Investigation of the impact of hand pollination on the yield of African horned cucumber (*Cucumis metuliferus* E. Mey. Ex Naudin) under protected structures

by

NKOSIKHONA GOODMAN MAGWAZA

55874444

Submitted in accordance

with the requirement for

the degree of

MASTER OF SCIENCE

in

ORNAMENTAL HORTICULTURE

in the

DEPARTMENT OF ENVIRONMENTAL SCIENCES

in the

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

at the

UNIVERSITY OF SOUTH AFRICA

Supervisor: Dr MK MALULEKE

Co-supervisor: Mr KG Koopa

May 2022

DECLARATION

I, Nkosikhona Goodman Magwaza, (Student number: 55874444) declare that this dissertation entitled **Investigation of the impact of hand pollination on the yield of African horned cucumber (*Cucumis metuliferus* E. Mey. Ex Naudin) under protected structures** which I hereby submit for the degree of Master of Ornamental Horticulture at the University of South Africa, is my own work and has not previously been submitted by me for a degree at this or any other institution.

I declare that the dissertation does not contain any written work presented by other persons whether written, pictures, graphs or data or any other information without acknowledging the source. Prior to the registration of this project, both the researcher and the Unisa library undertook a literature assessment to ensure that no other similar research had been conducted in South Africa/or abroad.

I declare that where words from a written source have been used, the words have been paraphrased and referenced and where exact words from a source have been used the words have been placed inside quotation marks and referenced.

I declare that I have not copied and pasted any information from the Internet, without specifically acknowledging the source and have inserted appropriate references to these sources in the reference section of the dissertation.

I declare that during my study I adhered to the Research Ethics Policy of the University of South Africa, received ethics approval for the duration of my study prior to the commencement of data gathering, and have not acted outside the approval conditions.

I declare that the content of my dissertation/thesis has been submitted through an electronic plagiarism detection program before the final submission for examination.

30 May 2022

Signature | Date

ACKNOWLEDGEMENTS

First and foremost, I am grateful to God for his unending love, mercy, and provision during this dissertation. I would also like to express my gratitude to the following individuals for their various contributions to this dissertation.

- Dr Mdungazi Knox Maluleke and Mr Katlego Gustaff Koopa, my supervisors, who made this work feasible. Their counsel and support helped me a lot to get through all of the stages of completing my research project.
- UNISA (University of South Africa) for contributing to the project's funding. This research project would not have been finished if it hadn't been for their contributions.
- Mr. Gordon Magaseng, Mr. Beetroot Maimela, Dr. Pierre Adriaanse, Mr. Roger Tuckeldoe, Mr. Nhlahla Hlengani and Mr. Jeffery Mogale are among the members of the team. Without them, this research effort would have been considerably more difficult.
- Mrs Baduvile Makhonco Mdunge, my late grandmother. Despite her lack of formal education, she never failed to take me to school and share her advice, support and encouragement to study.
- Miss Celiwe Mdunge and Mr. Dlokwakhe Magwaza, my parents, for their support and encouragement throughout my study endeavour.
- My former teacher, Mr. Xolani Luthuli for his unwavering support, motivation, direction and encouragement during this project.
- My friends, Mr. Celumusa Mthimkhulu and Mr. Khulekani Sipho Mathonsi, for being such an important part of my life and for their wise words.
- This research intended to fill a knowledge gap identified from the research conducted by my study supervisor, Dr. M.K Maluleke, entitled**, "Investigating the performance and quality of the *Cucumis metuliferus* E. Mey. Ex Naudin (African horned cucumber) under different growing environments for potential commercialization."**

ABSTRACT

Most growers prefer enclosed crop production over open space crop production to mitigate environmental conditions such as excessive rainfall, wind and hail. However, there is limited access to natural pollination agents like wind and bees when crops are grown in protective structures where pollination challenges arise. This study was conducted for two seasons in 2021 and 2022 to investigate the impact of hand pollination on the yield of African horned cucumber (*Cucumis metuliferus* E. Mey. Ex Naudin) grown under protective structures such as a greenhouse or under shade netting. Plants grown under these enclosed environments were hand pollinated in the morning during the flowering stage, where pollen was manually transported from the male to the female flowers on the same plant using fresh earbuds (selfing). The study results showed that in comparison to cultivation under shade netting, hand pollination was associated with at least a doubling in cucumber fruit number and up to a seven-fold increase in ripe fruit number in plants cultivated in the greenhouse compared to control plants grown under shade netting without hand pollination. Furthermore, the combination of hand pollination and greenhouse cultivation improved the harvest index from 0.11 to 0.35 kg over the control plants. In summary, the findings of this study support the use of hand pollination to increase the yield of African horned cucumber in growing environments such as shade netting and this increase in yield is particularly improved in plants cultivated in a greenhouse. Thus, growers are encouraged to employ hand pollination to improve cucumber crop yield and to maximise profits.

Keywords: *Cucumis metuliferus*, protected growing environments, hand pollination, yield**.**

OKUCASHUNIWE

Abalimi abaningi bakhetha ukukhiqizwa kwezitshalo okuvalekile kunokukhiqizwa kwezitshalo endaweni evulekile ukuze kuncishiswe izimo zemvelo ezifana nemvula enkulu, umoya nesichotho. Kodwa-ke, izinselelo zokuvuthwa kwempova ziyavela njengoba kukhona ukufinyelela okulinganiselwe ezimpoveni zemvelo njengomoya nezinyosi lapho izitshalo zitshalwa ezakhiweni zokuzivikela. Lolu cwaningo lwenziwa ezikhathini zonyaka ezimbili ngo-2021 nango-2022 ukuze kuphenywe umthelela wempova yezandla esivunweni se-*African horned cucumber* (*Cucumis metuliferus E. Mey. Ex Naudin*) etshalwe ngaphansi kwezakhiwo zokuzivikela ezifana nezakhiwo zengilazi noma ngaphansi kwenethi elinomthunzi. Izitshalo ezitshalwe kulezi zindawo ezivalekile zafakwa impova ngesandla ekuseni ngesikhathi sokuqhakaza, lapho impova yayithuthwa ngesandla isuka kweyeduna iye ezimbalini zesifazane esitshalweni esifanayo kusetshenziswa okuncane okusha okufakwa endlebeni (ukuvundiswa ngempova esitshalweni esifanayo). Imiphumela yocwaningo ibonise ukuthi uma kuqhathaniswa nokutshalwa ngaphansi kwenethi elinomthunzi, ukuvuthwa kwempova ngesandla kuhlotshaniswa okungenani nokuphinda kabili kwezinombolo zezithelo zekhukhamba kanye nokukhuphuka okuphindwe kasikhombisa kwezinombolo zezithelo ezivuthiwe ezitshalweni ezitshalwa ezakhiweni zengilasi uma kuqhathaniswa nezitshalo zokulawula ezitshalwe ngaphansi kwenethi elinomthunzi ngaphandle kwempova yezandla. Ngaphezu kwalokho, inhlanganisela yempova yezandla kanye nokutshalwa kwezakhiwo zengilasi kwathuthukisa inkomba yokuvuna isuka ku-0.11 kuya ku-0.35 kg ngaphezu kwezitshalo zokulawula. Kafushane, okutholwe kulolu cwaningo kusekela ukusetshenziswa kwempova yezandla ukuze kwandiswe isivuno se- *African horned cucumber* ezindaweni ezikhulayo ezifana nomthunzi wenethi futhi lokhu kwanda kwesivuno kuthuthukiswa ikakhulukazi ezitshalweni ezitshalwa ezakhiweni zengilasi. Ngakho-ke, abalimi bakhuthazwa ukuba basebenzise impova yezandla ukuze bathuthukise isivuno sesitshalo sekhukhamba kanye nokwandisa inzuzo.

Amagama asemqoka: *Cucumis metuliferus*, izindawo ezikhulayo ezivikelekile, impova yezanda, isivuno.

SICAPHUNO

Balimi labaningi bakhetsa kukhicitwa kwetitjalo lokuvalekile kunekukhicitwa kwetitjalo endzaweni levulekile kute kuncishiswe timo temvelo letifana nemvula lenkhulu, umoya nesangcotfo. Kodvwa-ke, tinselela tekuvutfwa kwemphova tiyavela njengobe kukhona kufinyelela lokulinganiselwe kuma-ejenti emvelo ekutfutsa imphova njengemoya netinyosi lapho khona titjalo titjalwa etakhiweni tekutivikela. Lolucwaningo lwentiwe kumasizini lamabili nga-2021 nanga-2022 kuze kuphenywe umtselela wemphova yetandla esivunweni sekhukhamba yase-Afrika (*Cucumis metuliferus* E. Mey. Ex Naudin) letjalwe ngaphasi kwetakhiwo letivikelako njengendlu lebamba kushisa nobe ngaphansi kwemtfunti wenethi. Titjalo letitjalwe kuletindzawo letivalekile tafakwa imphova ngesandla ekuseni ngesikhatsi sekuchakata, lapho imphova yayitfutfwa ngesandla isuka kulendvuna iye etimbalini tesifazane esitjalweni lesifanako kusetjentiswa ema-earbuds lamasha (selfing). Imiphumela yelucwaningo ibonise kutsi uma kucatsaniswa nekutjalwa ngaphasi kwenethi lenemtfunti, kutfutfwa kwemphova ngesandla kuhlotjaniswa lokungenani nekuphindza kabili kwetinombolo tetitselo tekhukhamba kanye nekukhuphuka lokuphindvwe kasikhombisa kwetinombolo tetitselo letivutsiwe etitjalweni letitjalwa ku-greenhouse uma kucatsaniswa netitjalo tekulawula letitjalwe ngaphasi kwemtfunti wenethi ngaphandle kwekwentiwa kwemphova ngesandla. Ngetulu kwaloko, inhlanganisela yemphova yesandla kanye nekutjalwa kwe-greenhouse kutfutfukiswe inkhomba yekuvuna kusuka ku-0.11 kuya ku-0.35 kg ngetulu kwetitjalo tekulawula. Kafishane, lokutfolwe kulolucwaningo kusekela kusetjentiswa kwemphova yetandla kute kwandziswe sivuno sekhukhamba yase-Afrika etindzaweni tekukhulisa letifana nemtfunti wenethi futsi lokwandza kwesivuno kutfutfukiswa ikakhulukati etitjalweni letitjalwa endzaweni lebamba kushisa. Ngako-ke, balimi bakhutsatwa kutsi basebentise imphova yetandla kute batfutfukise sivuno sesitjalo sekhukhamba futsi nekwandzisa inzuzo.

