}	6.06 ^{a}
36	12.00 ^{a}	7.93 ^{a}	6.05 ^{a}
48	10.66 ^{a}	8.01 ^{a}	6.09 ^{a}
72	10.86 ^{a}	8.10 ^{a}	6.06^{a}
MSD	***2.78***	***0.63***	***0.13***
Calcium nitrate (g)	K (cmol kg^1)	EC (mS cm^{-1})	pH
0.0	9.21^{b}	3.39^{d}	6.36^{a}
60.0	11.04^{ab}	6.81^{c}	6.07^{b}
100.0	12.59^{a}	9.42^{b}	6.00^{b}
150.0	11.44^{ab}	12.12^{a}	5.88^{c}
MSD	***2.09***	***0.53***	***0.11***

The means followed by the same letter(s) in the same column are not significantly different using Tukeys' HSD test at a 5% significance level. 0.0, 60.0, 100, and 150 gram of $Ca(NO_3)_2$ and 12, 24, 36, 48, and 72 soaking durations hours

3.3.3 Effects of soaking durations and calcium nitrate levels on the rate of change of K, Na, EC, and pH in the leachate

This section describes the rate of change of the measured parameter (K, Na, EC and pH) with an increase in $Ca(NO_3)_2$ application-level at a given soaking duration and the rate of change of the measured parameters with increasing soaking duration at a given $Ca(NO_3)_2$ level. The fastest decreasing rate of change (-0.0024 cmol kg^{-1} of $Ca(NO3)_2$) for K was observed in $Ca(NO_3)_2$ 100g, and the slowest rate of change (-0.0006 cmol kg^{-1} of $Ca(NO3)_2$) was in $Ca(NO_3)_2$ 0 g (Table 3.4) and (Fig. 3.1 (i)). In Na, only $Ca(NO_3)_2$ 100 g gave a decreasing rate of change (-0.0014 cmol kg^{-1}). The Na concentration in 0 g, 60 g, and 150 g $Ca(NO_3)_2$ were increasing as durations increased. The highest rate of change for Na was in 0g and the least was in 60 g of $Ca(NO_3)_2$ (Fig. 3.1 (ii)). Although, there was no significant change either in the pH or in the EC with an increase in duration. However, the rate of change for EC was high in 60 g and low in 100 g. On the other hand, the rate of change for pH in the leachate was high in 100 g (-0.002) and low in 150 g of $Ca(NO_3)_2$ (Fig. 3.1 (iii, iv)).

Table 3.4: Interaction effects of calcium nitrate and soaking duration on the rate of change of K, Na, EC, and pH in the leachate

$Ca(NO_3)_2$ (g)	Properties	Equation model	R^2	Rate of change
				(cmol kg^{-1})
0	K	$y = -0.0003x^2 + 0.0548x + 7.5946$	0.7001	-0.0006
60		$y = -0.0008x^2 + 0.0675x + 9.9453$	0.5725	-0.0016
100		$y = -0.0012x^2 + 0.0874x + 11.432$	0.2200	-0.0024
150		$y = -0.0005x^2 + 0.0128x + 11.886$	0.5812	-0.0010
0	Na	$y = 0.0011x^2 - 0.048x + 3.2754$	0.9363	0.0022
60		$y = 0.0006x^2 - 0.0421x + 6.3371$	0.3789	0.0012
100		$y = -0.0007x^2 + 0.0092x + 8.321$	0.6349	-0.0014
150		$y = 0.0009x^2 - 0.1224x + 9.8904$	0.8045	0.0018
				(mS cm^{-1})
0	EC	$y = 0.0052x + 3.191$	0.6531	0.0052
60		$y = 0.0155x + 6.2097$	0.444	0.0155
100		$y = 0.0011x + 9.3748$	0.0105	0.0011

150		y = -0.0036x + 12.257	0.3778	-0.0036
0	pH	y=-0.0017x + 6.4223	0.3701	-0.0017
60		y = 0.0007x + 6.0432	0.1205	0.00070
100		y = -0.002x + 6.0741	0.3917	-0.0020
150		y = -0.003x + 5.8804	0.0057	-0.003x

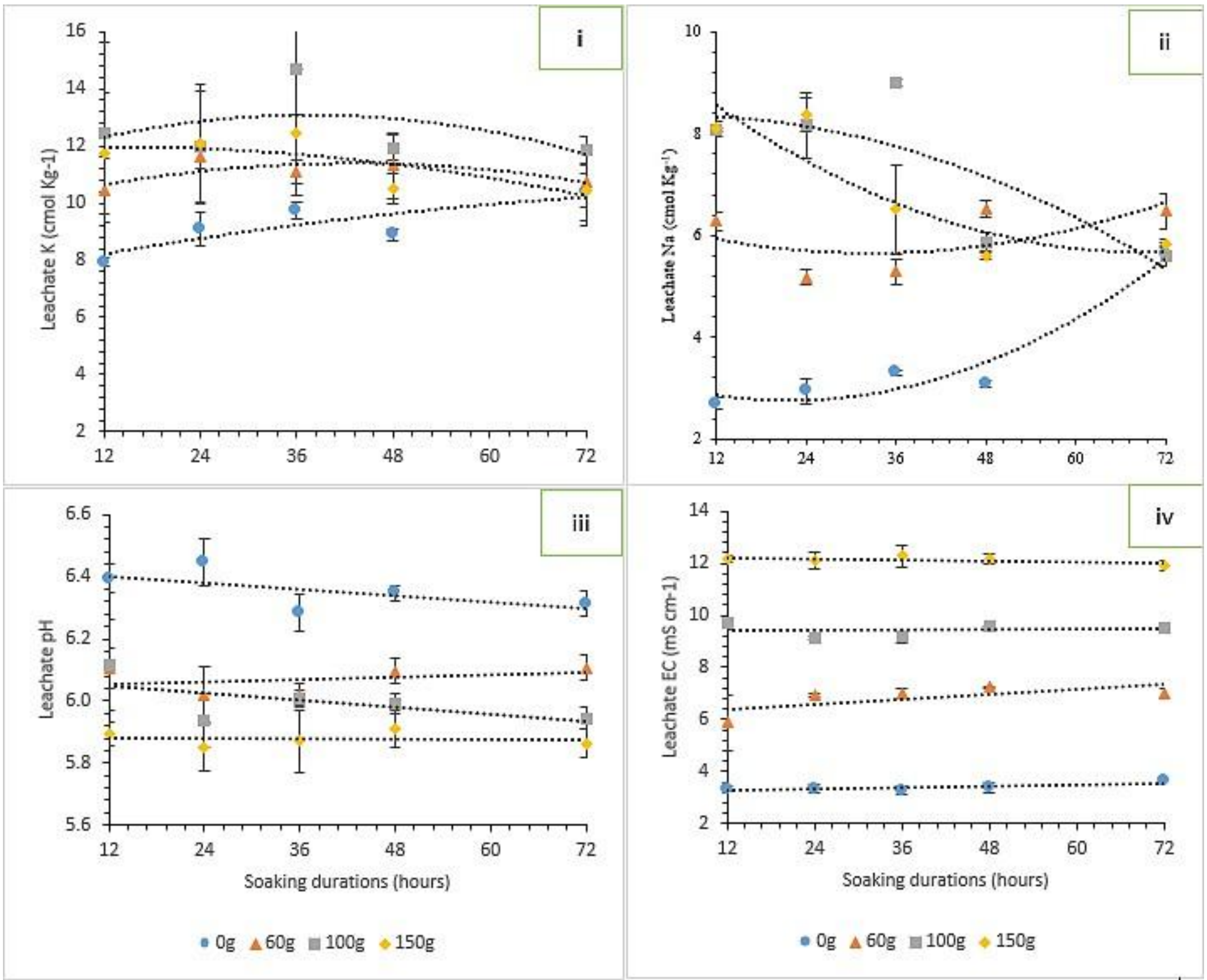

Figure 3. 1: Effects of soaking durations and calcium nitrate levels on extracted K (i), Na (ii) and the change in pH (iii) and EC (iv) in cocopeat leachate

3.3.4 Effects of calcium nitrate levels and soaking durations on chemical properties of the treated cocopeat

Amongst the parameters examined, the interaction between $Ca(NO_3)_2$ and soaking duration was only observed for N. No interaction effects were observed for K, Na, Ca, EC, and pH in the treated cocopeat (Appendix A.2). The main effects for $Ca(NO_3)_2$ showed that there was a significant inverse relationship between $Ca(NO_3)_2$ levels versus K and Na. In comparison, a direct relationship was observed between $Ca(NO_3)_2$ levels versus Ca and EC in the treated cocopeat (Table 3.5). The $Ca(NO_3)_2$ and soaking durations treatments did not significantly affect the pH of the treated cocopeat. The highest concentrations of K and Na were observed in the 0.0 g $Ca(NO_3)_2$ treatment level, while the least concentrations of the two elements were found in the treatment receiving the highest level of 150 g $Ca(NO_3)_2$. Similarly, the highest Ca (58.17 cmol kg^{-1}) and EC (0.98 mS cm^{-1}) were observed in the highest $Ca(NO_3)_2$ rate of 150g, followed by 100g, 60g, and least in the treatments where $Ca(NO_3)_2$ was not applied. Potassium, Na, Ca, total N and EC did not significantly ($P<0.001$) differ due to Soaking durations. Soaking duration of 12 hours had 9.8% and 10.9% more K than soaking durations of 48 and 72 hours, respectively. Although, durations of 24, 36, 48, and 72 hours were not significantly different. A similar trend was observed for Na. The concentration of Ca was highest in 72 and 48 hours (32.12 and 29.60 cmol kg^{-1}), respectively and lowest in ~~12 and 24 hours (22.63 and 24.25 cmol kg~~$^{-1}$), respectively. Electrical conductivity was below the threshold of 1 mS cm^{-1} after the cocopeat was treated with $Ca(NO_3)_2$ levels and all the soaking durations tested.

Table 3.5: Means separation for the effects of soaking duration and calcium nitrate on K, Ca, Na, EC, and pH in treated cocopeat

SD (hours)	K	Ca	Na	EC	pH
		(cmol kg^{1})		(mS cm^{-1})	
12	13.33a	22.63b	1.52a	0.64c	5.67a
24	11.65ab	24.25b	1.39ab	0.69bc	5.71a
36	11.37ab	26.90ab	1.29bc	0.70b	5.68a
48	10.09b	29.60a	1.22c	0.72ab	5.68a
72	9.72b	32.12a	1.16c	0.78a	5.67a
MSD	***1.98***	***5.30***	***0.15***	***0.06***	***0.16***
Calcium nitrate (g)					
0.0	19.59a	3.60d	1.97a	0.48d	5.68a
60.0	11.28b	15.03c	1.57b	0.63c	5.70a
100.0	7.09c	31.60b	1.07c	0.73b	5.68a
150.0	6.96c	58.17a	0.67d	0.98a	5.66a
MSD	***1.66***	***4.45***	***0.13***	***0.05***	***0.14***

The means followed by the same letter(s) within the same column are not significantly different using Tukeys' HSD test at a 5% significance level. SD: soaking durations, MSD: minimum significant difference

3.3.5 Effect of soaking durations and calcium nitrate levels on the rate of change of K, Ca, Na, total N and EC in the treated cocopeat

The results showed an increased rate of change for Ca, N, and EC levels in the treated cocopeat while a decreasing rate of change was observed for K and Na due to soaking duration at each of the $Ca(NO_3)_2$ levels (Table 3.6) and Fig. 3.2 (i, ii, iii, iv, v)). In Ca, the highest rate of change (0.2697 cmol kg^{-1}) was observed in 100 g of $Ca(NO_3)_2$ followed by 150 g, 60 g, and 0.0 g giving the least rate of change (0.0466 cmol kg^{-1}). The rate of change in the total N was directly proportional to the concentration of $Ca(NO_3)_2$ levels with 150 g giving the highest (0.0533 g kg^{-1}) although not significantly different from 100 g of $Ca(NO_3)_2$ while 0 g giving the least positive rate of change (0.0045 g kg^{-1}) (Fig. 3.2 (iii)). The EC rate of change was moderately high in 0.0 g and 150 g of $Ca(NO_3)_2$ (0.0032, 0.0031 mS cm^{-1}), respectively and low in 60 g (0.0006 mS cm^{-1}). For K, the highest decreasing rate of change was observed in 60 g (-0.0915 cmol kg^{-1}) and the least was observed in 150 g (-0.018 cmol kg^{-1}). As for Na, the highest decreasing rate of change was in 0 g (-0.0066 cmol kg^{-1}), while the least was in 150 g (-0.0035 cmol kg^{-1}).

Table 3.6: Interaction effects of calcium nitrate and soaking duration on the rate of change of Ca, K, Na, N, and EC in the treated cocopeat

$Ca(NO_3)_2$ (g)	Element	Equation model	R^2	Rate of change
				(cmol kg^{-1})
0	Ca	y = 0.0466x + 1.8131	0.4801	0.0466
60		y = 0.0843x + 11.797	0.8891	0.0843
100		y = 0.2697x + 21.243	0.9630	0.2697
150		y = 0.2609x + 48.149	0.8939	0.2609
0	K	y = -0.0728x + 22.384	0.9520	-0.0728
60		y = -0.0915x + 14.796	0.9406	-0.0915
100		y = -0.0496x + 8.9990	0.9767	-0.0496
150		y = -0.018x + 7.64710	0.0921	-0.018
0	Na	y = -0.0066x + 2.2229	0.8654	-0.0066
60		y = -0.0082x + 1.8874	0.9888	-0.0052
100		y = -0.0052x + 1.2647	0.8426	-0.0052
150		y = -0.0035x + 0.8015	0.4956	-0.0035
				(g kg^{-1})
0	N	y = 0.0045x + 4.9937	0.5560	0.0045
60		y = 0.013x + 6.3027	0.8838	0.0130
100		y = 0.0307x + 7.309	0.9631	0.0307
150		y = 0.0533x + 10.245	0.8098	0.0533
				(mS cm^{-1})
0	EC	y = 0.0032x + 0.356	0.9254	0.0032
60		y = 0.0006x + 0.6045	0.9549	0.0006
100		y = 0.0021x + 0.65	0.9725	0.0021
150		y = 0.0031x + 0.8644	0.7032	0.0031

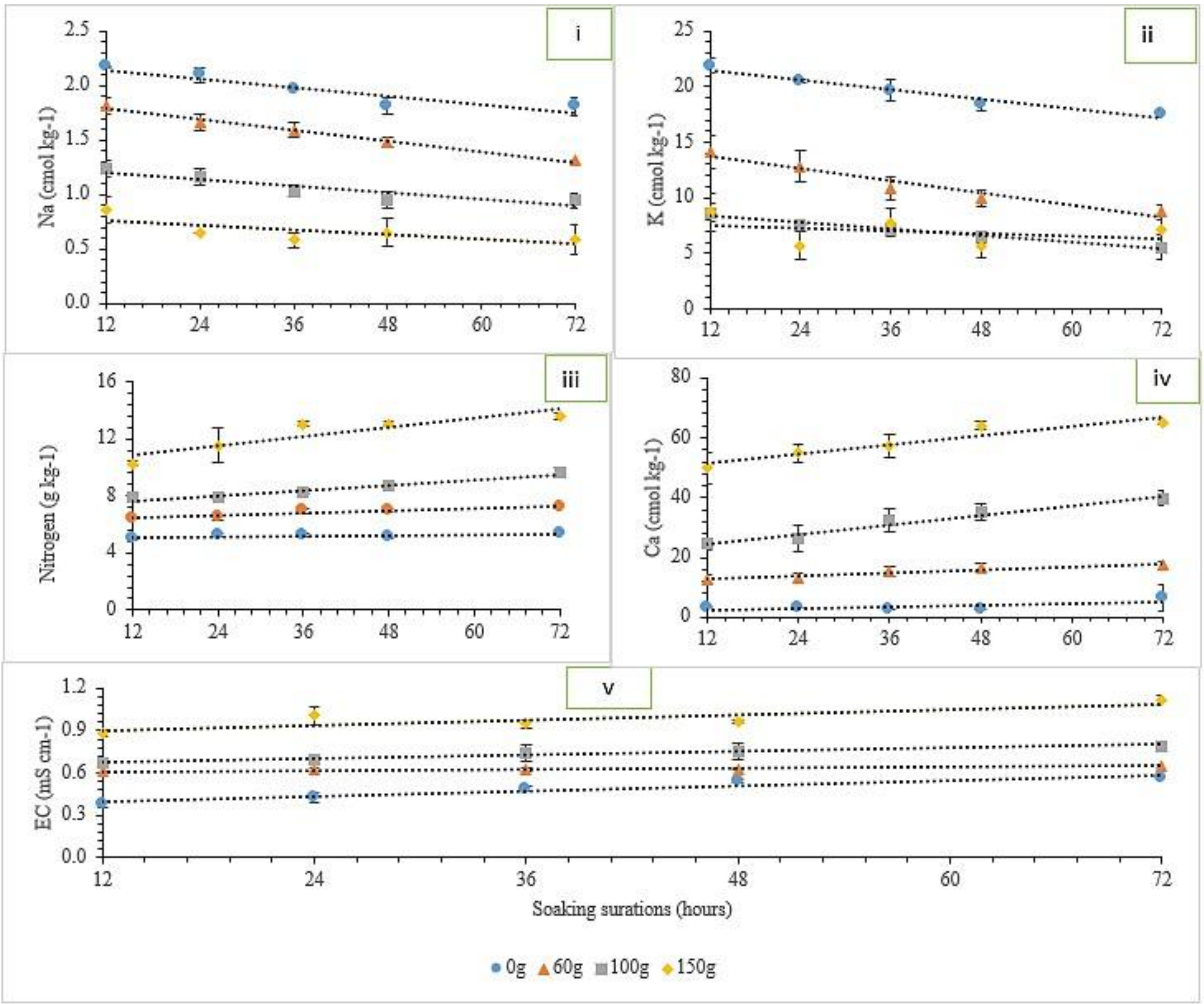

Figure 3. 2: Effects of soaking durations and calcium nitrate levels on filtrate Na (i), K (ii), N (iii), Ca (iv), and EC (v) rate of change

3.3.6 Pearson correlation for the main effects of calcium nitrate and soaking duration on the chemical properties in the treated cocopeat

The Pearson Correlation test for the main effect of soaking duration revealed strong negative correlations between Ca and K (*r*= -0.95*), Ca and Na (*r*= -0.97**), K and EC (*r*= -0.94*), Na and EC (*r*= -0.95*), and between total N and Na (*r*= -0.92*). On the other hand, strong positive significant correlations were also observed between N and Ca (*r*= 0.87*), K and Na (*r*= 0.98**), and Ca and EC (*r*= 0.95*) (Table 3.7).

Table 3.7: Pearson correlation coefficients between the treated cocopeat nutrients due to soaking durations

	N	K	Ca	Na	EC
K	-0.83^{ns}	-	-	-	-
Ca	0.87*	-0.95*	-	-	-
Na	-0.92*	0.98**	-0.97**	-	-
EC	0.84^{ns}	-0.94*	0.95*	-0.95*	-
pH	-0.28^{ns}	-0.07^{ns}	-0.36^{ns}	0.19^{ns}	-0.17^{ns}

There was no strong significant (P>0.05) correlation between pH and the rest of the elements/properties in both the soaking durations and $Ca(NO_3)_2$ levels. The correlation for the main effect of $Ca(NO_3)_2$ also showed that there were strong significant negative correlations between Ca and Na (r= -0.98*), EC and Na (r= -0.98), and between N and Na (r= -0.97*). Strong positive significant correlations were observed between N and Ca (r= 0.99*), N and EC (r= 0.99*), and between Ca and EC (r= 0.99*) (Table 3.8).

Table 3.8: Pearson correlation coefficients between the treated cocopeat nutrients due to calcium levels

	N	K	Ca	Na	EC
K	-0.81^{ns}	-	-	-	-
Ca	0.99**	-0.83^{ns}	-	-	-
Na	-0.97*	0.92^{ns}	-0.98*	-	-
EC	0.99**	-0.85^{ns}	0.99**	-0.98*	-
pH	-0.73^{ns}	-0.30^{ns}	-0.74^{ns}	0.65^{ns}	-0.68^{ns}

3.4 Discussion

3.4.1 Effects of calcium nitrate levels and soaking durations on the chemical properties of cocopeat leachate

The leachate analysis was done to determine whether $Ca(NO_3)_2$ could extract excessive K and Na from cocopeat. The interaction effect of soaking duration × $Ca(NO_3)_2$ was not observed in the leachate for K, EC, and pH because the buffering process was not completed as washing needed to be done for the full effect to be observed. After soaking, it is recommended to wash the cocopeat for complete K and Na extraction to be effective (Marock, 2021). Cocopeat with 100 g $Ca(NO_3)_2$ significantly extracted higher K and Na by 7.63% and 16.08%, respectively, compared to the cocopeat without $Ca(NO_3)_2$ in the soaking solution. Lower extraction of Na was observed in 0.0 g $Ca(NO_3)_2$ and soaking durations of 12, 24, 36, 48, and 72 hours probably due to the use of water (without $Ca(NO_3)_2$) in the mixture. Other researchers have similarly reported that adding $Ca(NO_3)_2$ to the cocopeat increases the extraction of K and Na (Handreck & Black, 2002; Marock, 2021).

The interaction effects showed that both $Ca(NO_3)_2$ and soaking duration should be used simultaneously for the effective extraction of Na. Electrical conductivity is directly proportional to the concentration of dissolved ions in a sample (Kestrup & Ricciardi, 2010). Therefore, treatments with 0.0 g and <100 g of $Ca(NO_3)_2$ had relatively low EC values. Neto *et al.* (2017) reported that when the concentration of $Ca(NO_3)_2$ increases, EC significantly increases in a solution. This occurs because the EC of a solution is a factor of hydrogen or hydroxyl ions. The inverse relationship observed between $Ca(NO_3)_2$ and pH was due to the effect of ammonium present in $Ca(NO_3)_2$. Excessive ammonium is known to acidify soils by decreasing the pH (Zhao *et al.*, 2007). Even though there were significant differences between the levels of pH in the leachate, all the values were in the suitable pH range (5.5-6.5) (Mohammed & Marzooqi, 2020; Schell, 2021). On the other hand, there was no significant difference between the soaking durations for K, EC, and pH. The time taken for complete reaction to occur between $Ca(NO_3)_2$ versus K, Na, EC, and pH may have occurred even earlier than 12 hours. A similar result was obtained by Mccudden (2013), who observed no significant ($P>0.05$) effect of soaking durations on pH in cocopeat. It is evident that irrespective of soaking durations, $Ca(NO_3)_2$ extracts more K and Na while increasing the EC and reducing the pH in the leachate.

3.4.2 Effect of soaking durations and calcium nitrate levels on the rate of change of K, Na, EC and pH in the leachate

Though the K in the leachate was high in treatments with higher $Ca(NO_3)_2$ indicating higher K extraction, these concentrations tend to reduce over time. The decreasing rate of change observed in K at $Ca(NO_3)_2$ 0.0g, 60g, 100g, and 150 g indicate that as soaking durations increase, the K present in the leachate tends to decrease. The rate of change in 100 g of $Ca(NO_3)_2$ was 32% faster than the rate of change in 0.0 g of $Ca(NO_3)_2$. The change in Na was decreasing with increasing with increase $Ca(NO_3)_2$ levels. There was no significant rate of change observed for EC and pH in the leachate. The changes in EC and pH do not require a long soaking duration.

3.4.3 Effects of calcium nitrate levels and soaking durations on the chemical properties in the treated cocopeat

Ions adsorption on surfaces depend on several factors, such as the mineral surface structure, the valency, size and hydration of an ion. Divalent cations are expected to bind stronger to the negatively-charged surfaces than monovalent cations (Brugman *et al.*, 2020). The inverse relationship between $Ca(NO_3)_2$ versus K and Na was due to their valences. As the concentration of Ca ions increases, the adsorption of K and Na decreases (Verhagen, 1999). Low K and Na extraction were observed in treatments without $Ca(NO_3)_2$ as the buffering process was ineffective. After the leaching process less K was observed in treatments with $Ca(NO_3)_2$, but the trend was inversely proportional to the concentration of $Ca(NO_3)_2$. Calcium nitrate levels 0.0 g and 60 g extracted less K compared to $Ca(NO_3)_2$ 100 g and 150 g. This means that 100 g $Ca(NO_3)_2$ is the equilibrium point for K extraction. A similar trend was observed in $Ca(NO_3)_2$ levels for Na. Calcium nitrate 0.0 g extracted less Na than 60, 100, and 150 g, thus the Na concentration in the treated cocopeat was relatively higher compared to the treatment with 100 g and 150 g $Ca(NO_3)_2$.

The hydration (soaking) effect is one of the factors that helps to detach K due to its low electrostatic force (Weil *et al.*, 2017).

Potassium is subdued when competing with Ca (divalent cations) due to its monovalent status. It could be that K was extracted but because of the high water holding capacity of the cocopeat, it has to be leached with the washing water. Significant differences were observed only after the cocopeat was washed. For the K extraction process to be fully completed, $Ca(NO_3)_2$ and water must be used and vigorous mixing and washing must be done after the soaking process. The movement of K in soils is largely by diffusion and this occurs more rapidly at adequate moisture levels. As observed by Afari-Sefa *et al.* (2004), moisture content greatly affects K availability since leaching leads to K loss. The significant differences found in the $Ca(NO_3)_2$ levels for Ca and total N in the treated cocopeat occurred due to the application of $Ca(NO_3)_2$. The Ca in treatments with 100 g and 150 g $Ca(NO_3)_2$ was greater than 0.0 g $Ca(NO_3)_2$. Nitrogen was one of the main elements in the $Ca(NO_3)_2$ used for the extraction. Hence, its attraction was higher as the levels of $Ca(NO_3)_2$ increased.

The higher exchange capacity of N and Ca was found with an increase in $Ca(NO_3)_2$ levels in the solution. Comparatively, higher EC (1.11 mS cm^{-1}) was observed in the interaction of $Ca(NO_3)_2$ 150 g × soaking duration 72 hours and $Ca(NO_3)_2$ 150 g × soaking duration 24 (1.01 mS cm^{-1}) due to the concentration of $Ca(NO_3)_2$. As observed in the leachate, the EC in these treatments was much higher than in treatments with 0 and 60 g of

$Ca(NO_3)_2$. After the cocopeat was washed, the EC was significantly reduced. The $Ca(NO_3)_2$ levels gave significant differences in the amount of EC in the treated cocopeat. The level of EC was higher at 150, 100, 60, and 0 g of $Ca(NO_3)_2$, respectively. Although, all the EC values were <1.0 mS cm^{-1} as observed (Poulter, 2014). A similar trend was shown in the durations (longer durations had higher EC, but <1.0 mS cm^{-1}). Addition of $Ca(NO_3)_2$ above 100 g 1.5 kg^{-1} of cocopeat in 15 L of water during the soaking increases the EC above 1 mS cm^{-1} in the treated cocopeat.

After the cocopeat was washed, significant differences were observed amongst K, Ca, Na, and EC durations. To achieve EC below 1 mS cm^{-1}, cocopeat can be soaked without adding $Ca(NO_3)_2$ for economic reasons, but this is not possible with K and Na as the extraction of these elements is insignificant with water alone. The results obtained for EC and pH are in line with those of Kalaivani and Jawaharlal (2019). The extraction of K for soaking durations was lower in treatments with lower soaking durations. As the soaking durations increased >36 hours, the extraction no longer increase (an equilibrium point). A similar trend was shown for Na. Soaking durations above 36 hours had no significant reduction of Na in cocopeat. Overall, soaking durations did not reduce K and Na considerably when soaked above 36 hours. A soaking duration of 36 hours appears to be an equilibrium point for K, Ca, and Na. Soaking below this point extracts less K and Na, and soaking above will extract an insignificant amount to 36 hours. Also, Ca equilibrium extraction was attained at 36 hours as there is no significant difference above 36 hours.

3.4.4 Effects of soaking durations and calcium nitrate levels on the rate of change of K, Ca, Na, total N and EC in the treated cocopeat

The increasing rate of change for Ca, N, and EC were due to $Ca(NO_3)_2$. As the soaking durations were increasing with fixed $Ca(NO_3)_2$ levels, the dissolved $Ca(NO_3)_2$ ions in the solution tend to increase the reaction rate, thereby increasing the Ca, N, and EC concentrations on the surfaces. Calcium was 34% faster in attraction in $Ca(NO_3)_2$ 100 g than 0.0 g of $Ca(NO_3)_2$. While total N attraction to the cocopeat was 49% and 26% faster in $Ca(NO_3)_2$ 150 g and 100 g, respectively, compared to 0.0 g of $Ca(NO_3)_2$. From the initial analyses, it was observed that Ca, and N were limited in the cocopeat. As such, the supplementation of these elements through soaking is as essential as the fertilization of the soil. On the other hand, the decreasing rate of change observed in K and Na was also due to cation exchange through $Ca(NO_3)_2$. Potassium and Na are known to be monovalent cations. In the presence of divalent cations (Ca), the attraction of K and Na is expected to reduce while Ca increases (Brugman *et al.,* 2020). Although the K extracted by 0.0 g and 60 g of $Ca(NO_3)_2$ was low, the rate of reduction of K was much faster in treatments without low $Ca(NO_3)_2$ compared to treatment with 150 g of $Ca(NO_3)_2$. The rate of change was 31, 39, 21, and 8% in 0, 60, 100, and 150 g of $Ca(NO_3)_2$, respectively. A similar decreasing trend was observed for Na with 32, 25, 25, and 17% in 0, 60, 100, and 150 g of $Ca(NO_3)_2$, respectively. Though $Ca(NO_3)_2$ extracted more K and Na, the rate of extraction is much slower with higher concentrations.