Emagama lamcoka: I-*Cucumis metuliferus*, tindzawo tekukhulisa letivikelekile, imphova yesandla, sivuno.

Table of contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

^oC	degrees centigrade
cm	centimetre
HI	harvest index
Kg	kilograms
LSD	least significant difference
M	metre
mmol m^{-2} s^{-1}	millimoles square meter per second
TB	total biomass
µmol/m^2	mass per area of leaf surface/milligram per square meter
VSN	Volume serial number

LIST OF APPENDICES

GLOSSARY

Chlorophyll	a pigment that gives plants their green colour and aids photosynthesis, which allows plants to manufacture their own sustenance (Van kooten & Snell, 1990).
Fruit number	the total quantity of fruits on the plant, both ripening and non-ripening fruits (Galpaz *et al*., 2008).
Germination	the metabolic process that transforms an embryo inside a seed into a seedling (Maluleke *et al.,* 2021).
Hand pollination	the manual transport of pollen from the stamen (male component of the flower) to the pistil (female part) (Ekeke *et al*., 2018).
Harvesting	the process of gathering a mature crop from the fields; some crops are harvested by hand, while others are picked mechanically (Aldoshin *et al*., 2019).
Harvest index	calculated by dividing the kilograms of dry fruits biomass by the total kilograms of above-ground biomass (Maluleke *et al.,* 2021).
Stomatal conductance	a measurement of stomatal opening that can be used to determine the water status of a plant (Manzoni *et al.,* 2013).
Total biomass	the total weight of living plant elements above (leaves, branches, and stems) and below (roots) the ground surface (Hao & Papadopoulos, 1999).

CHAPTER 1: INTRODUCTION

The major goal of this chapter is to introduce the research issue and provide a full explanation of what is required for *Cucumis metuliferus* growth. It also includes the research questions, problem statement, and study objectives.

1.1 Background

Cucumis metuliferus (African horned cucumber) is a Cucubitaceae (cucumber family) annual climbing plant (Golabadi *et al.*, 2017).The crop is native to southern and central Africa, where it is consumed as a fruit by the local population, making it one of the most important plants with the potential to become a valuable horticulture crop with nutritional benefits (Maluleke *et al*., 2021). According to Benzioni *et al.* (2019), African horned cucumber fruit is high in Vitamin C, Vitamin E, potassium, phosphorus, and zinc, all of which are required by the human body. This crop is characterized by hairy leaves and stems, yellow flowers, and green soft-shelled fruit that turns bright yellow and orange when ripe (Arrieta *et al*., 2020).

The crop is monoecious, which means that it produces both male and female flowers on the same plant (Guner & Wehner, 2004). English cucumber fruits are typically collected while still green and used in salads or for skin treatment (Sarwar *et al*., 2008). *C. metuliferus* fruit, on the other hand, should be harvested after it has reached maturity when it has an orange colour (Anyanwu *et al*., 2017).The plant thrives in hotter climates and requires well-draining soil (Eifediyi & Remison, 2010; Weng, 2010).

Pollination is defined by Azmi *et al.* (2017) as the process by which pollen grain is deposited from the anther to the stigma, resulting in fertilization. Although the staminate and pistillate flowers are on the same plant in the African horned cucumber (*C. metuliferus*), it is not self-pollinated and requires pollination agents such as wind, bees and humans for successful fruit formation (Yeasmin, 2016). Several studies have found that pollination issues exist in enclosed plant growth structures such as greenhouses and shade nets due to the limited activities of pollination agents such as wind and bees, resulting in poor fruit development and production (Slaa *et al*., 2006).

In the agricultural and horticultural industries, producing plants in protected areas (greenhouses or shade nets) has recently become a popular and preferred technique compared to open field cultivation. This results from growers exercising better control of plant development elements or factors like water, soil and light intensity in the protective structures (Shahak *et al*., 2008). Hand pollination of cucumber crops cultivated in protective structures has been reported by researchers such as Gajdová *et al*. (2012) as being the best practice to increase yield and quality of several fruit crops such as cucumbers. However, there is limited reports on the impact of hand pollination of African horned cucumber (*C. metuliferus*) cultivated under protective structures. Therefore, the current study filled the void.

1.2 Problem statement

Indigenous crops are a source of food in sub-Saharan Africa where rural communities experience nutritional challenges and rely on crop cultivation for revenue and sustenance (Boissard *et al.*, 2008). However, crop yield has become a major issue, resulting in a reduction in food supply and an increase in food costs (Premanandh, 2011)**.** Protective plant growth structures such as shade netting and greenhouses benefit plant growth by encouraging crop production outside of their natural habitat and water saving due to lower evapotranspiration and water drainage (Sigüenza *et al*., 2005). Indigenous crops have several advantages, including their growing organically in the wild (Reinten *et al*., 2011) and being resistant to most pests and diseases (Jäger & Van Staden, 2000). Thus, indigenous crops such as *C. metuliferus* should be researched to determine their yield and nutritional value to help alleviate malnutrition and food scarcity (Nyathi *et al*., 2019).

Cucumis metuliferus is an indigenous crop that has commercial potential to help rural populations achieve economic independence (Usman *et al*., 2015). However, it has not yet been commercialised, as with most indigenous fruits and vegetables, notably in Southern Africa, due to relatively few clear-cut agronomic methods aimed at increasing crop yield and to a lack of a market value chain due to low demand (Moyo *et al*., 2018). There is limited literature on the effect of hand pollination on the fruit yield of *C. metuliferus* cultivated under protective structures (greenhouse and shade net).

Maluleke et al. (2021) studied the yield response of African horned cucumber grown at different water levels, soil types, and growing conditions (greenhouse, shade net and open field). In comparison to protective structures, the authors reported a higher fruit number and yield in open field. They went on to suggests that poor fruit number and productivity could have been caused by less pollination activity in protected growing conditions, as opposed to open fields. As a result, the current research aimed to fill a gap in knowledge on the influence of hand pollination on African horned cucumber grown in a protected growing environment (greenhouse and shade net).

1.3 Research questions

The research study addressed the research questions below:

- Will hand pollination improve the overall yield of *C. metuliferus* grown in protective structures?
- What are the physical fruit qualities of hand pollinated *C. metuliferus* fruit harvested from protective structures?

1.4 Aim and objectives

1.4.1 Aim

The main aim of this study was to determine if hand pollination will increase fruit yield and physical quality of *C. metuliferus* fruit grown in protective structures, to enable a comparative assessment of fruit yield.

1.4.2 Objectives

In addressing this aim, the following study objectives were evaluated:

- To determine the growth and yield performance of hand pollinated *C*. *metuliferus* grown in a greenhouse or shade net environment.
- To measure the physical qualities of *C*. *metuliferus* fruit grown under shade nets and in greenhouse conditions**.**

1.6 Dissertation overview

The dissertation overview framework lays out the research study's procedure and activities, as well as the research findings, in a systematic and thorough manner. The following are the titles of the several chapters, as well as a summary of their contents:

Chapter 2: Literature review

The literature review provides a critical analysis of previous studies conducted on *C. metuliferus* or related crops. It also assesses relevant research on the performance and fruit yield of different crops in varied environments, such as greenhouses and shade nets.

Chapter 3: Methodology

This chapter covers the research methodological processes that were used to achieve the aim of this research study.

Chapter 4: Results and discussion

This chapter presents and discusses the study results generated from examining variables and procedures utilized in the study.

Chapter 5: Summary, conclusions and future work

The last chapter of the dissertation summarizes the major research findings, articulates the study's principal conclusions and describes future work.

CHAPTER 2: LITERATURE REVIEW

The purpose of this literature review is to critically evaluate prior studies on *C. metuliferus* or related crops. It also includes evaluating relevant research on the performance of other crops regarding fruit output under various environmental conditions, such as greenhouse and shade net. In the literature review, the numerous approaches and criteria used to measure agricultural performance and yield are key dynamics.

Due to the rapid increase in the worldwide population, the agricultural and horticultural industries are under immense pressure to meet the global food demand (Cakmak, 2002). Both wealthy and developing countries have a responsibility to generate sufficient high-quality food for their populations and to eradicate poverty (Maltsoglou *et al*., 2013). Therefore, it is of outmost importance to continuously investigate various methods to improve crop yield with the aim to improve food security.

2.1 Cultivation requirements of *Cucumis metuliferus.*

Atif *et al*. (2016) reported that African horned cucumber seeds have hard coats and thus should be stored for at least three months or soaked in warm water for at least 15 minutes before sowing. According to Walters and Wehner (2002), the ideal germination temperature for *C. metuliferus* seeds is between 20 and 30 degrees Celsius (^{o}C). However, because of different soil conditions and low performance following transplanting, it is recommended to sow seeds in seedling trays rather than directly into soil to improve root development (Abou-Hadid *et al*., 1995).

A study conducted by Liu *et al.* (2008) in Northeast China found that *C. metuliferus* seedlings are particularly vulnerable to frost and cold, resulting in poor growth and reduced production and quality of fruit. To increase fruit yield and quality, planting should make use of well-draining soil and take place in warmer weather, preferably in the spring or summer (Eifediyi & Remison, 2010).

The application of fertilizer in cucumbers increases soil structure, microbiological characteristics and plant nutrition (Zhang *et al.,* 2008). When dealing with food crops such as cucumbers, Lee and Kader (2000) stressed the importance of avoiding over- and under fertilization. In addition, the electrical conductivity (EC) of water should be taken into account when estimating the overall electrical conductivity for plant nutrients (Uusiku *et al.*, 2010). When employing a fertigation system to deliver nutrients, a grower should monitor the electrical conductivity and pH of the fertigation mix as it moves from the tank to the growing media (Hochmuth, 2015). *Cucumis metuliferus* requires fertile soil conditions but excess nutrients should be avoided because they stimulate leaf growth rather than fruit production (Tucker, 1999).

According to Russo and Schatzer (1991), trellising reduces damage and improves production and net photosynthetic rate in climbing plants such as cucumbers. During the growth and development stage, trellising will allow the plant to sustain fruit load and, eventually, increase fruit quality (Shetty & Wehner, 1998). Most climbing crops, such as English cucumber, are normally trellised as the best way to improve growth and fruit quality (Nweke *et al*., 2013).

Since African horned cucumber fruits are spiky, it is highly recommended to use gloves during the harvesting period (Dris *et al*., 2003). *Cucumis metuliferus* fruits should be harvested when they have reached the ripening stage. The fruits are bright yellow-oranges when ripe and they must be stored in a cool area after harvesting (Anyanwu *et al*., 2017). For this study, the up-rope trellising method used by Maluleke *et al*. (2021) was adopted for trellising *C. metuliferus* plants with the aim to improve fruit quality.

2.2 Cultivation of *Cucumis metuliferus* L

In a greenhouse experiment conducted by Sigüenza *et al.* (2005), *C. metuliferus* seedlings were grown in potting mix as the growth substrate. The crop was found to be an effective rootstock for reducing *Meloidogyne incognita* in a greenhouse environment. However, because natural pollinators such as bees and wind had little access, fruit production was low.

Nicodemo *et al.* (2013) conducted parallel greenhouse tests in Japan, the first of which used stingless bees and Africanized honey bees as pollinators for an English cucumber crop, and the second of which excluded bees, but relied on natural wind movement as pollination agent. The results showed that when bees were included in the experiment, the fruit set yield was 19.2% higher than when bees were not included. Natural pollinators such as bees, insects and wind were used in several cucumber growth experiments to produce fruits in protective structures (Thakur & Rana, 2008).

The impact of manual pollination on the fruit output of *C. metuliferus*. is little documented. Therefore, the current study aimed to fill the knowledge gap on the effect of hand pollination on the fruit yield of *C. metuliferus* under protective structures.

2.3 Factors affecting pollination

According to Brittain *et al*. (2013), pollination agents are the ecosystem services that contribute to environmental stability. As a result, pollination transportation or movement affects the efficiency of pollen transmission from anther to stigma (Knapp *et al.*, 2001). Pollination agents such as the wind, bees and other natural pollinators play a critical role in plant pollination and production so that climate change is expected to have the most negative impact on the environment and crop output (Toledo-Hernández *et al.*, 2017). Therefore, the present study investigated the factors involved in hand pollination and the impact of this method in increasing the fruit yield of *C. metuliferus* under protective structures.

2.3.1 Time

Flowers should be fully formed before pollination occurs (Sanzol & Herrero, 2001). Together with source and distance between pollinators and plants, the pollination period should be considered because it is crucial in ensuring that the fruit formation as well as the quality and quantity of the fruits are not compromised (Wood, 1997). However, adverse climatic conditions, such as harsh weather, can disrupt pollen transmission, causing the pollination process to be delayed (Tuell & Isaacs, 2010). For this study, flowers were hand pollinated in the morning with the aim of increasing fruit formation.

2.3.2 Wind

In the absence of other pollination agents, wind is one of the most significant pollinators since many plants lack a scent or brilliant colours to attract pollinating animals or insects (Wragg & Johnson, 2011). Wind, on the other hand, may limit a vast amount of produced pollen by blowing to plant-free areas (Friedman & Barrett, 2009). According to Klatt *et al.* (2013), it is best to close the greenhouse ventilation during strong winds. In the current study, suitable cucumber flowers were identified and was covered a day before hand pollination was applied to prevent wind pollination.

2.3.3 Insects

Insects are key pollination agents for numerous crops (Kevan *et al*., 1990), so they serve a critical role in increasing the yield of most crops including vegetables, fruits and other field crops. Furthermore, they may have a beneficial impact on the size and shape of the fruit produced, which helps to boost the market price of items, as suppliers want high-quality products to maximise profits (Garratt *et al*., 2014). In the current study, flowers were identified and closed a day before hand pollination was applied to prevent their pollination by insects.

2.3.4 Water

Descamps *et al.* (2018) indicated that water stress and rising temperatures are two major abiotic restrictions that affect plant performance, notably in flower production and development. As a result, total pollen quantity may be affected, resulting in poor fruit development, yield and quality. Furthermore, Gallagher and Campbell (2017) suggested that water availability should be considered because it may limit the plant's ability to maintain transpiration and nutrient uptake. For this study, plants were irrigated regularly in order to prevent water stress to reduce any negative impact on fruit formation and overall crop performance.

2.3.5 Flower quality

Flower quality, which is generally influenced by environmental factors such as high temperatures, lack of light and nutrients, can have a detrimental impact on pollination efficiency (Alqudah *et al.,* 2011). Because the quality and quantity of fruit set are dependent on the nutritional health of the flower. Therefore, fertilizer treatment is critical because it enhances floral quality, which in turn leads to good fruit and, as a result, increased fruit yield (Sanzol & Herrero, 2001). For this study, healthy flowers were identified and closed a day before hand pollination was applied.

2.4 Physiological effects of plants cultivated under protective structures

According to Savvas *et al*. (2008), plant physiological processes such as growth and development are influenced by the growing environment and availability of nutrients. Therefore, high production and quality of fruits are governed by the environmental conditions to which the plants are exposed. Furthermore, plant growth factors are important to consider when it comes to crop management of plants such as cucumbers, watermelons and squash, since these growth factors have a significant impact on the productivity and quality of crops grown under protective structures (Lin *et al*., 2011). In the present study, plant growth factors such as light, temperature and irrigation were monitored with the aim of increasing crop plant growth and outputs.

2.4.1 Stomatal conductance

Chamont *et al*. (1995) remarked that stomatal conductance plays a critical role in plant growth and development and it is influenced directly by environmental conditions. Furthermore, it involves the exchange of water and carbon dioxide through the stomatal pores of the leaf, a process critical for photosynthesis (Savvides *et al*., 2012). Warm climatic conditions may result in increased solar radiation in protective structures, which increases transpiration and, as a result, decreases water absorption in the leaf due to stomatal closure. As a result, stomatal closure in cucumber is mostly influenced by an increase in vapour pressure in the surrounding atmosphere (Li *et al*., 2012).

Maluleke *et al.* (2021) reported that water stress limits net photosynthesis in plants by reducing stomatal conductance. However, under overwatering conditions, plants may get waterlogged, which reduces reproduction and causes soil nutrient loss, all of which have a detrimental impact on stomatal conductance (Fan *et al*., 2019). Many scientists believe that water stress and excessive irrigation tension may disrupt critical biochemical and physiological processes (Nowak, 2002).

2.4.2 Chlorophyll

Yang *et al*. (2010) reported that chlorophyll is crucial for plant growth and development because it converts sunlight into energy through photosynthesis. On the other hand, Hao and Papadopoulos (1999) reported that cucumber requires a warm temperature and moderate water for optimal growth and development. As a result, light intensity and quality as well as water availability all affect the chlorophyll content of the plant, subsequently affecting growth, development and fruit yield in cucumbers (Hovi-Pekkanen & Tahvonen, 2008). Water stress has the potential to decrease or increase chlorophyll levels in plant leaves, hence affecting the rate of photosynthesis (Maluleke *et al*., 2021). Moreover, Steslow (2012) indicated that too much irrigation causes nutrient-deficiency in leaf chlorophyll and may result in leaf yellowing, preventing them from absorbing sunlight due to a lack of chloroplasts.