3.4.5 Pearson Correlation for the main effects of calcium nitrate level and soaking duration on the treated cocopeat

Some of the elements retained from the effects of $Ca(NO_3)_2$ and soaking durations showed significant correlations. In both $Ca(NO_3)_2$ and soaking duration, there was a strong significant negative correlation between Ca and Na and between Na and N. These relationships showed as Ca and N increase, Na tend to reduce. There was also a strong significant ($P<0.05$) negative correlation between Ca and K in the soaking durations, which showed a significant reduction of K as Ca increases. On the other hand, there was a significant positive correlation between Ca versus N and between Ca versus EC in both $Ca(NO_3)_2$ and soaking durations. The use of $Ca(NO_3)_2$ may have contributed to these relationships. The $Ca(NO_3)_2$ used was rich in N and Ca, as such, as the concentration increases, Ca, N and EC are expected to increase, depicting a positive relationship. The EC in a given sample is directly proportional to the concentration of dissolved ions (Kestrup & Ricciardi, 2010); thus, the EC in the cocopeat that was treated with 60, 100, and 150 g of $Ca(NO_3)_2$ was higher than the 0.0 g of $Ca(NO_3)_2$. Verhagen (1999) found a significant positive correlation (r=0.53**) between K and Na in the leachate. Kumar *et al.* (2017) also found a weak negative correlation (-0.40^{ns}) between exchangeable K and pH in the soil.

3.5 Conclusion

The untreated cocopeat has high K, Na, and EC with limited Ca and N concentrations. Through the use of $Ca(NO_3)_2$, these excessive elements can be minimized while the limited elements are supplemented. In the leachate, $Ca(NO_3)_2$ is seen to have the ability for K and Na extraction while increasing the EC and reducing the pH. After the cocopeat is soaked and washed, the K, Na, Ca, N, EC, and pH are more responsive to the main effects of $Ca(NO_3)_2$ and soaking duration than the interaction effects of $Ca(NO_3)_2$ × soaking duration. Comparatively, the single effect of Ca(NO3)2 extracted more K and Na compared to the single effect of soaking duration. The use of 100 g $Ca(NO_3)_2$ significantly enhanced the extraction of K and Na in cocopeat. After the cocopeat is washed, the EC and pH reduce within their suitable ranges irrespective of $Ca(NO_3)_2$ levels or soaking durations. A soaking duration of 36 hours is an equilibrium point for Ca and N supplementation, and for K and Na extraction. Higher Ca, and N supplementation in cocopeat is observed when 100 g of $Ca(NO_3)_2$ is used. On the other hand, K and Na tend to decrease faster in 0 g and 60 g than in 100 g and 150 g of $Ca(NO_3)_2$. There is a strong negative correlation between Ca versus Na, Ca versus K, Na versus N, and Na versus EC. Also, there is a strong positive correlation between Ca versus N, Ca versus EC, and N versus EC. For optimal reduction of K by 78.44% and effective supplementation of Ca and N in cocopeat, 100 g of $Ca(NO_3)_2$ 1.5 kg-1 of cocopeat in 15 litres of water with a soaking duration of 36 hours is much more effective. Sodium is also significantly reduced by 95.83% when 150 g is used and 92.59% when 100 g of $Ca(NO_3)_2$ with a constant soaking duration of 36 hours. Information about the leachability of K and Na is important for the standardization of cocopeat for a variety of horticultural crops grown in a hydroponics system using cocopeat as a growing medium.

CHAPTER FOUR

EFFECTS OF CALCIUM NITRATE LEVELS AND SOAKING DURATIONS IN COCOPEAT ON GROWTH, YIELD AND NUTRIENT UPTAKE OF POTATO (*Solanum tuberosum* L.)

Abstract

This study evaluated the effects of treating cocopeat with calcium nitrate ($Ca(NO_3)_2$) at different soaking durations on potato (*Solanum tuberosum* L.) Apical Rooted Cuttings (ARCs) growth and yield parameters. A greenhouse pot experiment was carried out at the Climate and Water Smart Agriculture Centre of Egerton University, Kenya. An air-dried cocopeat 1.5 kg per treatment, was treated using five soaking durations (12, 24, 36, 48 and 72 hours) × four levels of $Ca(NO_3)_2$ (0, 60, 100 and 150 g) soaked in 15 litres of water. Soil and untreated cocopeat were used as positive and negative controls, respectively. The treatments were arranged in a completely randomized design with three replicates. The results showed that there was no significant ($P>0.05$) interaction effect of $Ca(NO_3)_2$ × soaking duration for the number of branches and normalized difference vegetative index. The main effect of 150 g $Ca(NO_3)_2$ gave the highest average number of branches (16.13), NDVI (0.89) and plant height (73.51 cm) followed by 100 g of $Ca(NO_3)_2$. Soaking duration of 36 hours economically produced the highest growth parameters 12.75 and 61.46 cm an average number of branches and plant height, respectively. Significant ($P<0.001$) interaction effects were observed for the plant height and all the yield parameters. The interaction of 100 g $Ca(NO_3)_2$ and soaking for 36 hours gave the highest minituber yield of 464.67 g plant^{-1} and an average number of tubers of 21.67 tubers plant^{-1}. Therefore, 100 g $Ca(NO_3)_2$ and a soaking duration of 36 hours to treat 1.5 kg of air-dried cocopeat is recommended for higher ARCs yield and yield parameters.

Key words: ARCs, minituber, potassium, soilless, yield.

4.1 Introduction

In the coming decades, achieving nutrition and sustainability in food for the growing population estimated at 9.7 billion people by 2050 will require significant improvements to the global food system (FAO *et al.*, 2018; Waaswa & Satognon, 2020). In contribution to this, potato is one of the potential crops that need such improvement. Based on its demand in over 149 countries, its cultivation is estimated at 19 million hectares globally, with 378 million tonnes of productivity (Campos & Ortiz, 2020). Kenya is now the fourth biggest potato producer in Africa with a total production of 1.8 million tonnes cultivated on 217,315 hectares (FAOSTAT, 2018). Presently, after maize (*Zea mays*) potato is considered the second most important staple food and is valued at approximately USD 500 million annually (CIP, 2019; Wang'ombe & Dijk, 2013).

Regardless of Kenya's potential in potato production, there still exist major production challenges. According to KEPHIS (2016), approximately 2% of the potato-growing areas in Kenya are planted with certified seeds. This means that approximately 98% of the potato-growing areas are planted with uncertified seeds. Due to the use of uncertified planting materials, Kenya's average potato yield is currently at 9-10 tonnes ha^{-1} compared to global productivity of 20-40 tonnes ha^{-1} (VIB, 2019). Increased shortage of certified planting materials has led to low yields, the spread of pests and diseases and poor-quality products (Demo *et al.,* 2015). A study conducted by Gildemacher *et al.* (2011), showed that a positive selection of seeds provided smallholder farmers with better quality seeds and led to high yields. To minimize these challenges, techniques such as hydroponics are cardinal for minituber production. Hydroponics technique includes the use of soilless culture and nutrient supply through a fertigation system. This technique is introduced into Sub-Saharan Africa (SSA) to provide a simple but effective technique for multiplying early-generation seeds (Parker *et al.,* 2019). The introduction of hydroponics in SSA has resulted in increased minituber production (Harahagazwe *et al.,* 2018).

The use of appropriate growth media leads to higher productivity and returns. Growing media are materials, other than soils, in which plants are grown. This includes organic materials such as cocopeat, compost, tree bark and poultry feathers or inorganic materials such as clay, perlite, vermiculite and mineral wool, amongst others (Rehman *et al.,* 2020). Alternative methods for seed multiplication are gradually shifting to the use of soilless media such as cocopeat, pumice, peat moss, vermiculite and sawdust, amongst others (Zimba *et al.,* 2014). Minituber production is one of the primary methods for potato production. As such, growth media systems can be used as an effective technique for producing certified seed potato (Campos & Ortiz, 2020; Lakhiar *et al.,* 2018). Soilless culture is in the process of becoming a vital part of the world's agriculture. Commercial application of soilless culture has increased over the years as an alternative to costly soil disinfection and high productivity and increased water use efficiency (Chiipanthenga, 2012; Kakuhenzire *et al.,* 2017). Using soil as growth media for seed potato production increases the low multiplication rate of tubers and lowers disease prevalence and laborious weed control (Kamrani *et al.,* 2019). Aeration, water holding capacity and drainage requirements are typically low in soil compared to soilless media.

Widespread adoption of soilless potting media in global food production has been reported as the technical solution for problems including low productivity, root diseases, root zone oxygen deficiency and fertility control in soil (Kamrani *et al.*, 2019). One of the most widely used soilless growing media is cocopeat (Halamba & Kuack, 2021; Kamrani *et al.,* 2019; Wittman, 2020). Cocopeat is a planting media made from coconut husk, but its salinity problem is not to be underestimated. It has an easily absorbing and water holding ability which facilitates the exchange of air, and water, it can be reused for about four years, allow for maximum root growth to support the plant physically, and has a low environmental impact (Gohil, 2018; Putra *et al.*, 2019). The advantages of soilless systems over soil are that it is pathogen-free, growth and yield are independent of the soil type, has better support for growth through a targeted supply of nutrient solution due to its favourable physical and chemical properties (Goddek *et al.,* 2019).

Nevertheless, cocopeat has its challenges. Cocopeat's initial cation exchange sites are naturally loaded with K Sachin *et al.* (2020) and Na with little or no calcium (Ca) and Nitrogen (N) (Halamba & Kuack, 2021; Wittman, 2020). Cocopeat is loaded with high potassium (K) 38.5-40 cmol kg^{-1} and sodium 13.04-15 cmol kg^{-1} depending on the source (Kimbonguila *et al.,* 2019; Putra *et al.,* 2019; Wittman, 2020). Excessive concentration of K may increase the leaching of Ca and Mg from the soil, causing soil acidification (Puga *et al.,* 2016). Efforts are made to optimize K in cocopeat before using it as a growing media. Optimizing a high level of K in cocopeat reduces K toxicity, stimulates root development, and grow crops like potato (Shanmugasundaram *et al.,* 2014). Due to the limited knowledge about cocopeat treatment in Kenya, most horticultural producers import their cocopeat from India, Finland, Sir-Lanka, and the Netherlands, amongst other countries (AFA-NOCD, 2020). Efforts have been made to make cocopeat suitable for the production of horticultural crops instead of soil.

Soaking and leaching of cocopeat with $Ca(NO_3)_2$ reduces elements that are naturally bonded to the cation exchange complex of cocopeat (Marock, 2021). The use of $Ca(NO_3)_2$ in this process presents a potential approach to reduce the adverse effects of the locally available cocopeat for use as seed potato growth media. Treated cocopeat has consistent quality in terms of salinity and exchangeable cation concentrations. This research objective was to determine the effects of nutrient contents in cocopeat as the result of $Ca(NO_3)_2$ and soaking duration on the growth and yield of potato under a greenhouse condition. The findings of this study will improve the use of soilless media among potato producers and increase hydroponics minituber production, thereby, increasing minituber productivity and contributing to global food security.

4.2 Materials and Methods

4.2.1 Experimental site description

See section 3.2.2. The average maximum and minimum greenhouse temperatures were 30.79 °C and 14.38 °C, respectively. For the soil treatment, the soil used was Mollic Andosols with well-drained, dark reddish clays, slightly acidic as classified by Satognon *et al.* (2021).

4.2.2 Experimental procedure and treatments

The experiment was arranged in a completely randomized design with three replicates. The cocopeat used (1.5 kg treatment^{-1}) was treated using five (5) soaking durations (12, 24, 36, 48, and 72 hours) and four (4) levels of $Ca(NO_3)_2$ (0, 60, 100, and 150 g) mixed in 15 L of water. The mixtures were then soaked for their respective soaking durations. After every six hours, each treatment was mixed to ensure a uniform reaction. Each treatment was separately rainsed using 15 L of tap water after the soaking durations. Thereafter, hydrogen peroxide (H_2O_2) 0.5 ml into one (1) litre of tap water was used for the second rinsing. Ten litres of the H_2O_2 solution were used to rinse each treatment. A third rinsing was done with 5 litres of tap water (without hydrogen peroxide) for each treatment and the media was left standing for 24 hours to drain the remaining water. Seed potato apical rooted cuttings sourced from Stockman Rozen Limited, Naivasha, Kenya were planted in each treatment after 24 hours. The treatments amounted to 22 after the soil and the untreated cocopeat were included as positive and negative controls, respectively.

4.2.3 Treatments and determination of the chemical properties

Samples of the treated cocopeat, the untreated cocopeat that was sourced from Cocoponics Africa Limited and the soil were taken and analysed at the Kenya National Agricultural Research Laboratory (NARL)-Kabete for K, Na, Ca, N, EC, and pH (Table 4.1). The water quality was evaluated because it affects the exchange reactions of K, Na and Ca on the adsorption complex of cocopeat (Ko *et al.,* 2017). The pH and EC were determined using a 1:2 (w/v) ratio of media to water suspension using a pH metre and conductivity metre for EC (Yadata, 2014). Using the Kjeldahl digestion method as in Okalebo *et al.* (2002) for total N determination, samples of the substrates were dried in an oven at 70 ˚C and oxidized with hydrogen peroxide 30% at a relatively low temperature (100 ˚C). After decomposition of the excess H_2O_2 and water evaporation, digestion was completed with a concentrated 96% sulphuric acid (H_2SO_4) at elevated temperature (330 ˚C) under the influence of selenium powder as the catalyst. After the digested samples were cooled overnight, the exchangeable Ca was determined using an Atomic Absorption Spectrophotometer (AAS) at a wavelength (λ) of 422.7 nm while exchangeable K and Na were determined using a flame photometer at a λ of 766 nm and 589 nm, respectively.

Table 4.1: Treatments combination for the growth, yield and nutrient uptake experiment

Combinations	$Ca(NO_3)_2$ g pot^{-1}	Soaking durations (hours)
C0D1	0	12
C0D2	0	24
C0D3	0	36
C0D4	0	48
C0D5	0	72
C1D1	60	12
C1D2	60	24
C1D3	60	36
C1D4	60	48
C1D5	60	72
C2D1	100	12
C2D2	100	24
C2D3	100	36
C2D4	100	48
C2D5	100	72
C3D1	150	12
C3D2	150	24
C3D3	150	36
C3D4	150	48
C3D5	150	72
C0D0	untreated	untreated
Soil	soil	soil

Note: C0, C1, C2, C3: calcium nitrate 0, 60, 100, and 150g, respectively. D1, D2, D3, D4, and D5: soaking durations 12, 24, 36, 48 and 72 hours, respectively

4.2.4 Description of the potato variety used

One apical rooted cuttings potato variety, *Shangi* was used for this experiment. *Shangi* is one of the most grown varieties in Kenya and it is a semi-erect medium-tall variety (slightly below 1 m in height) with moderately strong stems and light green broad leaves with pink flowers (NPCK, 2019). *Shangi* is suitable for almost potato-growing regions in Kenya, but mainly in Central, Rift Valley, and Eastern regions. It grows well at an altitude of 1500 metres above sea level or higher. Under favourable conditions, it matures early in about 3 months and has a potential yield of 30-40 tonnes ha^{-1} and it is moderately susceptible to late blight disease (NPCK, 2019).