2.4.3 Light

Light is the most important environmental component that influences plant growth, biomass production and metabolic activities in cucumbers (Brazaityte *et al.,* 2009). In addition, Pettersen *et al*. (2010) studied how cucumber plants convert sunlight into chemical energy through photosynthesis. These authors found that fruit quality and yield are determined by the amount of light that the plant received. On the other hand, Kaiser *et al*. (2019) found differences in terms of height and leaf index for tomato seedlings grown in different light intensity. Under low-light intensity, most seedling leaves become etiolated and more prone to disease, whereas seedlings grown under high light intensity demonstrated longer stem height and an intensive leaf area index.

In summary, this section discussed some of the physiological factors including stomatal conductance, water and light that are intimately involved in cucumber growth and optimising fruit yield. The amount of light intensity between the greenhouse and shade net vary according to the cladding material used to manufacture the structure. Therefore, it has a direct and indirect impact on plant growth development and yield (Lenka, 2020). Thus, the current study included monitoring light intensity under both growing environments (greenhouse and shade net) and also measured stomatal conductance and chlorophyll during different growth (pre-flowering, flowering and fruiting) stages since it has a direct impact on plant growth, development and yield of cucumber fruit.

2.5 Yield components of *Cucumis metuliferus*

Most Cucurbita crops require a warm climate and prefer to be cultivated in soil with good drainage (Salehi *et al*., 2019). As a result, plant growth factors such as light, temperature, water availability and soil type dictate the cucumber plant yield (Benzioni *et al*., 2019). Several authors have reported on yield components such as total biomass, fruit number, length, above-ground biomass, and harvest index of various crops. Erdem *et al*. (2006), for example, studied sweet potato yields under various irrigation regimes and noted that when irrigation is applied at lower frequencies, crop yields decline but increase under moderate and higher irrigation frequencies. However, there is relatively little literature on the effect of hand pollination on the yield of *C. metuliferus* crop grown under protective structures. Therefore, the current study aimed to fill this knowledge gap.

2.5.1 Total biomass

Hao and Papadopoulos (1999) defined biomass as the entire weight of living plant elements, namely above-ground (leaves, branches, and stems) and below-ground (roots). The photosynthetic process, in which radiant energy is absorbed and converted into chemical energy, may result in an increased plant biomass output, is influenced by elements such as solar energy, carbon dioxide and water (Demura & Ye, 2010). On the other hand, Smitha and Sunil (2017) reported that the biomass productivity of cucumbers grown in a protective structure such as a greenhouse was higher than those under shade netting and open field. They remarked that protection offered to plants against natural conditions such as hail and wind damage by the greenhouses could have played a pivotal role in biomass variation. In addition, Torres-Olivar *et al*. (2016) remarked that weather conditions have a persistent impact on crops produced in shade nets and open fields, which normally results in a reduced biomass compared to greenhouse crops (Ferreira *et al.*, 2010).

2.5.2 Fruit number

According to Rahil and Qanadillo (2015), water availability, light intensity and growing environment are some of the most critical elements affecting total fruit yield such as fruit biomass, and fruit number in cucumber cultivation. On the other hand, Nerson (2015) remarked that pollination by bees significantly increased fruit number and size on open field grown cucumber when compared to those that were grown under protective structures. Most flowering crops attract pollinating agents such as honeybees for pollination (Holzchuh *et al.*, 2012). There appears to be scanty knowledge on the effect of hand pollination of *C. metuliferus* on crop yield responses and components such as fruit number under protective structures, for optimum productivity. The present study used hand pollination under varying growing environment such as greenhouse and shade net to fill a void on its effect in fruit number.

2.5.3 Fruit length and diameter

Zhao *et al*. (2019) reported that cucumber fruit length and diameter are essential critical agronomic characteristics because consumers pay attention to them prior to making purchase decisions. Wei *et al*. (2016) suggested that cucumbers planted in a greenhouse grow faster than those grown under a shade net even though Jiang *et al*. (2015) stated that the length and diameter of the fruit is determined by one or more dominant genes present in the plant.

For an English cucumber crop, fruit length may range from 8 to 10 cm whereas fruit diameter may range from 4 to 5 cm (Anyanwu *et al*., 2014). In addition, Nunes *et al.* (2009) reported that the fruit length and diameter are directly affected by the growing environment. Furthermore, fruit load has a direct impact on fruit length and diameter due to competition for water and nutrients within the plant (Gevens *et al*., 2006). The current study investigated the impact of hand pollination on *C. metuliferus* fruit length grown under varying environment.

2.5.4 Harvest index

The harvest index (HI) is calculated by dividing the weight of dry fruits biomass by the total weight of above-ground biomass (Maluleke *et al.,* 2021). The increase in plant biomass and harvest index is dependent on photosynthetic performance, crop growth rate, and radiation use efficiency within the plant. Therefore, an increase in plant biomass and harvest index is critical to yield (Wang *et al.*, 2020). Moreover, Sinclair (1998) indicated that of all resources, photosynthesis is the most essential component in determining how the harvest index changes.

Tardieu (2013) remarked that harvest index is susceptible to environmental conditions such as climate, soil conditions and water availability during crop reproductive development. Therefore, these aspects should be considered because they may affect the plant's growth, development and productivity (Fageria, 2014).

The current study sought to fill the gap on the harvest index of *C. metuliferus* crop grown under different environment (greenhouse and shade net).

In summary, this section reviewed some of the yield components associated with cucumber cultivation. These included total biomass, fruit number, length and diameter as well as harvest index. Therefore, the current study studied the effect of hand-pollination on the total biomass of *C. metuliferus* crops grown under greenhouse and shade netting to help determine its effect on fruit number, length and diameter as well as harvest index.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter describes the research study involving the hand pollination of cucumber flowers and comparing the fruit yield when plants were cultivated in protective structures such as greenhouses or under shade netting. The impact of hand pollination was investigated under varying growing environments (within a greenhouse and under shade netting). Plant growth parameters (chlorophyll, stomatal conductance, fruit number, fruit length and fruit diameter) and yield components (total biomass, aboveground biomass, harvest index) were measured. Thus, most of the study research data were quantitative in nature while qualitative data were restricted to determining the stage of fruit ripeness according to a colour chart described by Nambi *et al*. (2015).

3.2 Material and methods

3.2.1 Plant material and experimental design

Study area

As indicated, this study was conducted during [summer-autumn 2021] and repeated during similar season [summer-autumn 2022] in a controlled greenhouse environment and also under shade netting – an uncontrolled environment. These were sited at the Florida Science Campus of the University of South Africa (26^{o} 10' 30''S, 27^{o} 55' 22.8'' E). The average temperatures for these settings were 16-28˚C (Summer-autumn 2021) and 16-30˚C (summer-autumn 2022) respectively. The relative humidity within the greenhouse environment was measured and maintained between 60 and 75% using automated aerial sprinklers controlled by humidistat (Anden Wall Mount Digital Humidistat, Condair, South Africa). Certified seeds were sourced from a commercial seed supplier (Seed for Africa, Cape Town, South Africa).

A simple factorial experiment was conducted with one factor, namely growing environment (greenhouse and shade net) conducted during summer to autumn in 2021 and 2022, respectively. The pot experiment was a completely randomised design with nine (9) replicates, which resulted in a total number of 36 plants per site. The pots were spaced 1 m apart, and an up-rope vertical trellising method was used to support the plants. Each site had plants used as guard plants, in order to separate the plants from the external effects outside the experimental plot. Well-established, uniform, and healthy African horned cucumber seedlings, germinated from peat substrate, that were 30 days old, were transplanted into 30 cm depth × 30 cm width. Briefly,

Area (depth × width) 30 cm × 30 cm = 900 cm^2, A =$\pi \left(\frac{d}{2}\right) \times 2$ d =286.5 cm^2 planting pots.

Data on plant growth parameters were collected during different phenological stages (pre-flowering, flowering and fruiting).

3.3 Measurement of light intensity

Table 3.1 describes the light intensity exposure to different plant stages in the two protected growth environments. During season 1 under shade netting, plants at the pre-flowering stage were exposed to a mean light intensity value of 1750 lux, whereas similar stage plants in the greenhouse were exposed to a lower mean light intensity of 1100 lux. For season 2, under the shade netting, plants at the pre-flowering stage were exposed to a mean light intensity value of 1650 lux, while the greenhouse light intensity value was set at 1200 lux. The observed trend demonstrated that light intensity was higher in the shade net environment than in the greenhouse. The extreme variation in the light intensity measured under the shade netting depended on the cladding material used in this environment.

Table 3.1: Variation in light intensity on *C. metuliferus* grown under two different environments.

	Light intensity (lux)	
Treatment	Summer-Autumn 2021	Summer-Autumn 2022
Greenhouse		
Pre-flowering stage	1100	1200
Flowering stage	1000	900
Fruiting stage	1500	1500
Shade net		
Pre-flowering stage	1750	1650
Flowering stage	8500	7550
Fruiting stage	925	985

3.4 Application of hand pollination

According to Ekeke *et al*. (2018), fruit set occurs best in cucumber flowers pollinated between 06:00 am and 08:00 am and so this time interval was chosen to hand pollinate the study *Cucumis metuliferus* plants during the flowering stage. The pistillate and staminate flower buds which were identified the day before pollination were covered to prevent possible insect pollination by enclosing the corolla with paper bags. Pollen was then manually transferred by hand using a new earbud from the male to the female flowers on the same plant (selfing). A staminate flower was taken out and pollen applied on the receptive stigma of identified pistillate flowers. This were achieved by rubbing the pollen-containing earbud against the stigma. Plants used as controls were not hand-pollinated, meaning they were left to self-pollinate during the experimental period.