4.2.5 Experimental management

A drip irrigation system with hydroponics nutrient solutions (A and B) composed of the essential macro and micro-elements were each mixed at the ratio of 1 g L^{-1}. Water + nutrient (fertigation) was supplied at 0.30 litres $plant^{-1}$ every two days up to the flowering period. After flowering, the nutrient/water supply was reduced to 0.30 litres $plant^{-1}$ after three days. Insect pests were controlled with Thunder (Imidacloprid 100 g L^{-1} + Beta-cyfluthrin 45 g L^{-1}) applied at the rate of 0.5ml L^{-1}. Late blight was controlled using *Infinito* at the ratio of 0.5 ml L^{-1} of water. Weeding was done regularly only on the soil treatment (positive control).

4.2.6 Data collection

Data was collected on the number of branches, NDVI using a GreenSeeker handheld gadget, plant height, yield (total), minituber number, and minituber classes <8.00 g, 8-15.99 g, 16-18 g, and >18.00 g represented as C1, C2, C3 and C4, respectively. The yield projection was computed using the formula:

$$\text{Yield (tonnes hectare)} = \frac{Yield\ obtained\ (kg) \times 10{,}000M^2}{Number\ of\ plants\ harvested \times planting\ distance}$$

4.2.7 Data analyses

See section 3.2.4.

4.3 Results and Discussion

4.3.1 Correlation between nutrient uptake and cocopeat nutrient content

There were strong positive correlations between K in the media and K uptake (r= 0.90***), Ca in the media and Ca uptake (r= 0.96***) and between N in the media and N uptake (r= 0.84***). These positive relationships were due to the presence of the nutrients in the media thus increasing the uptake. In plants, approximately 80% of all nutrients absorbed by roots are translocated to the shoots (Hochmuth *et al.,* 2018). Nitrogen in the media and Ca uptake was positively correlated (r= 0.94***) as the concentration of N in the tissue depended on the level of $Ca(NO_3)_2$. At higher $Ca(NO_3)_2$ levels, more N was made available for plant uptake. On the other hand, there was a strong negative correlation between K in the media and Ca uptake (r= -0.66**). Potassium and Ca are strongly antagonistic to each other. An excess concentration of one element inhibits the uptake of other elements (Huu *et al.,* 2017). The negative correlation between K in the media and Ca uptake showed that as K concentration decreases, the Ca uptake by potato increases. The positive correlations showed that the higher the concentration of a particular element in the media, the higher the uptake.

4.3.2 Main effects of soaking durations and calcium nitrate levels on *Shangi* potato growth and yield parameters

There was no significant (P>0.05) interaction effect of soaking duration × $Ca(NO_3)_2$ for the number of branches and the NDVI values. However, there was a significant (P<0.01) interaction effect for the plant height. The results for the main effect of soaking duration showed that soaking durations 36, 48, and 72 hours significantly gave the highest growth parameters compared to soaking durations 12 and 24 hours. An average number of branches plant^{-1} ranged from 7.2 (0 g) to 16.13 (150 g); NDVI ranged from 0.61 (0 g) to 0.89 (150 g) and plant height from 39.83 cm (0 g) to 73.51 cm (150 g) all at 77 days after planting. Soaking duration of 36, 48, and 72 hours were not significantly different from each other (Table 4.2). In all the soaking durations, the NDVI values were not significantly different. As for the $Ca(NO_3)_2$ effects, the growth parameters were significantly (P<0.05) increased with an increase in the calcium nitrate levels (Table 4.2). The increasing trend was: 0< 60< 100< 150 g, respectively. The main effect of $Ca(NO_3)_2$ is sufficient to enhance the number of branches and the NDVI of *Shangi* potato apical rooting cuttings. The insignificant differences between soaking durations 36, 48, and 72 hours suggest that soaking cocopeat above 36 hours does not increase the growth parameters. Hence, growers should not waste their time soaking cocopeat for < or > 36 hours to attain higher growth parameters. The growth parameters were also directly proportional to the $Ca(NO_3)_2$ application. Sidhu *et al.* (2018), reported that the applications of $Ca(NO_3)_2$ at different concentrations increase plant growth-related parameters. The growth parameters tend to increase as the $Ca(NO_3)_2$ levels increase.

Table 4. 2: Means separation for the effects of soaking duration and calcium nitrate on potato growth parameters

Soaking durations (hours)	Number of branches	NDVI	Plant height (cm)
12	11.58^{c}	0.74^{a}	57.05^{b}
24	11.92^{bc}	0.76^{a}	57.95^{b}
36	12.75^{ab}	0.78^{a}	61.46^{a}
48	12.83^{ab}	0.78^{a}	62.14^{a}
72	13.33^{a}	0.78^{a}	63.17^{a}
MSD	***0.95***	***0.06***	***2.57***
Calcium nitrate (g)	Number of branches	NDVI	Plant height (cm)
0	7.20^{d}	0.61^{d}	39.83^{d}
60	11.87^{c}	0.76^{c}	59.37^{c}
100	14.73^{b}	0.81^{b}	68.68^{b}
150	16.13^{a}	0.89^{a}	73.51^{a}
MSD	***0.80***	***0.05***	***2.15***

The means followed by the same letter(s) in the same column are not significantly different using Tukeys' HSD test at a 5% significance level. 0.0, 60.0, 100, and 150 gram of $Ca(NO_3)_2$ and 12, 24, 36, 48, and 72 soaking durations hours, ***MSD:*** Minimum significant difference

There were significant ($P<0.001$) interaction effects of $Ca(NO_3)_2$ × soaking duration for all the yield parameters. The results revealed that except for minituber C1, soaking durations of 36 and 48 hours significantly ($P<0.05$) produced the highest yield parameters: minituber C2, C3, C4, number of tubers, and the total yield plant^{-1} (Table 4.3). As in the growth parameters, soaking cocopeat for more than 36 hours does not also increase the yield parameters. Longer soaking durations may have extracted more elements than needed. Also, soaking cocopeat for <36 hours may extract less K and Na thus affecting the yield parameters and the full effects may not be observed. The yield in durations of 36 and 48 hours was 284.92 g plant^{-1} and 274.42 g plant^{-1}, respectively while the yield in 12 hours was 227.08 g plant^{-1}. As for the $Ca(NO_3)_2$ levels, 100 g of $Ca(NO_3)_2$ significantly ($P<0.01$) gave the highest yield (371.73 g plant^{-1}), number of tubers (15.73 tubers plant^{-1}), C2, C3, and C4 classes (Table 4.3). The lowest yield parameters were observed in 0 g of $Ca(NO_3)_2$. The total percentage production was 10.1%, 19.7%, 34.4%, and 35.8% in $Ca(NO_3)_2$ 0, 60, 150, and 100 g, respectively. Although the growth parameters are directly proportional to the

$Ca(NO_3)_2$ levels, this does not necessarily mean that the yield parameters are also directly proportional to the $Ca(NO_3)_2$ levels. As seen in the results, 100 g of $Ca(NO_3)_2$ significantly produced the highest yield parameters than 150 g of $Ca(NO_3)_2$. This means that $Ca(NO_3)_2$ >100 g may merely increase the growth parameters, but not the yield parameters which are most important to farmers. As reported by Najm *et al.* (2010), the use of excessive N for potato production leads to immoderate growth. The NDVI was directly proportional to the number of branches and plant height because, it quantifies the plant biomass (Xue and Su, 2017). As N increases, the growth parameters tend to increase thus increasing the NDVI of the plant.

Table 4.3: Main effects of soaking duration and calcium nitrate on *Shangi* potato yield parameters

Soaking durations (hours)	Yield (g plant^{-1})	Tubers plant^{-1}	Tuber weight classes C1	C2	C3	C4
12	227.08^{d}	10.50^{c}	4.00^{a}	2.08^{c}	2.17^{bc}	2.25^{b}
24	247.42^{c}	11.92^{b}	4.33^{a}	2.33^{c}	2.83^{a}	2.42^{b}
36	284.92^{a}	13.17^{a}	4.42^{a}	2.83^{a}	2.50^{ab}	3.42^{a}
48	274.42^{a}	12.00^{ab}	4.00^{a}	2.67^{ab}	2.67^{ab}	2.67^{ab}
72	263.08^{b}	10.33^{c}	4.67^{a}	2.00^{c}	1.66^{c}	2.00^{b}
MSD	***11.13***	***1.20***	***0.69***	***0.48***	***0.54***	***0.77***
Calcium nitrate (g)	Yield (g plant^{-1})	Tubers plant^{-1}	C1	C2	C3	C4
0	104.67^{d}	7.93^{d222}	4.13^{b}	2.33^{b}	1.27^{c}	0.20^{c}
60	204.33^{c}	9.87^{c}	3.60^{bc}	2.13^{b}	2.07^{b}	2.07^{b}
100	371.73^{a}	15.73^{a}	3.53^{c}	2.93^{a}	3.87^{a}	5.40^{a}
150	356.80^{b}	12.80^{b}	5.87^{a}	2.13^{b}	2.67^{b}	2.53^{b}
MSD	***9.34***	***1.01***	***0.58***	***0.40***	***0.46***	***0.64***

The means followed by the same letter(s) in the same column are not significantly different using Tukeys' HSD test at a 5% significance level. 0.0, 60.0, 100, and 150 gram of $Ca(NO_3)_2$ and 12, 24, 36, 48, and 72 soaking durations hours, ***MSD:*** minimum significant difference

4.3.3 Interaction effects of calcium nitrate levels and soaking durations on *Shangi* potato growth and yield parameters

There were significant (P<0.001) differences amongst treatments for all the growth parameters: number of branches, NDVI, and plant height (Table 4.4). For the number of branches per plant, C2D3 to C3D5 (treatments with >100 g $Ca(NO_3)_2$) had significantly higher branches between 14-17 $plant^{-1}$ than the other treatments. The least number of branches (4.67) were found in Soil (positive control), C0D0 (5.33) (negative control) C0D1, C0D2 and C0D3, respectively. The growth parameters were highly influenced by the concentration of N in the media. Treatments with high $Ca(NO_3)_2$ levels had high N availability, and therefore growth was higher. The tissue analyses showed excessive N concentrations in C3D1 to C3D5. This is one of the factors for high vegetative growth. According to Ruža *et al.* (2013); Banjare *et al.* (2014), N is well known for its influence on potato growth parameters. The highest NDVI values were obtained from C1D4 to C3D5 where the application of $Ca(NO_3)_2$ was 60 to 150 g 1.5 kg^{-1} of cocopeat in 15 litres of water were done. The least NDVI values were found in treatments without $Ca(NO_3)_2$ (C0D1 to C0D5), the untreated cocopeat (C0D0), and the soil treatment. The NDVI values increased with an increase in $Ca(NO_3)_2$ levels. The C3D5, which had the highest N, produced 56.90% and 52.26% more branches than positive and negative controls. Due to the high N concentration in this C3D5, its NDVI and plant height was more significant than the negative and positive controls.

All the growth parameters were highly correlated ($P<0.001$) with the yield parameters, and this was also observed by Larkin *et al.* (2021). These positive correlations were due to the nutrient availability to plants, plant health, and the media's suitability in the higher yield treatments. The normalized difference vegetation index that reflects the N level of the plant was correlated with the number of branches and plant height due to the plant's vegetative growth. Other studies have reported that NDVI quantifies the canopy growth, vegetation cover, and growth dynamics of plants (Xue & Su, 2017). The highest plant height was observed in C3D5, C3D4, C3D3, and C2D3. While the least plant height was observed in C0D1 to C0D5 (treatments without $Ca(NO_3)_2$), C0D0, and Soil. The positive relationship between yield and the number of tubers per plant was also observed by Khayatnezhad *et al.* (2011). Contrary to Badr *et al.* (2012), the number of tubers greatly influenced potato yield, as revealed by the correlation test. The growth parameters are important components of crop production under normal circumstances as they are highly correlated with the yield parameters in most crops.

Table 4.4: Means separation for the interaction effects of calcium nitrate levels and soaking durations on potato growth parameters

Treatment	Number of branches	NDVI	Plant height (cm)
C0D1	6.00^{jk}	0.54^{efg}	37.33^{hi}
C0D2	6.33^{ijk}	0.58^{ef}	39.18^{h}
C0D3	7.00^{hij}	0.62^{de}	39.50^{h}
C0D4	8.00^{hi}	0.61^{de}	40.83^{h}
C0D5	8.67^{h}	0.60^{def}	42.33^{h}
C1D1	10.67^{g}	0.72^{bcd}	57.67^{g}
C1D2	11.33^{fg}	0.72^{bcd}	58.67^{g}
C1D3	11.67^{fg}	0.73^{bcd}	57.33^{g}
C1D4	12.67^{ef}	0.79^{abc}	62.00^{efg}
C1D5	13.00^{def}	0.78^{abc}	61.20^{fg}
C2D1	14.00^{cde}	0.78^{abc}	65.70^{def}
C2D2	14.00^{cde}	0.78^{abc}	66.17^{def}
C2D3	16.00^{ab}	0.85^{ab}	73.00^{abc}
C2D4	15.00^{bc}	0.81^{abc}	68.33^{cd}
C2D5	14.67^{abc}	0.83^{abc}	70.20^{bcd}
C3D1	15.67^{abc}	0.85^{ab}	67.50^{cde}
C3D2	16.00^{ab}	0.85^{ab}	67.73^{cde}
C3D3	16.33^{ab}	0.87^{a}	76.00^{ab}
C3D4	15.67^{ab}	0.87^{a}	77.40^{a}
C3D5	17.00^{a}	0.88^{a}	78.93^{a}
C0D0	5.33^{jk}	0.47^{fg}	32.47^{ij}
Soil	4.67^{k}	0.43^{g}	30.12^{j}
MSD	***1.95***	***0.13***	***6.29***

Means followed by the same letters(s) in the same column are not significantly different using Tukeys' HSD test at a 5% level of significance. ***MSD:*** minimum significant difference, NDVI: moralized difference vegetation index

For all the yield parameters: total yield, number of tubers, and tuber class C1, C2, C3, and C4 treatments were significantly ($P<0.001$) different (Table 4.5). The highest yield (464.67 g $plant^{-1}$ and 415.68 g $plant^{-1}$) was observed in C2D3 and C2D4, respectively. Similarly, C2D3 and C2D4 gave the highest percentage yield of 8.82% and 7.89%, respectively. On the other hand, the lowest percentage of tuber (3.13% and 2.31%) and yield (0.90% and 0.63%) production was observed in untreated cocopeat and soil, respectively. Out of the total number of tubers (244.95), C2D3 and C2D4 produced 8.85% and 7.35%, respectively. The least number of tubers per plant was also observed in treatments without $Ca(NO_3)_2$, the positive and negative controls. This low production in the soil and the untreated cocopeat treatments may be due to soil compaction in the experimental pots and high Na and K concentrations in the untreated cocopeat. The nutrient availability and balance in media highly influence potato growth and yield parameters (Naumann *et al.*, 2020). In all treatments combined, the highest number of tubers $class^{-1}$ were observed in C1 (95.00), C4 (50.99), C2 (50.67), and C3 (48.32). Comparatively, treatments with the highest N and Ca concentrations in the media gave the highest tubers in minitubers C1. This was due to high N in the media that lead to higher vegetation and low yield. The use of soil for minituber production has been reported as unsatisfactory, especially in the greenhouse. The yield projection showed that D2D3 and C2D4 productivities were 20.65 and 18.47 tonnes ha^{-1}, respectively. Zimba *et al*. (2014) obtained a similar result, who obtained 19.08 tonnes ha^{-1} of potato using vermiculite, 11.36 tonnes ha^{-1} using sand, and 4.3 tonnes ha^{-1} using sawdust as a growth media. The untreated cocopeat and soil productivities were 2.10 and 1.48 tonnes ha^{-1}, respectively. Due to the high N in the media, C3D2 to C3D5 had higher growth parameters and higher minituber class C1 production compared to C2D3 and C2D4.

Excessive N leads to poor tuber quality and delayed crop maturity, whereas nitrogen deficiency usually results in poor vegetative growth and low yield (Banjare *et al.,* 2014). Concisely, cocopeat is an alternative to the soil medium for minituber production when it is well treated. The most demanded minituber class by most farmers C4 >18.00 g was dominantly produced in C2D3 (17.63%) and C2D4 (12.41%), while the least percentage production was 0.0%, was in C0D1 to C0D4, untreated cocopeat and soil. This means that when K and Na are not fully reduced in cocopeat, production tends to reduce significantly. Struik (2007) also argued that using soil for the production of minitubers in a greenhouse reduces the number of tubers between 2-5 $plant^{-1}$ depending on the cultivar used. Other studies by Jane *et al.* (2013) and Kamrani *et al.* (2019) have also discouraged the use of soil for minituber production. Putra *et al.* (2019) also obtained an average of 5.27 tubers $plant^{-1}$

when an untreated cocopeat was used for minituber production. Significantly, C2D3, C2D4, and C2D2, respectively, gave the highest number of tubers in C4, the most needed minitubers class in the market. On the other hand, from C0D1 to C0D4, the positive and negative controls could not produce any tuber in minitubers class C4. The relationships between growth parameters and yield showed that there were strong positive correlations between the number of tubers and NDVI (r= 0.67), the number of tubers and plant height (r= 0.70), tubers and branches (r= 0.73), yield and NDVI (r= 0.90), yield and number of branches (r= 0.95), yield and number of tubers (r= 0.87), yield and plant height (r= 0.93), and between NDVI and branches (r= 0.92) all at $P<0.001$.

Table 4.5: Means separation for the interaction effects calcium nitrate levels and soaking durations on the yield, number of tubers, and tuber weight classes

Treatment	Yield (g plant^{-1})	Number of tubers plant^{-1}	Tuber weight classes			
			C1	C2	C3	C4
C0D1	77.33^{k}	8.00^{gh}	4.67^{cde}	2.00^{bcd}	1.33^{def}	0.00^{j}
C0D2	98.33^{jk}	10.00^{efg}	4.33^{bcde}	3.00^{ab}	2.67^{bcd}	0.00^{j}
C0D3	104.33^{jk}	7.00^{gh}	4.33^{bcde}	2.33^{bc}	0.33^{f}	0.00^{j}
C0D4	119.33^{j}	7.33^{gh}	4.00^{cde}	2.33^{bc}	1.00^{ef}	0.00^{j}
C0D5	124.00^{j}	7.33^{gh}	3.33^{de}	2.00^{bcd}	1.00^{ef}	1.00^{hij}
C1D1	175.67^{i}	7.67^{gh}	4.00^{cde}	1.67^{cd}	1.33^{def}	0.67^{ij}
C1D2	192.67^{hi}	9.00^{fg}	3.67^{cde}	1.67^{cd}	2.00^{cde}	1.67^{fghij}
C1D3	204.33^{h}	11.33^{def}	4.00^{cde}	3.00^{ab}	2.00^{cde}	2.33^{efghi}
C1D4	209.67^{h}	11.33^{def}	3.00^{de}	2.33^{bc}	3.00^{bc}	3.00^{cdefg}
C1D5	239.33^{g}	10.00^{efg}	3.33^{de}	2.00^{bcd}	2.00^{cde}	2.67^{defgh}
C2D1	303.33^{f}	11.67^{cdef}	2.67^{e}	2.00^{bcd}	3.00^{bc}	4.00^{cde}
C2D2	328.00^{ef}	14.67^{c}	3.33^{de}	2.67^{bc}	4.00^{ab}	4.67^{bc}
C2D3	464.67^{a}	21.67^{a}	3.33^{de}	4.00^{a}	5.33^{a}	9.00^{a}
C2D4	415.67^{b}	18.00^{b}	3.00^{de}	4.00^{a}	4.67^{a}	6.33^{b}
C2D5	347.00^{cde}	12.67^{cde}	5.33^{abc}	2.00^{bcd}	2.33^{cde}	3.00^{cdefg}
C3D1	352.00^{cde}	14.67^{c}	4.67^{bcd}	2.67^{bc}	3.00^{bc}	4.33^{cd}
C3D2	370.67^{c}	14.00^{cd}	6.00^{ab}	2.00^{bcd}	2.67^{bcd}	3.33^{cdef}
C3D3	366.33^{cd}	12.67^{cde}	6.00^{ab}	2.00^{bcd}	2.33^{cde}	2.33^{efghi}
C3D4	353.00^{cde}	11.33^{def}	6.00^{ab}	2.00^{bcd}	2.00^{cde}	1.33^{ghij}
C3D5	342.00^{de}	11.33^{def}	6.67^{a}	2.00^{bcd}	1.33^{def}	1.33^{ghij}
C0D0	47.33^{l}	7.67^{gh}	4.67^{bcd}	2.00^{bcd}	1.00^{ef}	0.00^{j}
Soil	33.33^{l}	5.67^{h}	4.67^{bcd}	1.00^{d}	0.00^{f}	0.00^{j}
Total	*5268.32*	*244.98*	*95.00*	*50.67*	*48.32*	*50.99*
MSD	***28.52***	***3.08***	***1.87***	***1.17***	***1.34***	***1.92***

Means followed by the same letter(s) in the same column are not significantly different using Tukeys' HSD test at a 5% level of significance. MSD: minimum significant difference

4.4 Conclusion

The use of $Ca(NO_3)_2$ above 100 g to treat 1.5 kg of cocopeat irrespective of the soaking durations leads to excessive Ca and N in the media thus inhibiting potato K uptake. Potato growth parameters are increased with an increase in $Ca(NO_3)_2$. The use of $Ca(NO_3)_2$ above 100 g increases the N concentration in the media to excessive levels thus increasing the vegetative parts of the plant and resulting in low yield. Higher minituber yield is attained when 1.5 kg of cocopeat is soaked with 100 g of calcium nitrate for 36 hours. The study further recommends the comparison study of treated cocopeat with other soilless media for minituber production.

CHAPTER FIVE

EFFECTS OF TREATED COCOPEAT-PUMICE MIXTURES ON MEDIA PHYSICAL PROPERTIES, NUTRIENT UPTAKE, GROWTH AND YIELD OF POTATO (*Solanum tuberosum* L.)

Abstract

The use of soil for minituber production from apical rooted cuttings (ARCs) is generally unsatisfactory due to its low and variable productivity, inherent soil-borne pests and insufficient soil-water. This study was therefore conducted to determine the effect of an admixture of treated cocopeat and pumice ratios on the resultant soilless media physical properties, nutrient uptake and yields of grown potato apical rooted cuttings. A greenhouse experiment was conducted at the Climate and Water Smart Agriculture Centre of Egerton University, Kenya. It was arranged in a completely randomized design with three replicates and six treatments, *viz.*, 100% cocopeat, 75:25%, 50:50%, 25:75% cocopeat to pumice (C:P), respectively along with pure pumice (100%) and soil (100%) treatments i.e., T1, T2, T3, T4, T5, and T6, respectively. The results revealed that the use of 100% cocopeat, 75:25 and 50:50 C/P significantly improve the bulk density, particle density, air-filled porosity, moisture content, and water holding capacity. The highest water holding capacity of 52.0% was observed in the soil treatment. Nitrogen, potassium and calcium uptake was significantly ($P<0.05$) enhanced with the use of 25:75 and 50:50 cocopeat-pumice mixtures. Plant height and number of branches plant^{-1} were significantly highest under 100% (67.57 cm) followed by 50:50 % (63.87 cm) growing media. The NDVI reduced by 9.40% 14 days after the flowering period due to leaf-fall (senescence). The total yield production was 24.64, 22.95, and 22.80% in T1, T2, and T3, respectively. The use of 100% cocopeat significantly increased the production of minituber under greenhouse conditions. For economic purposes, cocopeat and pumice can be mixed at the ratio of 50:50% to still attain high production of minitubers.

Key words: Minituber, mixture, soil, ratios, soilless.

5.1 Introduction

Potato is the second most important food crop in Kenya and the world's third-largest food crop after wheat (*Triticum*) and rice (*Oryza sativa*) (Campos & Ortiz, 2020). Approximately 800,000 farmers are involved in potato production in Kenya; therefore, potato production has an important role in contributing to food security, poverty alleviation through employment, and income generation in urban and rural areas (Jane *et al.* 2013; Kaguongo *et al.* 2014). To combat food insecurity in Kenya and Africa at large, certified potato production is one of the key practices that need to be considered. Due to the inappropriate potato production practices in Kenya, its yield had been drastically low. Most potato farmers in Kenya are currently using uncertified seeds and soil for minitubers multiplication and this has led to low potato productivity of 9-10 tonnes ha^{-1} compared to global productivity of 20-40 tonnes ha^{-1} (Kiptoo *et al.,* 2016; VIB, 2019). For rapid multiplication of minitubers, a hydroponics system has been used as an alternative to soil medium.

Soilless culture is the cultivation of plants without soil as an anchorage for rooting in hydroponics or aeroponic system (Lal, 2006; Savvas & Gruda, 2018). This system is practised globally for its ability to support efficient and higher productivity. In soilless culture, either a liquid or aggregate medium is used. Other general advantages of the soilless systems include control of plant nutrition, and tillage being avoided, thereby increasing the potential length of the cultivation time, and yields are increased (Raviv & Lieth, 2008). One commonly used media today in a hydroponics system is cocopeat (Gohil, 2018; Kahrizi *et al.,* 2008; Kamrani *et al.,* 2019). Cocopeat, a product of coconut (C*ocos nucifera L.*), is an organic planting media made from coconut husk (Kimbonguila *et al.,* 2019; Putra *et al.,* 2019). In a hydroponics system, cocopeat can be used solely or with other components like pumice, vermiculite, sphagnum peat, and perlite amongst others (Awang *et al.,* 2009; Kalaivani & Jawaharlal, 2019). Depending on the source, the cocopeat's cation exchange capacity (CEC) is between 40-100 cmol kg^{-1} which is loaded with K and Na with little or no calcium (Halamba & Kuack, 2021; Marock, 2021; Sachin *et al.,* 2020; Wittman, 2020). Potassium can be attached between 38.5-40 cmol kg^{-1} of the total sites and Na 13.04-15 cmol kg^{-1} of the total sites (Marock, 2021). Due to the location cocopeat is produced and the saline water used for the primary processing, its Na and K levels tend to increase (Nichols, 2013; Schmilewski, 2008). There is, therefore, a need to reduce these chemically bonded elements before using cocopeat in a hydroponics system for any production. Through cation exchange, in the presence of Ca, the sites will release their Na and K cations and lock onto Ca, thus lowering the Na and K content. Favourable nutrient balance, air porosity, water holding capacity, ease of root penetration, nutrient uptake, and economically viable are some of the attributes needed in a soilless media (Barrett *et al.,* 2016; Tsakaldimi & Ganatsas, 2016).

In most instances, cocopeat is mixed at different proportions of a soilless growing media to form a single component (Barrett *et al.,* 2016). Soils are generally unsatisfactory for the production of plants in pot culture (Kamrani *et al.,* 2019). The production in a soilless system is more cost-effective compared to a soil medium (Schmilewski, 2009). Using soil as growth media for potato minitubers production increases the low multiplication rate of tubers and increases disease prevalence and laborious weed control (Darvishi *et al*., 2012). Aeration, water holding capacity, and drainage requirements are typically low in soil compared to media. Widespread adoption of soilless potting media in global food production has been reported as the technical solution for problems such as low productivity, root diseases, root zone oxygen deficiency, and fertility control in soil (Kamrani *et al.,* 2019). Pumice is a natural lightweight aggregate, sponge-like, that forms during the rapid cooling and solidification of molten lava (Rashad, 2021). In Kenya, pumice is readily available and cost-effective. Introducing pumice in the soil increases the soil's ability to retain moisture content. For economical, aeration, and water percolation purposes, pumice has been used for mixing with other substrates in soilless production (Marinou *et al.,* 2013; Patil *et al.,* 2020; Pérez-Urrestarazu *et al.,* 2019). Despite the previous research done to enhance the use of soilless media in a hydroponics system, the use of suitable soilless media for potato minituber production is still a major challenge. Therefore, this study evaluated the effects of treated cocopeat and pumice mixture on the physical properties, nutrient uptake, and growth and yield of potato minitubers.

5.2 Materials and methods

5.2.1 Experimental site description

See section 3.2.2. Within the greenhouse, average maximum and minimum temperatures were 38.5 ^{0}C and 9.4 ^{0}C, respectively. The ambient maximum and minimum temperatures were 26.6 ^{0}C and 9.0 ^{0}C, respectively. The soil used was Mollic Andosols with well-drained, dark reddish clays, slightly acidic as classified by Jaetzold *et al.* (2006).

5.2.2 Characteristics of the potato variety used

One potato variety *Shangi* (apical rooted cuttings) was used for this experiment. *Shangi* is one of the most grown varieties in Kenya, and it is a semi-erect medium-tall variety (slightly below 1 m in height) with moderately strong stems and light green broad leaves with pink flowers (NPCK, 2019). *Shangi* is suitable for almost all the potato growing regions in Kenya, but mainly in Central, Rift Valley, and Eastern regions. It grows well at an altitude of 1500 metres above sea level or higher. Under favourable conditions, it matures early in about 3 months and has a potential yield of 30-40 tonnes ha^{-1} and it is moderately susceptible to late blight disease (NPCK, 2019).