3.5 Plant growth parameter measurements

3.5.1 Measurement of chlorophyll content

Chlorophyll content was measured at different growth stages (pre-flowering, flowering and fruiting) during the experimental period. The leaf chlorophyll content (µmol/m^2) was measured every fifth day weekly, in the morning using a leaf chlorophyll meter (OPTI-SCIENCES-CCM 200 PLUS, USA). The instrument records four (4) replicate readings of chlorophyll on the adaxial or upper leaf surface, since chlorophyll activity is more dominant on the upper leaf surface when compared to the lower surface (Shu *et al*., 2013), to then provide an average chlorophyll value.

3.5.2 Measurement of stomatal conductance

A porometer (Delta-T Device, AP4 Leaf Porometer, United Kingdom) was used to measure stomatal conductance (mmol m^{-2} s^{-1}) every fifth day weekly, in the morning at different plant growth stages (pre-flowering, flowering and fruiting) during the experimental period. The abaxial or lower leaf surface was measured, due to the fact that stomatal opening and conductance activities are more dominant on the lower leaf surface when compared to the upper surface (Savvides *et al*., 2012).

3.5.3 Yield component

(a) Above-ground biomass and total biomass

Above ground fresh biomass (stem, leaves and fruits) was weighed at the end of the experiment using an electronic scale (Uni-Bioc, China). Plant material that had already been counted and weighed was placed in paper bags and then dried in an oven for 72 hours at 80˚C. The cooled, dry material was then re-weighed to determined dry plant weight. *Cucumis metuliferus* total biomass was measured or calculated by summing the dry biomass of all above ground biomass in kg of plant material (stem, leaves and fruit) grown from the greenhouse and shade net environments.

Total biomass = above-ground biomass (dry) + fruit biomass (dry) **………….. 1**

(b) Fruit number and length

The number of fruits on each plant were visually counted, and fruit length (cm) were measured at the end of the experiment (12 weeks) after transplanting.

(c) Harvest index

The *C. metuliferus* harvest index was determined by adopting the formula used by El-mageed and Semida (2015) below:

$$\mathbf{HI} = \frac{\text{fruit dry biomass (dry)}}{\text{total biomass (dry)}} \qquad \textbf{……………. 2}$$

(d) Fruit ripening rate

Fruit ripening rate

The fruit colour chart developed by Nambi *et al*. (2015) was used to determine the ripeness of the fruit (Figure 3.1).

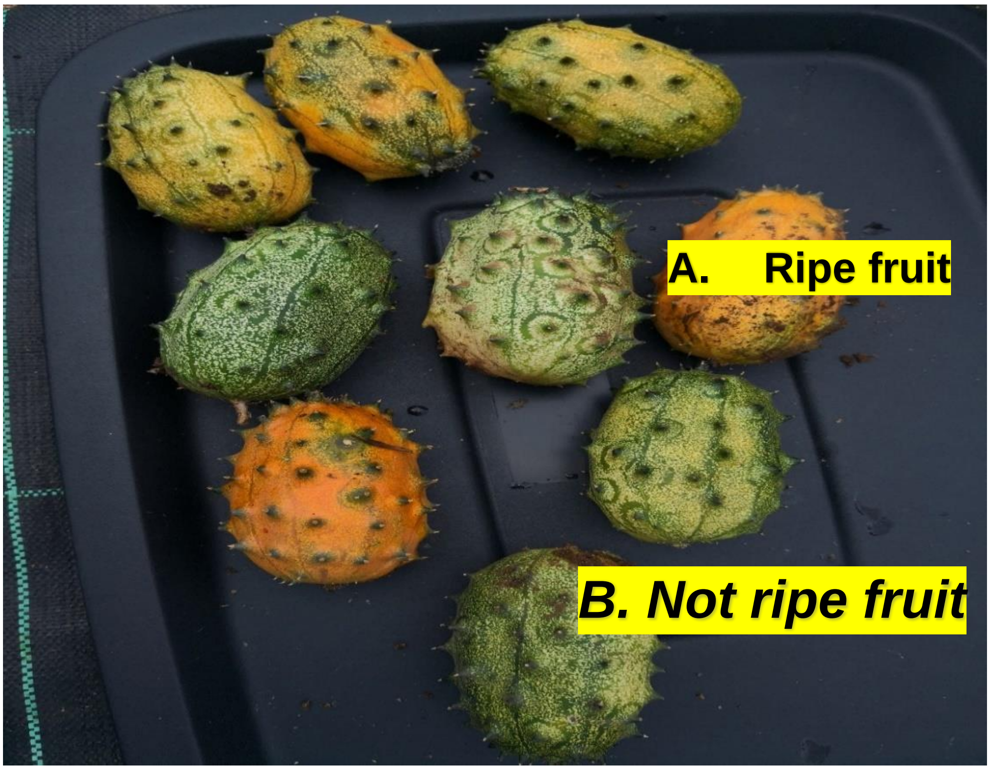


Figure 3.1: Estimation of ripeness of African horned cucumber fruit: A means ripe fruit (yellow); B unripe fruit (light green).

3.6 Statistical analysis

Generalised linear mixed model procedures for GenStat (version 14, VSN, UK) were used for data analysis. The model was used to assess the fixed effects of two treatments (hand-pollination and non-hand pollination) under greenhouse and shade environment on the studied variables. Significant interactions between studied treatments (hand pollination and non-pollination) and factors (greenhouse and shade net) were considered and reported under the results section to determine the effects of all study variables (chlorophyll content, stomatal conductance, fruit length, fruit number, above-ground biomass, total biomass, harvest index, and fruit number). Shapiro Wilk's and Bartlett's test were used to check the normality and homogeneity of variance. All statistical analysis was done using GenStat (version 14, VSN, UK).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the results of the study designed to determine the effect of hand pollination on the yield of African horned cucumber (*Cucumis metuliferus* E. Mey. Ex Naudin) grown in protective structures. Previous studies have evaluated the effect of honeybees and stingless bees on pollination, fruit setting and yield of English cucumber (Nerson, 2009). However, to the best of our knowledge, there is little research that has been conducted to assess the effect of hand pollination versus non-hand pollination on the yield response of African horned cucumber, therefore, the findings of this study serve as a benchmark.

The results of the current study are twofold and describe (1) the features of plants grown under the protective structures followed by (2) the results of analysis of the *C. metuliferus* fruit yield.

4.2 Physiological results of plants grown under the protective structures

4.2.1 Chlorophyll content

Table 4.1 presents the results of analysis of chlorophyll content of *C. metuliferus* plants grown in a greenhouse or under shade netting. Apart from a slight increase in chlorophyll content in the pre-flowering stage of plants cultivated under shade netting, study results show no significant ($P>0.05$) difference on the chlorophyll content in leaves of *C. metuliferus* grown under different growing environments during different growth stages. When measuring chlorophyll content in leaves from greenhouse-cultivated plants in the pre-flowering stage through to the flowering stage during season 1 [2021], the chlorophyll content ranged from 28.5 to 72.3 µmol/m^2. As indicated, a relative increase in chlorophyll content was noted in leaves in flowering plants and this further increased in fruiting plant leaves. Variation in chlorophyll content in season 2 [2022] showed, in general, a slightly more restricted range compared to season 1. An example of this was that the chlorophyll content ranged from 32.3 to 66.3 µmol/m^2 from pre-flowering to fruiting stage leaves in greenhouse-cultivated plants.

Table 4.1: Leaf chlorophyll content (µmol/m²) of *C metuliferus* grown under different protective environments

Note: 2021 means season 1 and 2022 means season 2. Numbers in brackets represent the standard deviation of the mean while the $LSD_{0.05}$ is the least significant difference.

	Chlorophyll (µmol/m²)			
	Hand pollinated		**Control**	
Treatment	**2021**	**2022**	**2021**	**2022**
Greenhouse				
Pre-flowering stage	28,5(0,2)	32,3(0,1)	38,6(0,3)	40,6(0,1)
Flowering stage	57,3(0,1)	59,7(0,3)	68,4(0,1)	58,3(0,2)
Fruiting stage	72,3(0,1)	66,3(0,1)	54,3(0,2)	66,8(0,2)
Shade net				
Pre-flowering stage	45,4(0,1)	66,9(0,2)	41,5(0,3)	64,3(0,1)
Flowering stage	46,4(0,1)	59,2(0,2)	63,3(0,1)	54,7(0,3)
Fruiting stage	50,7(0,2)	58,6(0,1)	65,7(0,1)	67,8(0,2)
Grand mean	43.0	43.0	43.0	43.0
LSD0.05	13.86	13.86	13.86	13.86
P_{value}	0.682	0.682	0.682	0.682

4.2.2 Stomatal conductance

Table 4.2 illustrates the stomatal conductance of *C. metuliferus* grown under varying environments. The results of the study indicated no significant (P>0.05) difference on the stomatal conductance of *C. metuliferus* grown under different environment during varying plant growth stages. In general, stomatal conductance increased as the plants developed from the pre-flowering stage through to the fruiting stage and the stomatal conductance figures for the plants cultivated under shade netting were larger than those shown by plants reared in the greenhouse.

Table 4.2: Measurement of stomal conductance (mmol m^{-2} s^{-1}) of *Cucumis metuliferus* grown under different protective environments.

Note: 2021 means season 1 and 2022 means season 2. Numbers in brackets represent the standard deviation of the mean. The figures for $LSD_{0.05}$ indicate the least significant difference.

	Stomatal conductance (mmol m^{-2} s^{-1})			
	Pollinated		**Control**	
Treatment	**2021**	**2022**	**2021**	**2022**
Greenhouse				
Pre-flowering stage	42,2(0,2)	46,4(0,1)	46,3(0,3)	48,4(0,1)
Flowering stage	52,7(0,1)	53,8(0,2)	44,8(0,2)	56,8(0,2)
Fruiting stage	47,2(0,1)	65,3(0,1)	48,1(0,1)	53,4(0,1)
Shade net				
Pre-flowering stage	57,6(0,2)	52,4(0,1)	61,2(0,3)	64,5(0,1)
Flowering stage	64,5(0,1)	67,4(0,2)	57,6(0,1)	63,8(0,2)
Fruiting stage	66,8(0,3)	71,8(0,1)	54,2(0,2)	57,6(0,2)
Grand mean	45.35	45.35	45.35	45.35
LSD0.05	4.408	4.408	4.408	4.408
P_{value}	0.098	0.098	0.098	0.098

4.3 Yield components

4.3.1 Fruit number

Figure 4.1 presents the beneficial effect of hand pollination on the fruit number of *C. metuliferus* and indicates a significant increase in cucumber fruit yield following use of this technique particularly when plants were cultivated in the greenhouse. A comparison of fruit yield according to year indicated no significant (P>0.05) difference between the fruit number grown under either greenhouse or shade netting. Comparing hand pollinated plants from under shade netting with those cultivated in the greenhouse environment showed a significant increase in fruit yield in the greenhouse. Conversely, the lowest fruit yield was associated with a combination of growth under shade netting and non-hand pollination (control). These findings support those of Motzke *et al*. (2015) who reported higher yield from pollinated cucumber crops, when compared to those that were not pollinated.

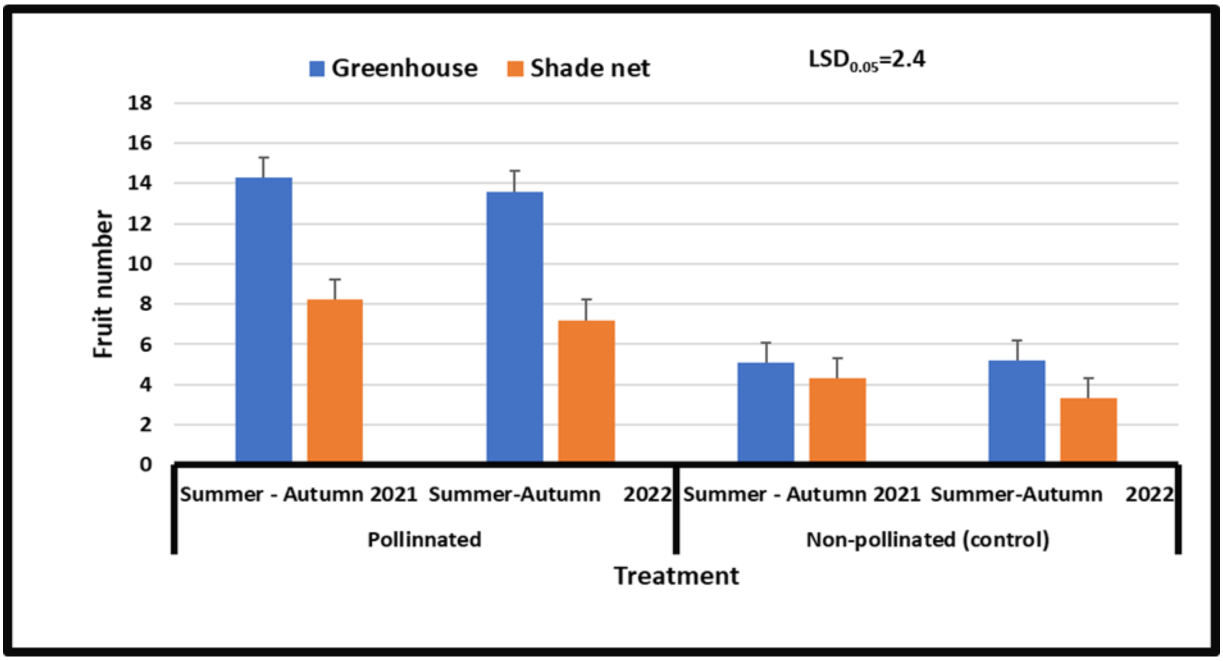


Figure 4.1: The effect of hand pollination on the fruit number of *C. metuliferus* grown under different environments (greenhouse and shade net). Note: 2021 means season 1 and 2022 means season 2. $LSD_{0.05}$ is the least significant difference of the means.

4.3.2 Ripe fruit number

The data in Figure 4.2 show a similar trend as in Figure 4.1. Thus, ripe fruit development in the greenhouse was higher than that under shade netting, particularly when the flowers were hand pollinated. There was no significant (P>0.05) difference as to fruit ripening of *C. metuliferus* in the non-hand pollinated and pollinated control plants. Conversely, the study results illustrated that a three- to seven-fold increase in ripe fruit number resulted from combining hand pollination within a greenhouse cultivation environment. Numerically, these conditions increased the average ripe fruit number for season 1 [2021] from an average of 2 for to 7 ripe fruit and this increase was more marked in season 2 [2022] when the ripe fruit number increased from an average of 1 to 7. The increase in ripe fruit number was less dramatic in fruit from plants grown under shade netting. Thus, in season 1, ripe fruit number increased under shade netting from non-hand pollination (n=2) to hand pollination (n=5) while in season 2 this increase was less dramatic with an increase from non-hand pollination (n=1) to hand pollination (n=3).

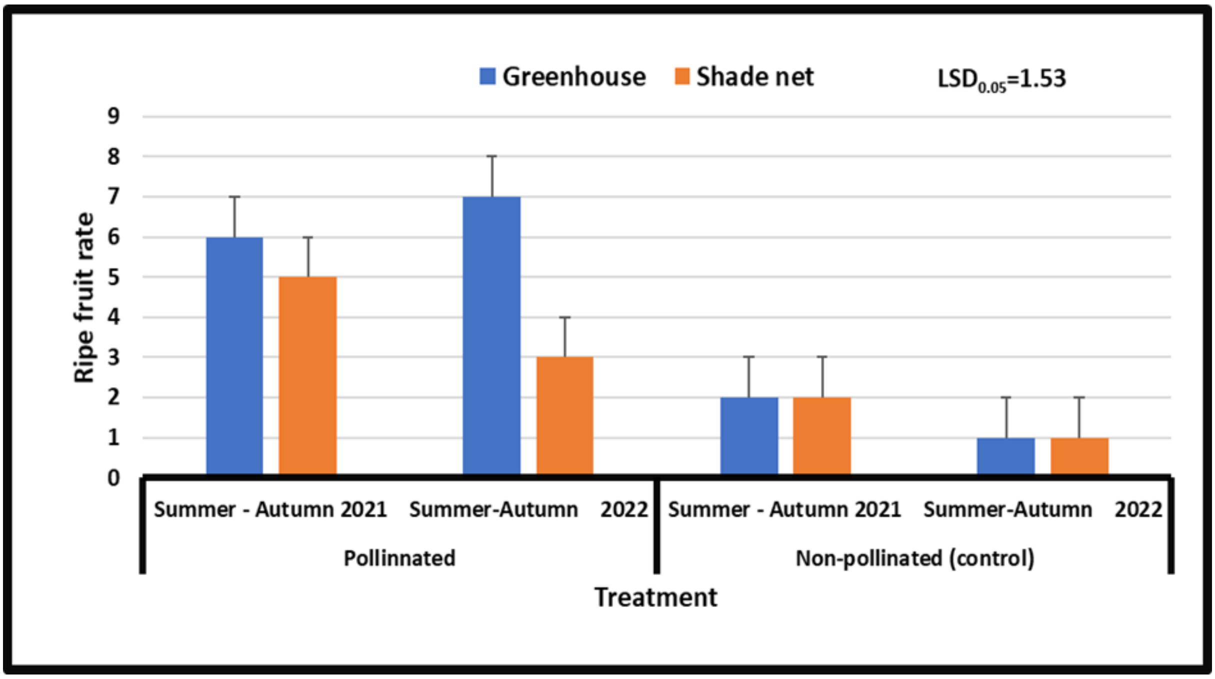


Figure 4.2: The effect of hand pollination on the ripe fruit number of *Cucumis metuliferus* grown under different environments (greenhouse and shade netting). Note: 2021 means season 1 and 2022 means season 2. $LSD_{0.05}$ is the least significant difference of the means.

4.3.3 Fruit length

Figure 4.3 indicates that hand pollination was associated with an increase in fruit length particularly in plants hand pollinated in the greenhouse. However, little effect on the fruit length of *C. metuliferus* was noted when comparing the length of fruits from plants that were grown under either of the two different cultivation environments. In addition, study results indicated that there was no significant ($P \geq 0.05$) difference regarding fruit length of *C. metuliferus* according to year of cultivation.

Perhaps the fact that fertilization was more efficient in the hand pollination treatment compared to non-hand pollination could have optimized pollen grain fusing with an ovule (Rani *et al*., 2016).