5.2.3 Chemical properties of cocopeat, pumice and soil used

Samples of the treated cocopeat, pumice, and soil were analyzed at the Kenya National Agricultural Research Laboratory (NARL)-Kabete for K, Na, Ca, total N, EC, and pH. The pH and EC were determined using a 1:2 (w/v) ratio of media to water suspension using a pH metre and conductivity metre for EC (Cheng *et al.,* 2006). Using the Kjeldahl digestion method as in Okalebo *et al.* (2002) for total N determination, samples of the substrates were dried in an oven at 70 ˚C and oxidized with hydrogen peroxide 30% at a relatively low temperature (100 ˚C). After decomposition of the excess H_2O_2 and water evaporation, digestion was completed with a concentrated 96% sulphuric acid (H_2SO_4) at elevated temperature (330 ˚C) under the influence of selenium powder as the catalyst. After the digested samples were cooled overnight, the exchangeable Ca was determined using an Atomic Absorption Spectrophotometer (AAS) at a wavelength (λ) of 422.7 nm, while exchangeable K and Na were determined using a flame photometer at λ of 766 nm and 589 nm, respectively (Walinga *et al.*, 1989). The chemical characteristics of the cocopeat, pumice and soil used are presented in Table 5.1.

Table 5. 1: Chemical properties of cocopeat, pumice and soil

Elements	Cocopeat	Pumice	Soil
Potassium (cmol kg^{-1})	7.18	6.15	1.13
Calcium (cmol kg^{-1})	32.33	16.50	0.29
Sodium (cmol kg^{-1})	1.03	0.50	2.10
Total N (g kg^{-1})	3.30	3.00	3.31
EC (mS cm^{-1})	0.74	0.55	0.41
pH	5.71	7.14	5.60

5.2.4 Experimental procedure and treatments

The experiment was arranged in a CRD with the following treatments: 100% cocopeat, 75:25% cocopeat to pumice, 50:50% cocopeat to pumice, 25:75% cocopeat to pumice, 100% pumice and 100% soil, represented as; T1, T2, T3, T4, T5, and T6, respectively (Table 5.2). Before the cocopeat was mixed with pumice and placed in the troughs for planting, 1.5 kg of cocopeat was treated with 100 g of $Ca(NO_3)_2$ dissolved in 15 litres of water and soaked for 36 hours. During the soaking process, the mixture was mixed after every six hours to ensure a uniform reaction. After 36 hours, the cocopeat was rinsed using hydrogen peroxide (H_2O_2) (0.5ml into one litre of tap water). Ten (10) litres of this solution were used to rinse the 1.5 kg of cocopeat. A second rinsing was done with 5 litres of tap water, and the media was left standing for 24 hours to drain the remaining water.

After 24 hours, potato apical rooted cuttings sourced from Stockman Rozen Limited Naivasha, Kenya, were planted in each treatment. The second and third media used were pumice and soil. The pumice and soil were sieved through a 8 mm sieve. The treated cocopeat and pumice were measured in a bucket with a height of 0.24 m and width of 0.30 m to obtain the volume-to-volume ratio of cocopeat to pumice (100% cocopeat, 100% pumice, 50:50, 75:25, and 25:75 cocopeat: pumice, respectively). One bucket of the media was used for one plant. Six troughs each with a length of 10.9 m and width of 0.30 m were used for this experiment. Each trough was divided into three plots with a measurement of 0.3 m × 3.3 m. A spacing of 0.30 m and 0.50 m was left between troughs and plots, respectively. Eleven plants were planted in each plot at a planting spacing of 0.30 m between the plant.

5.2.5 Experimental management

Drip irrigation with hydroponics nutrient solutions (A and B) composed of the essential macro and micro-elements were each mixed at the ratio of 1 g L^{-1}. Water + nutrient (fertigation) was supplied at 0.30 litres plant^{-1} every two days up to the flowering period. After flowering, the nutrient/water supply was reduced to 0.30 litres plant^{-1} after three days. Insect pests were controlled with Thunder (Imidacloprid 100 g L^{-1} + Beta-cyfluthrin 45 g L^{-1}) applied at the rate of 0.5ml L^{-1}. Late blight was controlled using *Infinito* at the ratio of 0.5 ml L^{-1} of water. Weeding was done regularly only on the soil treatment (positive control).

5.2.6 Data collection

For the physical properties determination, the samples were collected accordingly (volume-to-volume ratio) and put to specific analyses for; evaporation rate, moisture content determination, air-filled porosity, water holding capacity, bulk density, and particle density. For nutrient uptake evaluation, potato tubers at the early blooming stage were analysed for total N, Ca, and K (see the chemical properties section for the procedures used). The growth parameters data were collected before and after flowering for plant height, the number of branches, and NDVI using a GreenSeeker handheld. The yield parameters data were collected after harvest on yield (total), minituber number, and minituber classes (C1, C2, C3 and C4).

5.2.7 Data analyses

See section 3.2.4. Treatment means for the main effects of soaking duration and $Ca(NO3)_2$ were separated using Tukey's Honestly Significant Difference (HSD) test at a 0.05 level of significance.

5.3 Results

5.3.1 Effects of the cocopeat-pumice mixture on media's physical properties

Before the experiment was conducted, the following physical properties of the mixture of cocopeat and pumice were determined: evaporation rate, moisture content, air-filled porosity, water holding capacity, bulk density and particle density. The evaporation rate was determined by taking the oven-dry weights of all the samples treatment^{-1}. The samples were fully saturated with tap water and weighed again. The saturated samples were left under observation in a room temperature for five days. The loss in weight day^{-1} was calculated and the results were expressed in percentage (%) (Kalaivani & Jawaharlal, 2019). Moisture content was determined by drying a known weight of the sample in an electric oven at 105 ^{0}C for 15 minutes. The moisture bottles and the stoppers were removed and placed in a desiccator, and their weights were recorded. The moisture bottles were filled to about 2/3 of their capacity with the respective media. The weight of the moisture bottles with the media was recorded, and they were placed in an oven at 105 ^{0}C for 24 hours. After, the samples were removed and cooled in the desiccator and weighed. The process was repeated till the constant weights of the oven-dry samples were obtained. The moisture content was computed by subtracting the weight loss over time (Viji & Rajesh, 2012). Air-filled porosity (AFP) was determined using the saturation and drainage method as described by Yahya *et al.* (1997). The percentage of AFP was calculated by dividing the volume of water collected by the volume of the media.

$$\%AFP = \frac{volume\ of\ water\ collected}{volume\ of\ the\ medium} \times 100$$

In the AFP test, the volume of water that drains from the pot is equivalent to the volume of air and therefore, the volume of water collected represents the amount of air diffused into the media. Water holding capacity was determined using the Kneer-Rackzowski box method as described in (Viji & Rajesh, 2012). Water holding capacity was calculated using the formula:

%WHC= volume of water added-volume of water in the flask.

Bulk density was evaluated using the core rings method (Sung & Talib, 2006). The samples in the core ring were saturated by allowing water to diffuse into the media for two days. After recording their weights, the samples were oven-dried at 105°C for 24 h. The bulk density (*ρb*) was calculated using the formula:

$\rho b = Wb\text{-}Wr / (\pi h\ d^2/4)$

where;

π = 3.142, Wb = weight of the media + core-ring after oven-drying (g), Wr = weight of the core ring (g),

h = core ring height (cm) and d = core ring diameter (cm).

Particle density determination was done using the measuring cylinder method (Kalaivani & Jawaharlal, 2019). The particle density was calculated using the formula:

Particle Density (g cc^{-1}) = Weight of the sample / (V1 – Pore space volume)

where;

V1=Volume of the sample taken, V2= Volume of water added, V3=Volume of sample + the increase in volume at the end of the experiment, Pore space volume= (V1+V2) – V3 ml

In all the treatments, the evaporation rate was increasing over time up to the fourth day and it started reducing on the fifth day. The highest evaporation rates were observed in treatments with the highest cocopeat content while the least rate of evaporation over time was in T6 and T5 for all the days (Fig. 5.1).

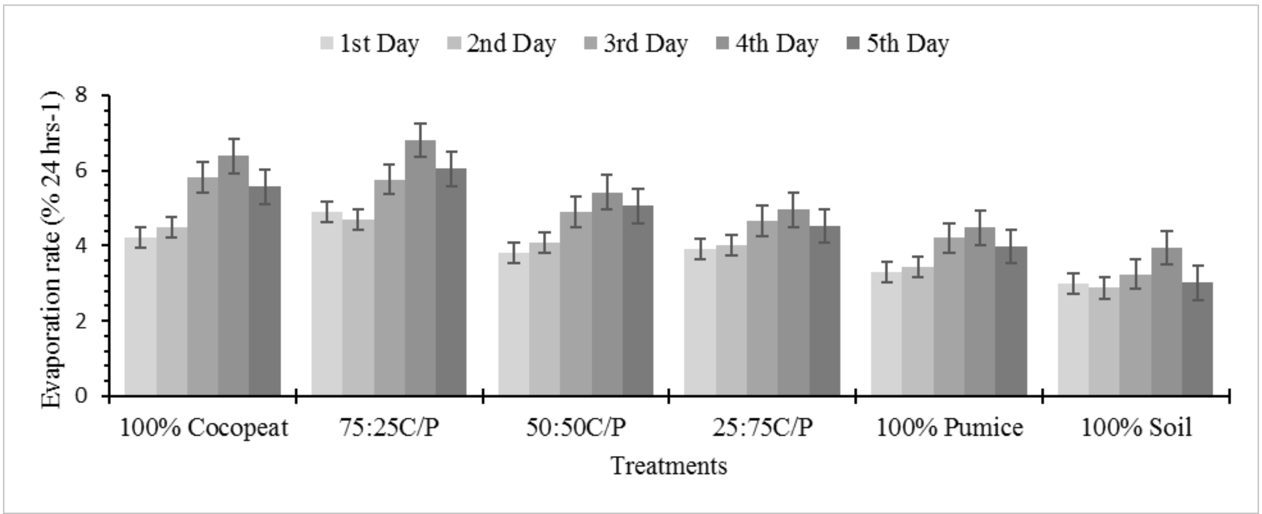

Figure 5. 1: Effects of cocopeat and pumice mixtures on the % evaporation rate of total evaporation in a day over five days' period

The moisture content was found to be higher in 100% cocopeat, 100% pumice, and 50:50% cocopeat: pumice ratio than in the other media. Soil and T2 had the least moisture content (Table 5.2). The results showed that the %AFP increased with an increase in the quantity of cocopeat and reduced with an increase in the pumice particles (Table 5.2). Soil treatment had the least % AFP due to its higher bulk density, while other treatments had significantly the same %AFP. The %WHC tends to increase when the cocopeat particles increase and reduce when the quantity of pumice increases. The %WHC was high at 100% soil due to the bulk density of 0.84 g/cm^3 (Table 5.2). The results showed that the bulk density of media differed significantly (Table 5.2). As the volume of pumice in the mixture increases, the bulk density of the substrate tends to increase. The least bulk density was in 100% cocopeat and 75:25 C/P while the highest was in 100% soil and 100% pumice. Comparatively, the weight of an individual soil particle was much heavier than pumice and cocopeat (Table 5.2). For the mixture of cocopeat: pumice, the particle density tends to increase with the increased volume of pumice in the mixture. Pumice particles were found to be heavier than the cocopeat particles. The particle density was similar to that of the bulk density.

Table 5.2: Effects cocopeat and pumice mixtures on the media physical properties

Treatment	Media mixture	%MC	%AFP	%WHC	D_b (g/cm^3)	D_p (g cc^{-1})
T1	100%cocopeat	10.0^{a}	30.5^{a}	36.3^{b}	0.06^{e}	0.06^{f}
T2	75:25 C/P	3.7^{c}	30.7^{a}	31.7^{b}	0.23^{de}	0.17^{ef}
T3	50:50 C/P	9.4^{a}	32.2^{a}	17.0^{c}	0.31^{cd}	0.25^{de}
T4	25:75 C/P	7.0^{b}	27.8^{a}	15.3^{c}	0.41^{cd}	0.36^{cd}
T5	100% pumice	9.7^{a}	28.4^{a}	13.6^{c}	0.54^{bc}	0.46^{abc}
T6	100% soil	3.9^{c}	12.3^{b}	52.0^{a}	0.84^{a}	0.62^{a}

The means followed by the same letter(s) within the same column are not significantly different using the standard errors. MC: moisture content, AFP: air-filled porosity, WHC: water holding capacity, D_b: bulk density, D_p: particle density

5.3.2 Effects of cocopeat-pumice mixtures on potato nutrient uptake

At the early blooming stage, tubers from two plants 50 g each were selected from each treatment for total N, Ca, and K determination. The samples were dried in an oven at 70 °C for 72 h. The procedures described in the chemical properties section were used for the determination of total N, Ca, and K (see section 3.2.1 for the procedures used). The nutrient uptake was calculated using the formula proposed by Rani and Sukumari (2013).

$$U_i = \frac{n_i \times DW_{tubers}}{100}$$

where;

U_i = uptake of nutrient (i) cmol kg^{-1}, n_i = concentration (cmol kg^{-1}) of nutrient (i) in potato tubers, i =specific nutrient (N, Ca, K), DW_{tubers} = dry weight of potato tubers (g).

The results for the nutrient uptake efficiency are in (Table 5.3). Potassium uptake was higher in all the treatments except the soil treatment, with the least K uptake. For Ca and total N, the higher uptakes were in T4 and T3 for both parameters, while the lowest uptake was 100% cocopeat. This means the nutrient uptake is enhanced when cocopeat and pumice are mixed at T4 or T3.

Table 5. 3: Effects of cocopeat and pumice mixture on minituber potassium, calcium, and nitrogen uptake at the early blooming stage of potato apical rooted cuttings

Treatments	Potassium (cmol kg^{-1})	Calcium (cmol kg^{-1})	Nitrogen (g kg^{-1})
100%cocopeat (T1)	5.35^{a}	0.23^{e}	1.50^{d}
75:25 C/P (T2)	5.66^{a}	0.91^{de}	2.12^{bc}
50:50 C/P (T3)	5.37^{a}	2.31^{ab}	2.31^{ab}
25:75 C/P (T4)	5.78^{a}	2.58^{a}	2.65^{a}
100% pumice (T5)	5.34^{a}	1.47^{cd}	1.78^{cd}
100% soil (T6)	4.75^{b}	1.82^{bc}	2.19^{b}

The means followed by the same letter(s) within the same column are not significantly different

5.3.3 Effects of cocopeat and pumice mixture on potato growth and yield parameters

The results showed there were significant (P<0.001) differences amongst treatments and stages for plant height, number of branches, and the NDVI values (Fig. 5.2). Plant height and number of branches increased significantly after flowering compared to heights before flowering in all the treatments. In contrast, the NDVI values were significantly higher before the flowering period than after flowering in all the treatments. Before flowering, plant height was much higher in 75:25 C: P and 25:75 C:P.

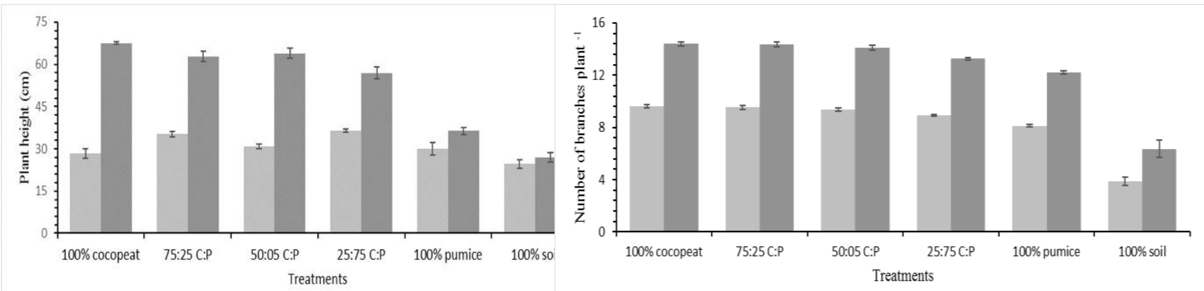

Figure 5. 2: Effects of cocopeat and pumice mixture on plant height and number of branches at different growth stages

After flowering, the trend changed; treatments with a higher cocopeat to pumice ratio (100% cocopeat, 75:25 C:P, and 50:50 C:P) gave the highest plant height up to 67.57 cm, and the least was obtained in 100% soil and 100% pumice treatments. The trend for the number of branches before and after flowering was constant. Treatments with higher cocopeat content in the mixture (100% cocopeat, 50:50 C:P, and 75:25 C:P) had a significantly higher number of branches before and after flowering, and the least branches were observed in the soil and 100% pumice treatments at the various growth stages. As for the NDVI before and after flowering, 100% cocopeat and the treatments with cocopeat and pumice mixtures had the highest vegetation compared to the 100% pumice and 100% soil treatments (Fig. 5.3). The interactions between treatment and stage of data collection were also significant for plant height and number of branches and not for the NDVI.

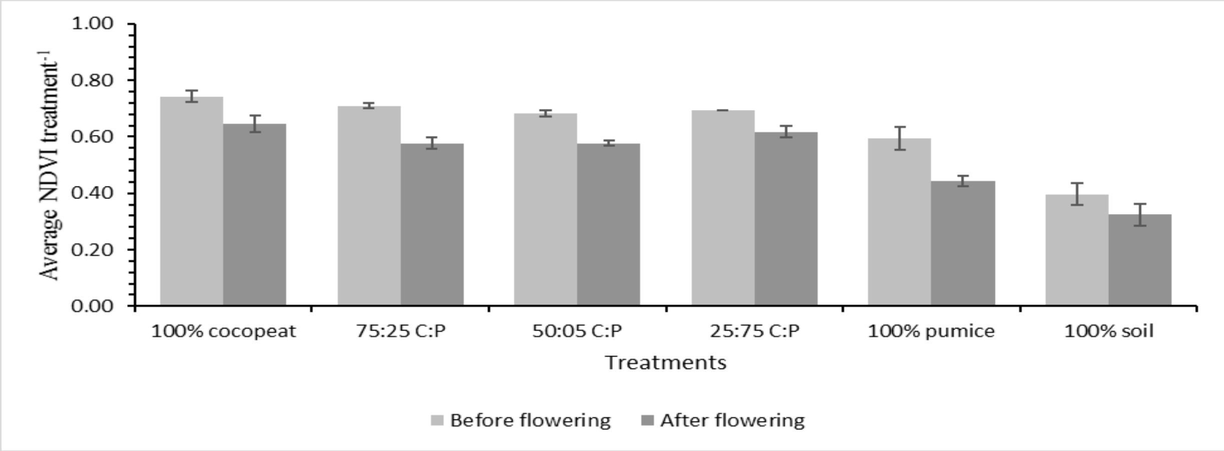

Figure 5. 3: Effects of cocopeat and pumice mixture on potato NDVI values at different growth stages

There were significant differences among the yield parameters examined. Except for C1, where 100% pumice and 100% soil gave the highest production of minitubers, treatments with higher cocopeat to pumice ratios (100% cocopeat, 75:25 C:P, and 50:50 C:P) recorded the highest values in the rest of the yield parameters (Table 5.4). Treatment 1 gave the highest yield, the number of tubers, minitubers weight class 4 and 3 by 24.64%, 25.00%, 34.49%, and 29.06%, respectively. This was followed by T2 and T3 producing 22.95 and 22.80% for yield, 20.28 and 19.34% for the number of tubers, producing 19.07% for C2, 25.46 and 20.01% for C3, and 20.68 and 24.15%, respectively. Other than C1, the least production was observed in the soil and 100% pumice.

Table 5. 4: Means separation for potato yield, number of tubers, and tuber weight classes

Treatments	Yield (g plant^{-1})	Number of tubers plant^{-1}	C1 <8.00g	C2 8-15.99g	C3 16-18g	C4 >18.00g
T1	402.68^{a}	17.67^{a}	2.33^{b}	3.33^{a}	5.33^{a}	6.67^{a}
T2	375.08^{b}	14.33^{b}	3.00^{b}	2.67^{ab}	4.67^{ab}	4.00^{bc}
T3	372.68^{b}	13.67^{b}	2.68^{b}	2.67^{ab}	3.67^{ab}	4.67^{b}
T4	298.87^{c}	11.00^{c}	3.00^{b}	2.00^{ab}	3.00^{b}	3.00^{c}
T5	137.14^{d}	7.67^{d}	4.00^{a}	2.00^{ab}	1.00^{c}	0.67^{d}
T6	48.10^{e}	6.33^{d}	4.00^{a}	1.33^{b}	0.67^{c}	0.33^{d}
MSD	***2.47***	***1.83***	***0.91***	***1.71***	***1.71***	***1.29***

The means followed by the same letters are not significantly different using Tukeys' HSD test at a 5% level of significance. MSD: minimum significant difference.

5.4 Discussion

5.4.1 Effects of cocopeat and pumice mixture on the media's physical properties

The results from this study showed that the physical properties examined varied. The evaporation rates of the different media increased from day 1 to day 4. They began to reduce on day five, probably due to temperature and the less moisture content in the media. This may be the result of the room temperature, air humidity, and wind. The rate of evaporation increases with time, as also reported by Kalaivani and Jawaharlal (2019). The treatments that had a higher %AFP had a higher evaporation rate. The %AFP was only low in the soil treatment, while the rest had significantly the same %AFP. Materials with small particles and less bulk density, such as cocopeat, tend to fill up the pores with air, thus increasing the AFP after drainage has stopped (Handreck & Black, 2002). Aeration depends mainly on the size of pore spaces in the substrate. The lowest bulk densities and particle densities of the treatments with high cocopeat content may have contributed to this effect. When a substrate's bulk density is low, the pore spaces will likely be filled with air (under unsaturated conditions) or water (under saturated conditions). Lower bulk density in a substrate enhances root penetration and nutrient uptake. The differences in the bulk density amongst treatments in this study are most likely due to the variation in the particle-size distribution of the material (Richards *et al.,* 1986). The results obtained for the media bulk density are consistent with the results of Awang *et al*. (2009), who found low bulk density in cocopeat (0.07 g per cm^3) compared with cocopeat mixed with rice hull. Due to the surface area, lower substrate particle density tends to develop lower bulk density and higher moisture content. Particles with a higher surface area have higher water holding capacity (Easton & Bock, 2016).

In this study, the soil treatment with the highest particle density (0.62 g cc^{-1}) also had the highest bulk density and the least moisture content. The opposite is true with 100% cocopeat with the least particle density and bulk density but the highest moisture content. Metwally and Hadid (2013) concluded that perlite: peat moss 1:1 v/v could be the most appropriate growing medium for the growth of carnation flowers. According to Kamrani *et al.* (2019), the bulk density of a growing media tends to increase when soil is used alone or mixed with other substrates, and it decreases when growing media contains perlite, peat moss, or vermiculite are used alone. The higher %WHC in treatments with a higher cocopeat and pumice mixture was due to the ability of cocopeat and pumice to absorb water. According to Sachin *et al.* (2020), cocopeat has a high water-holding capacity of about 8-9 times its weight. Pumice is well known for its high water absorption ability when saturated (Mboya & Makunza, 2011).

5.4.2 Effects of cocopeat and pumice mixture on plant nutrient uptake

Nutrient uptake is a mechanism by which plants capture nutrients through root interception, mass flow, and diffusion (Barber, 1995; Cramer *et al.,* 2009; Rausch & Bucher, 2002). Nutrient uptake is influenced by factors such as pH, air humidity, light and temperature, and the species, amongst others. However, other factors also influence nutrient uptake (Hawkesford *et al.*, 2014). Potassium uptake was low in the soil treatment due it the high bulk density that affects root penetration and nutrient absorption. In soilless media, nutrient availability to plant roots can be better enhanced than in most arable soils (Raviv & Lieth, 2008). Bulk density is likely to affect the mass flow, root interception, and diffusion of nutrients (Hawkesford, 2014). Irrespective of the mixture ratio between cocopeat and pumice, the K uptake remained the same. Calcium and total N uptakes were low in 100% cocopeat due to the readily available content of these elements in the cocopeat. The addition of extra nutrient solution with N and Ca available caused the low uptake. Although Ca and N uptake was low in T1, the compositions of nutrients recorded for the tissue analysis were in the normal range for healthy mature leaf tissue of potato (Hochmuth *et al.*, 2018). The nutrients (Ca and N) uptake in potato was enhanced when cocopeat and pumice were mixed at the ratio of 50:50 C/P and 25:75 C/P. The presence of the pumice particles may have contributed to this effect.

5.4.3 Effects of cocopeat and pumice mixture on potato growth and yield parameters

Generally, the quantity of cocopeat used in the mixture increased the growth and yield of potato in a hydroponics system. The plant height and the number of branches significantly increased by 24.90% and 19.70%, respectively during and after the flowering periods while the NDVI reduced by 9.40% during and after the flowering periods. This means that the nitrogen content in the leaves tended to decrease as the leaves became more mature. A similar result was obtained by Muñoz-Huerta *et al.* (2013), who found a decrease in NDVI values in maize after the vegetative stage. At the maturity stage, the chlorophyll of plants tends to reduce, thus reducing the nutrient content in leaves. The NDVI in soil and pumice treatments were low, resulting in low yield compared to other treatments. Normalized difference vegetation index has also been considered one of the useful tools for assessing leaf chlorophyll variability when the leaf area index is moderately high (Anatoly *et al.*, 1996).

The NDVI has shown high correlations with plant yield. The plant height in T1, T3, and T2 increased by 19.44, 17.75, and 17.25%, respectively, while branches increased by 16.33, 15.72, and 16. 19%, respectively, over the soil treatment. The higher particle density in the soil and 100% pumice treatments may have limited root penetration, thus reducing these treatments' growth and yield parameters. Soil is known for its compaction ability under a controlled environment. Gizas and Savvas (2007) reported that the larger particle size of pumice affected the growth and yield of greenhouse crops in soilless culture. In all the yield parameters, except C1, treatments with a higher cocopeat to pumice ratio (T1, T3, and T2) recorded higher productivity, with T1 giving the highest. On the other hand, sole pumice and soil treatments were found to be unsuitable for minituber production. The soil and pumice gave relatively poor physical properties compared to the mixtures. The total yield production was 24.64, 22.95, and 22.80% in T1, T2, and T3, respectively. This showed that the use of 100% cocopeat resulted in significantly higher production of minituber under greenhouse conditions than 100% pumice and 100% soil. Alternatively, for economic purposes, cocopeat and pumice can be mixed at the ratio of 1:1 to attain higher production of minitubers still.

5.5 Conclusion

To attain higher minituber production under a greenhouse condition, the use of soilless culture is essential. To improve the soilless media's physical properties in hydroponics production, 100% cocopeat, or the mixture of cocopeat to pumice at 50:50%, can be used. Higher nutrient uptake does not necessarily increase the growth and yield of potato. The mixture of cocopeat and pumice increased the nutrient uptake compare to when they are used solely. Nitrogen was found to significantly reduce in the tissue of potato as it approaches the maturity state. Higher plant height and minituber production is achieved when cocopeat is used alone or economically when mixed with pumice at 50:50%. The study found that the use of 100% soil or 100% pumice for minituber production generally results in lower production than the use of 100% cocopeat and the mixture of cocopeat to pumice at 50:50%. The study suggests using different potato varieties under 100% cocopeat, 50:50 cocopeat to pumice, and the mixture of 75:25 cocopeat to pumice for minituber production.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussion

Cocopeat is an important soilless media with relatively high initial EC, K, and Na (Gohil, 2018). When the levels of these elements are reduced, it becomes suitable for horticultural production (Iasiah & Khanif, 2004). This study showed that K and Na were relatively high in an untreated cocopeat from this region. Using 100 g of $Ca(NO_3)_2$ 1.5 kg^{-1} of cocopeat with a soaking duration of 36 hours, K and Na were reduced by 78.44% and 92%, respectively. The strong negative correlations between Ca and Na, Na and N, and between Ca and K showed that $Ca(NO_3)_2$, which contains calcium and nitrogen, could reduce K and Na in cocopeat. Other studies have also recommended the use of magnesium nitrate, water (without any additional chemical), and barium chloride for the extraction of K and Na in cocopeat (Poulter, 2014; Verhagen, 1999; Wittman, 2020). This study showed that irrespective of soaking durations, water alone does not extract a significant amount of K and Na to improve the suitability of cocopeat for hydroponics uses. Saturation/soaking is one way to reduce K due to its low electrostatic force (Weil & Brady, 2017).

Minituber production in soilless media is one of the determinants of quality potato production. Cocopeat is one of the soilless media used in hydroponics production with many advantages: it is pathogen-free, growth and yield are independent of the soil type, the nutrient solution is reusable, tillage is avoided, higher productivity (Goddek *et al.*, 2019; Raviv & Lieth, 2007). Most importantly, cocopeat can be reused for about four years in a hydroponics system (Gohil, 2018). This study suggests that potato minituber production is increased through the use of cocopeat, especially when 1.5 kg of cocopeat is treated with 100 g of $Ca(NO_3)_2$ with a soaking duration of 36 hours. As in this study, Sengupta and Banerjee (2012), proposed the use of cocopeat to soil. Blok and Vermeulen (2010), also reported that the use of soil media for ornamental crops was generally unsatisfactory. The productivity in soilless media is 50% higher than in soil. The results in this study have also shown that for cocopeat to give higher return/income, it must be treated to reduce the K, Na, and EC. The physical properties of the growth medium also play an essential role in plant nutrient uptake, growth and development (Awang *et al.*, 2009b). This can be improved in cocopeat when mixed with pumice at 50:50 or 75:25 C/P. Growing media has a significant role to support plants while holding nutrients and water for the plants to use during the growth period (Gohil, 2018).