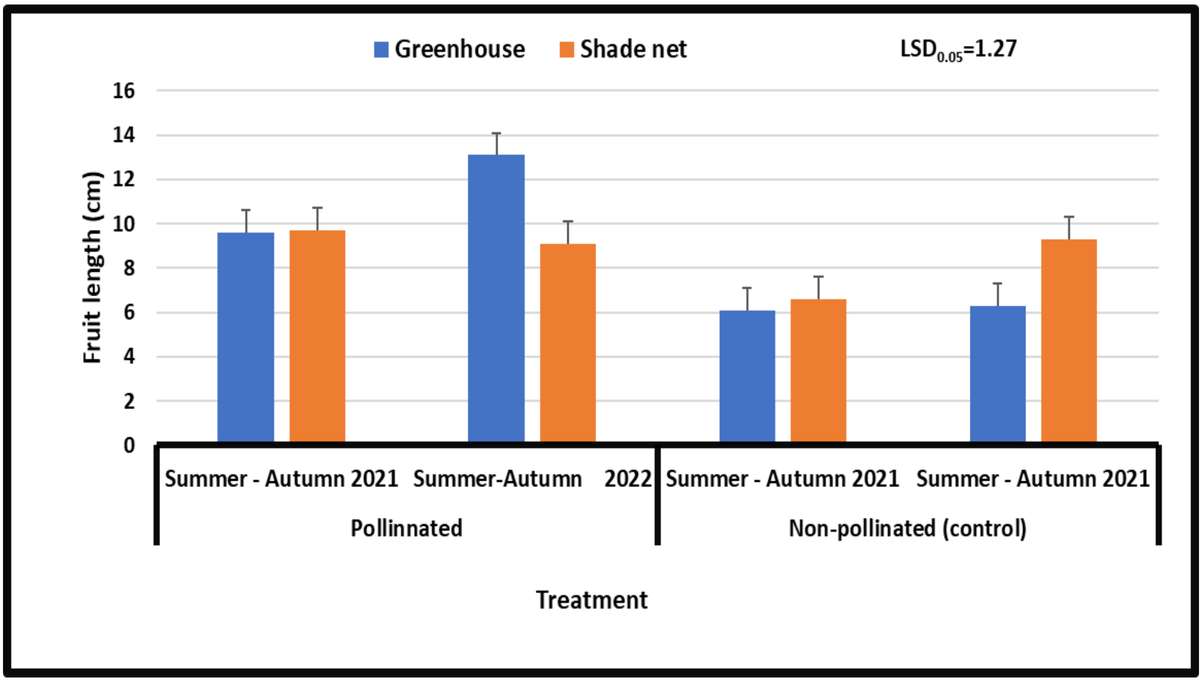


Figure 4.3: The effect of hand pollination on the fruit length of *Cucumis metuliferus* grown under different environments (greenhouse and shade net). Note: 2021 means season 1 and 2022 means season 2. The $LSD_{0.05}$ is the least significant difference of the means.

4.3.4 Aboveground biomass

Figure 4.4 presents the analysis of the aboveground biomass of *C. metuliferus* grown under the two different environments. Results showed that greenhouse cultivation together with hand pollination resulted in a mean aboveground biomass of 0.36 Kg compared to a mean aboveground biomass of 0.19 Kg shown under shade netting growth with hand pollination. Thus, there was almost a twofold increase in aboveground biomass when cultivating hand pollinated plants in a greenhouse compared to similarly pollinated plants grown under shade netting. However, the efficacy of hand pollination should be carefully determined as results from this study did not support a significant (P≥0.05) difference regarding the aboveground biomass of *C. metuliferus* when comparing plants grown in the two environments – greenhouse growth appeared to be the significant factor leading to increased aboveground biomass.

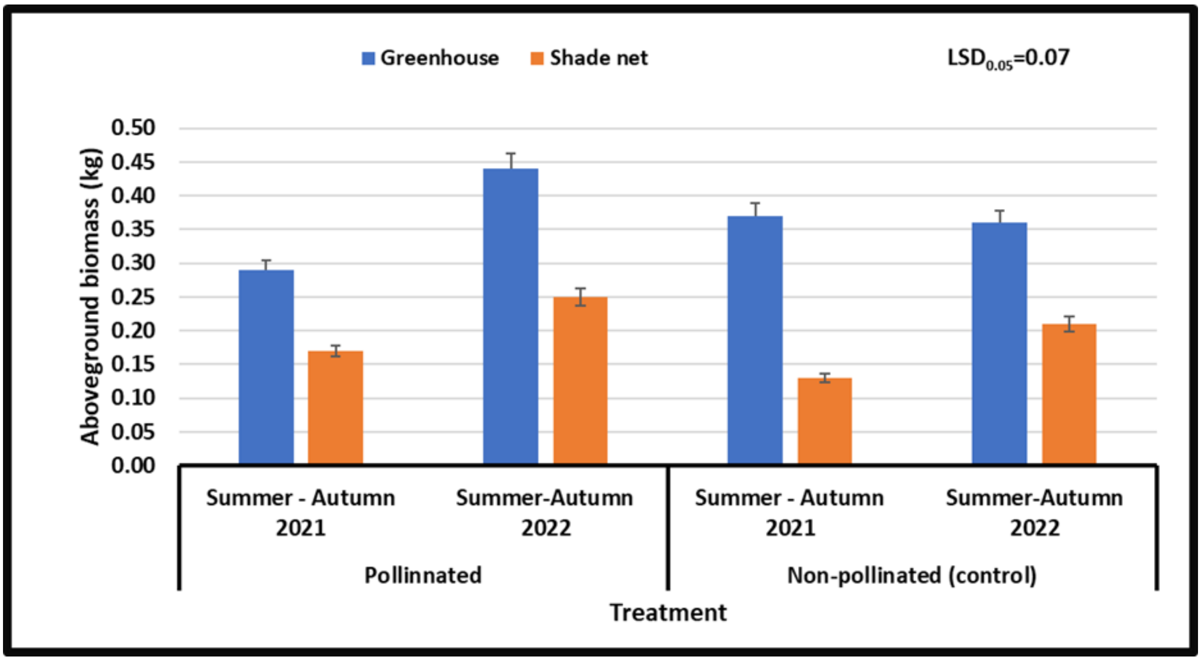


Figure 4.4: The effect of hand pollination on the aboveground biomass of *Cucumis metuliferus* grown under different environments (greenhouse and shade net). Note: 2021 means season 1 and 2022 means season 2. The $LSD_{0.05}$ is the least significant difference of the means.

4.3.5 Total biomass

Similar to the results of aboveground biomass analysis, Figure 4.5 indicates that there was a general increase in total biomass in both hand pollinated and non-hand pollinated plants cultivated in the greenhouse compared with cultivation under shade netting. However, there appeared to be a relatively more consistent increase in total biomass in hand pollinated plants grown in a greenhouse compared with non-hand pollinated plants. Thus, there was no significant (P>0.05) difference between the total biomass of *C. metuliferus* according to the pollination method used or according to the year of cultivation.

As with the aboveground biomass results, this total biomass findings support the use of greenhouses to maximize crop yield following hand pollination.

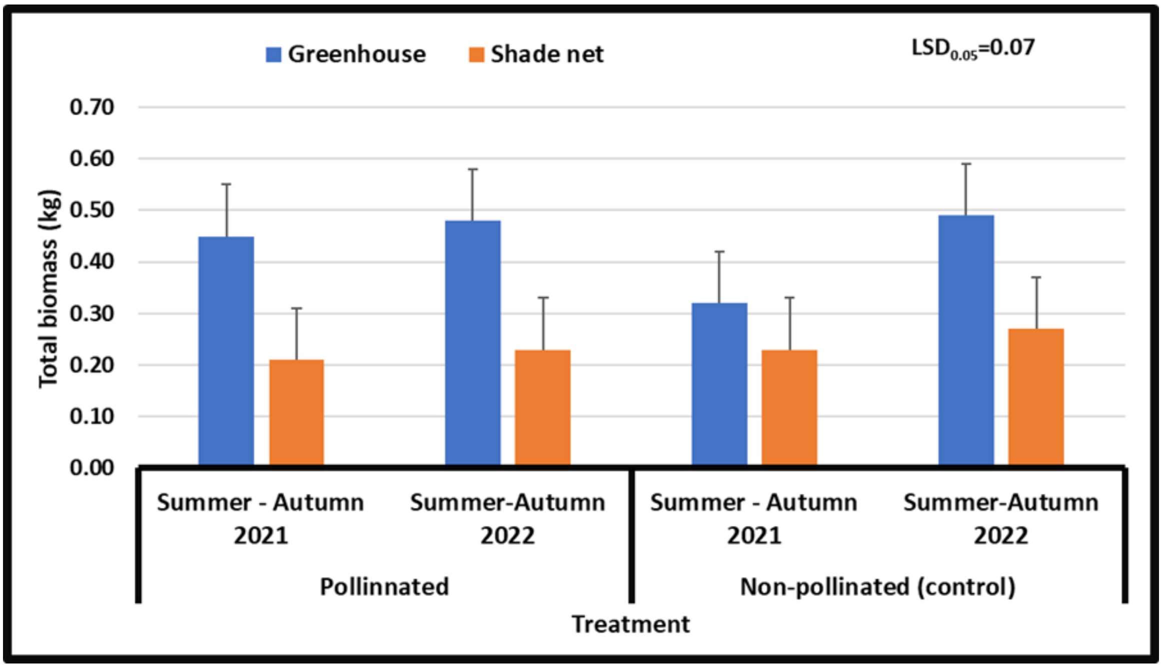


Figure 4.5: The effect of hand pollination on the total biomass of *Cucumis metuliferus* grown under different environments (greenhouse and shade net). Note: 2021 means season 1 and 2022 means season 2. The $LSD_{0.05}$ is the least significant difference of the means.