The results of this study suggest that the use of 100% treated cocopeat results in the highest production of potato minitubers. The mixture of cocopeat and pumice at 50:50 is the second most effective media after 100% cocopeat for potato minitubers. Awang *et al.* (2009b) proposed the mixture cocopeat and perlite 70:30 for better physical properties and higher *Celosia cristata.* The moisture content and water holding capacity were improved when 100% and the mixture of cocopeat and pumice at ratio 50:50, 75:25 were used. The findings also suggest that higher nutrient uptake does not necessarily increase the growth and yield of potato minitubers as perceived. There was less nutrient uptake in 100% cocopeat compared to the 25:75 cocopeat to pumice ratio, but the production of minitubers in 100% cocopeat was significantly higher. The pumice particles appear to have enhanced the nutrient uptake in potato.

6.2 Conclusions

Based on the findings of this study, the following conclusions can be made:

i. Optimal K and Na reduction in cocopeat was achieved with a minimum addition of 100 g of $Ca(NO_3)_2$ per 1.5 kg of cocopeat, and a soaking duration of 36 hours.

ii. Higher minituber multiplication (rate) in the hydroponics system by using cocopeat was achieved when 1.5 kg of cocopeat was treated with 100 g of $Ca(NO_3)_2$ and soaked for a duration of 36 hours.

iii. The highest plant height and minituber yields were achieved with the use of $Ca(NO_3)_2$ treated 100% cocopeat, followed by a 50:50% cocopeat-pumice mixture.

6.3 Recommendations

From the above conclusions, the following recommendations are made:

i. For optimal potassium and sodium extractions in cocopeat, 1.5 kg of cocopeat be treated with 100 g of $Ca(NO_3)_2$ and a soak for 36 hours by hydroponic potato producers.

ii. For profitable potato minituber production in a hydroponics system by potato producers, the use of 1.5 kg of cocopeat treated with 100 g of $Ca(NO_3)_2$ and a soaking duration of 36 hours is recommended.

iii. For higher productivity of minitubers, 100% treated cocopeat be used, alternatively; cocopeat mixed with pumice at a ratio of 50:50 be used by potato minituber producers.

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APPENDICES

Appendix A. 1:

Mean squares of the analysis of variance for the effect of calcium nitrate levels and soaking durations on K, Na, EC, and pH in cocopeat leachate

Source of variation	df	K cmol kg^{-1}	Na cmol kg^{-1}	EC mS cm^{-1}	pH
Calcium nitrate	3	29.55^{**}	43.29^{***}	208.08^{***}	0.62^{***}
Soaking durations	4	3.83^{ns}	1.90^{***}	0.20^{ns}	0.01^{ns}
CN × SD	12	2.08^{ns}	5.17^{***}	0.33^{ns}	0.01^{ns}
Error	40	5.66	0.27	0.28	0.01
CV (%)		19.28	8.70	6.66	1.85
R-Square		0.51	0.95	0.98	0.80

Values in the table are represented as mean squares. *, **, *** significant at ($p \leq 0.05$); ($p \leq 0.01$),

($p \leq 0.001$), respectively. ns: not significant, CN: Calcium nitrate, Sd: Soaking duration

Appendix A. 2:

Mean squares of the analysis for the effect of calcium nitrate levels and soaking durations on variance for K, Na, Ca, N, EC, and pH in treated cocopeat

Source of variation	df	K (cmol kg^{-1})	Na	Ca	N ($g\ kg^{-1}$)	EC mS cm^{-1}	pH
CN	3	526.25^{***}	4.88^{***}	8415.43^{***}	139.99^{***}	0.67^{***}	0.00^{ns}
SD	4	24.60^{***}	0.24^{***}	179.02^{***}	4.40^{***}	0.03^{***}	0.00^{ns}
CN × SD	12	2.72^{ns}	0.01^{ns}	27.81^{ns}	1.05^{**}	0.01^{ns}	0.01^{ns}
Error	40	2.89	0.02	20.64	0.31	0.00	0.02
Cv (%)	-	15.14	9.94	16.77	6.76	7.41	2.02
R^2	-	0.94	0.96	0.97	0.97	0.95	0.65

Note: Values in the table are represented as mean squares. *, **, *** significant at ($p \le 0.05$); ($p \le 0.01$), ($p \le 0.001$), respectively. ns: not significant, CN: Calcium nitrate, Sd: Soaking duration, Cv: Coefficient of variation, R^2: R-square

Appendix A. 3:

Mean squares of the analysis of variance for the effect of calcium nitrate levels and soaking durations on number of branches, NDVI, and plant height across treatments

Source of variation	df	Branches	NDVI	Plant heitht
Soaking durations	4	6.14***	0.00^{ns}	87.31***
Calcium nitrate	3	233.39***	0.22***	3322.75***
CN × SD	12	1.13^{ns}	0.00^{ns}	18.00**
Error	40	0.67	0.00	4.86
Coefficient of variation (%)		6.54	6.93	3.65
R-square		0.97	0.86	0.98

***, **, *, ^{ns}: significant at 0.001, 0.01, and >0.05, respectively

Appendix A. 4:

Mean squares of the analysis of variance for the effect of calcium nitrate levels and soaking durations on yield, number of tubers, tubers weight classes; C1, C2, C3, and C4 across treatments

Source of variation	df	Yield (g plant^{-1})	Tubers plant^{-1}	C1	C2	C3	C4
SD	4	6234.40***	16.58***	0.98*	1.57***	2.57***	3.53***
CN	3	245401.39***	174.86***	17.79***	2.15***	17.80***	69.39***
SD × CN	12	3396.09***	17.58***	1.74***	1.07***	2.13***	7.10***
Error	40	91.13	1.07	0.35	0.17	0.22	0.43
Cv (%)		3.68	8.92	13.81	17.12	19.67	25.81
R^2		0.99	0.95	0.85	0.79	0.91	0.95

***, *, ^{ns}: significant at 0.001, 0.05, and >0.05, respectively

Appendix A. 5:

Mean squares of the analysis of variance for the effects of cocopeat and pumice mixtures on plant height, number of branches, and NDVI

Source of variation	df	Plant height	Branches	NDVI
Treatments	5	571.26***	41.91***	0.09***
Stages	1	3889.06***	159.18***	0.10***
Treatment × stage	5	373.46***	1.22**	0.00^{ns}
Error	24	6.80	0.19	0.01
Coefficient of variation (%)		6.26	4.18	10.87
R-square		0.98	0.98	0.86

Appendix A. 6:

Experiment one: Effect of calcium nitrate levels and soaking durations on untreated cocopeat chemical properties.

Appendix A. 7:

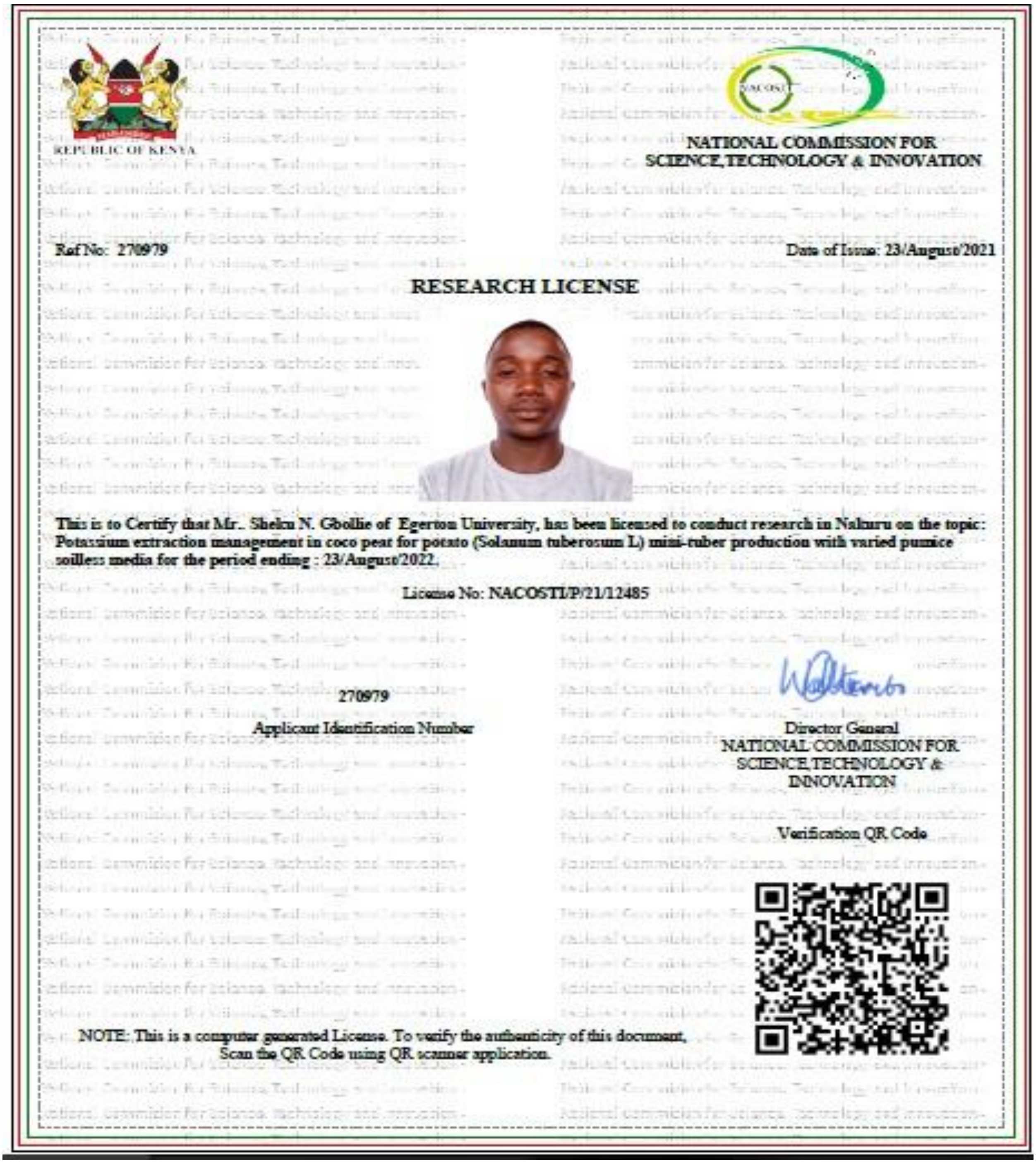
Experiment two: Effect of calcium nitrate levels and soaking durations on growth, yield and nutrient uptake of potato apical rooted cuttings

Appendix A. 8:

Experiment three: Effect of treated cocopeat-pumice mixture on media physical properties, nutrient uptake, growth and yield of potato.

Appendix A. 9:

The media (cocopeat, pumice, and soil) used during the experiments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Appendix A. 10:

Candidate's research permit

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Effects of Calcium Nitrate Levels and Soaking Durations on Cocopeat Nutrient Content

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Abstract

Cocopeat, a by-product of the coconut (*Cocos nucifera* L.), is an important soilless media that contains high potassium (K), sodium (Na), and electrical conductivity (EC) depending on its source. Methods for extracting these elements and thus lowering EC are yet to be standardized. This study was therefore carried out to investigate two extraction methods of these elements in cocopeat. A greenhouse pot experiment was carried out at the Climate and Water Smart Agriculture Centre of Egerton University, Kenya. It was laid out in a 5 × 4 factorial completely randomized design. Five soaking durations (12, 24, 36, 48, and 72 hours) and four calcium nitrate ($Ca(NO_3)_2$) levels (0, 60, 100, and 150 g) were used. The experiment was done in two folds: the leachate and treated cocopeat examination for their chemical properties. The General Linear Model procedures were used for Analysis of Variance at ($P \leq 0.05$). The results showed that the addition of $Ca(NO_3)_2$ 100 g extracted significantly more K and Na in the leachate than $Ca(NO_3)_2$ 0.0 g and 60 g. The EC levels in the leachate increased with the application levels of $Ca(NO_3)_2$ while the pH levels were reducing. In the treated cocopeat, $Ca(NO_3)_2$ 100 g and soaking duration 36 hours significantly reduced K and Na and sufficiently supplemented Ca and N. Irrespective of $Ca(NO_3)_2$ and soaking durations, after the cocopeat is washed, the EC and pH values fall within their suitable ranges. There was a strong negative correlation between Ca and Na, Ca and K, and between Na and EC. Also, strong positive correlation between Ca and N and Ca and EC. Effective supplementation of Ca and N, and optimal reduction of K and Na by 78.44% and 92%, respectively can be achieved with 100 g of $Ca(NO_3)_2$ 1.5 kg^{-1} of cocopeat in 15 liters of water with a soaking duration of 36 hours.

Keywords

Calcium Nitrate, Cocopeat, Leachate, Potassium, Soaking

Appendix A. 11:

Candidate's published article

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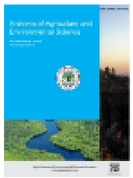

ORIGINAL RESEARCH ARTICLE

CrossMark

Effects of calcium nitrate levels and soaking durations in cocopeat on the growth and yield of potato (*Solanum tuberosum* L.) apical rooted cuttings

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ABSTRACT

This study evaluated the effects of treating cocopeat with calcium nitrate ($Ca(NO_3)_2$) at different soaking durations on potato (*Solanum tuberosum* L.) Apical Rooted Cuttings (ARCs) growth and yield parameters. A greenhouse pot experiment was carried out at the Climate and Water Smart Agriculture Centre of Egerton University, Kenya. An air-dried cocopeat 1.5 kg per treatment, was treated using five soaking durations (12, 24, 36, 48 and 72 hours) × four levels of $Ca(NO_3)_2$ (0, 60, 100 and 150 g) soaked in 15 litres of water. Soil and the un-treated cocopeat were used as positive and negative controls, respectively. The treatments were arranged in a completely randomized design with three replicates. The results showed that there was no significant ($P>0.05$) interaction effect of $Ca(NO_3)_2$ × soaking duration for the number of branches and normalized difference vegetative index. The main effect of 150 g $Ca(NO_3)_2$ gave the highest average number of branches (16.13), NDVI (0.89) and plant height (73.51 cm) followed by 100 g of $Ca(NO_3)_2$. Soaking duration of 36 hours economically produced the highest growth parameters 12.75 and 61.46 cm an average number of branches and plant height, respectively. Significant ($P<0.001$) interaction effects were observed for the plant height and all the yield parameters. The interaction of 100 g $Ca(NO_3)_2$ and soaking for 36 hours gave the highest mini-tuber yield of 464.67 g plant^{-1} and an average number of tubers of 21.67 tubers plant^{-1}. Therefore, 100 g $Ca(NO_3)_2$ and a soaking duration of 36 hours to treat 1.5 kg of air-dried cocopeat is recommended for higher ARCs yield and yield parameters.

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Appendix A. 12:

Candidate's published article