4.3.5 Harvest index

Figure 4.6 indicates that greenhouse cultivation led to an increase in harvest index (HI) compared to that shown by the control plants and hand pollination appears to contribute to this increase. Except for plants that were hand pollinated and grown in the greenhouse, the HI of plants cultivated under shade netting was consistent and low. In addition, a trend was noted of a lower HI in plants cultivated in 2022 compared to those grown in 2021, particularly in plants cultivated in the greenhouse. These findings agree with those of Barber *et al*. (2011) who showed that hand pollination increased fruit number and other yield components of cucumber crop but decreased in plants that were exposed to pollination agents such as bees.

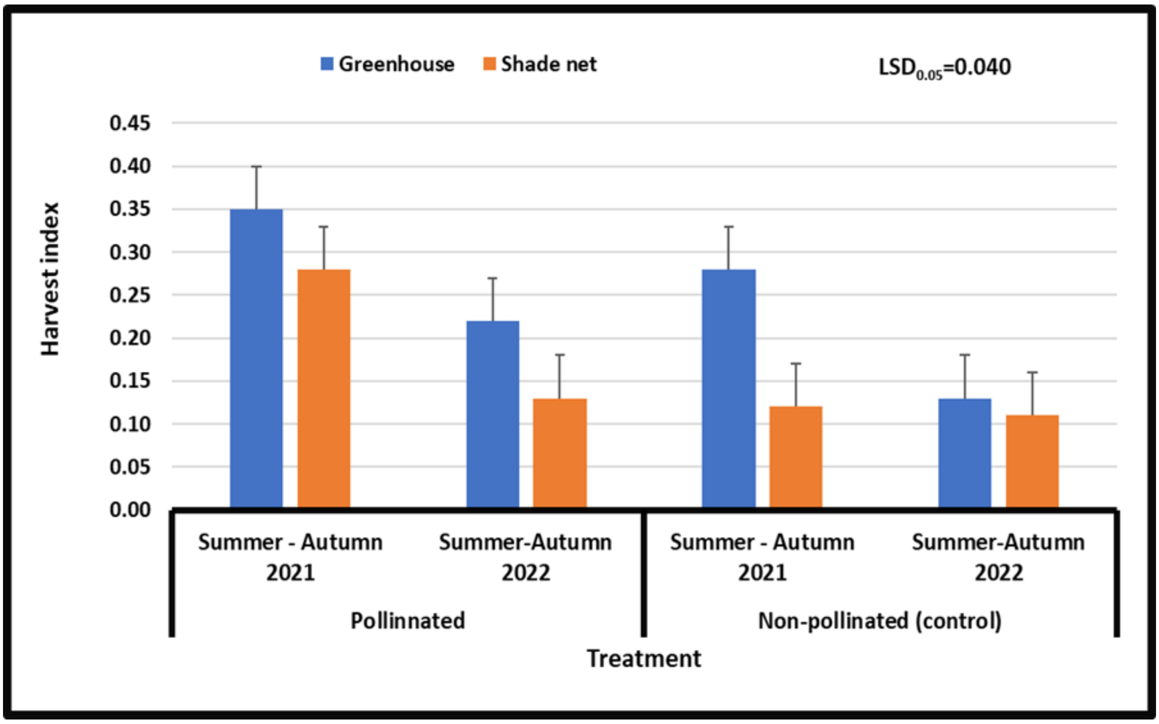


Figure 4.6: The effect of hand pollination on the harvest index of *Cucumis metuliferus* grown under different environments (greenhouse and shade net). Note: 2021 means season 1 and 2022 means season 2. $LSD_{0.05}$ is the least significant difference of the means.

CHAPTER 5: SUMMARY, CONCLUSIONS AND FUTURE WORK

5.1 Summary

It is important to maximise agronomics particularly in sub-Saharan Africa. Indigenous crops have several advantages, including their growing organically in the wild (Reinten *et al*., 2011) and being resistant to most pests and diseases (Jäger & Van Staden, 2000). The fruit of the *C. metuliferus* is high in health-providing elements such as vitamin C, vitamin E, potassium, phosphorus and zinc (Benzioni *et al.,* 2019). Thus, indigenous crops such as the African horned cucumber *C. metuliferus* should be researched to determine their yield and nutritional value to help alleviate malnutrition and food scarcity (Nyathi *et al*., 2019).

Hand pollination of cucumber crops cultivated under protective structures was reported as being the best practice to increase yield and quality of several fruit crops such as cucumbers (Gajdová *et al*., 2012). The current study confirmed that hand pollination directly contributed to an increase in the yield of African horned cucumbers. This was particularly evident when cultivated under protective environments such as greenhouses where the crop is protected from rainfall and extreme heat in summer and might also minimize the potential risk caused by bee importation. Moreover, use of these practices led to an increase in crop quality parameters such as fruit number and length, particularly in areas that experienced extreme weather conditions such as frost, hail and strong wind. These are important findings, particularly in the fresh market and juice industry, where many fruits are required to meet specific consumer demands. Information describing an increase in crop yield and organoleptic quality by cultivating this crop in greenhouses together with hand pollination is useful to farmers considering production of quality produce and profit maximisation.

5.2 Conclusions

Conclusion 1

The objective of this study was **to determine the yield performance of hand pollinated *C. metuliferus* grown in a greenhouse or shade net environment**.

Results of the study showed that fruit number and the number of ripe fruits were higher when plants were hand pollinated and grown in a greenhouse. Around a two- to three-fold increase in fruit number was noted in plants that were hand pollinated and grown in the greenhouse compared to the fruit from plants grown under shade netting and which may or may not have been hand pollinated. A relatively larger increase to between three- and sevenfold in ripe fruit was noted in the hand pollinated greenhouse plants compared to plants grown under shade netting and which may or may not have been hand pollinated.

Because plants are sedentary organisms, pollen delivery is largely entrusted to external agencies such as insects, wind and animals and these study results support the suggestion that hand pollination treatment could be the solution to low fruit production of African horned cucumber (Shah *et al*., 2009), particularly when these plants are cultivated in a greenhouse. Furthermore, further pollination research is essential for understanding the evolution of angiosperm plants and their distribution.

Analysis of fruit length indicated that hand pollination appeared to be the main factor contributing to an increase in fruit length. The present study supports previous findings by van Wyk (2005) who reported that hand-pollinated plants produced heavier and longer fruits compared to those that were not hand pollinated. Results of the study showed that, compared to growth shown under shade netting, greenhouse cultivation led to an increase in aboveground biomass as well as total biomass. Thus, around a twofold increase in aboveground and total biomass was noted when cultivating plants in a greenhouse compared to similarly pollinated plants grown under shade netting. There appeared to be a relatively more consistent increase in total biomass in hand pollinated plants grown in a greenhouse compared with non-hand pollinated plants.

This brief discussion of study results relating to an increased yield in cucumber fruit following an intervention involving cultivation of cucumber plants in a greenhouse together with hand fertilization supports the assertion that objective 1 of the study was suitably addressed. Furthermore, study results support the economic feasibility of improving the yield of African horned cucumber following cultivation under a protective structure such as a greenhouse, and that hand pollination may result in a consistently increased cucumber crop, supports the assertion that objective 2 of the study was suitably addressed.

Conclusion 2

- Furthermore, study results support the economic feasibility of improving the yield of African horned cucumber following cultivation under a protective structure such as a greenhouse, and that hand pollination may result in a consistently increased cucumber crop, supports the assertion that the study was suitable in addressing food security by increasing productivity. These findings were crucial in providing validated information to potential farmers interested in learning more about the agronomy and commercialization of *C. metuliferus* fruit farmed in South Africa.

5.3 Future work

The current research is the first to examine the impact of hand pollination on the production of African horned cucumbers (*Cucumis metuliferus* E. Mey. Ex Naudin) grown in protective structures. Therefore, more research should be done on this crop to establish the optimal plant breeding approach, as it has the potential to become a profitable horticultural crop with nutritional benefits such as Vitamin C and Vitamin E. Therefore, future research should consider the following:

- The impact of different fertilizers on the growth and nutritional content of *C. metuliferus* grown under different environments.
- The effect of different water stress and growing environments on the secondary metabolite profile of *C. metuliferus.*

6. REFERENCES

Abou-Hadid, A. F., El-Beltagy, A. S., Medany, M. A., & Hafez, M. M. (1995). Performance of soilless media on greenhouse production of cucumber, *Cucumis sativus*, in Egypt. *Journal of Vegetable Crop Production*, 1(1), 93–98.

Aldoshin, N., Didmanidze, O., Mirzayev, B., & Mamatov, F. (2019). Harvesting of mixed crops by axial rotary combines. In *Proceeding of 7th International Conference on Trends in Agricultural Engineering* (pp. 20-26).

Alqudah, A. M., Samarah, N. H., & Mullen, R. E. (2011). Drought stress effect on crop pollination, seed set, yield and quality. In *Alternative farming systems, biotechnology, drought stress and ecological fertilisation* (pp. 193-213).

Anyanwu, A A, Jimam, N. S., Dangiwa, D. A., Wannang, N. N., Falang, K. D., & August, J. (2014). Protective effects of alkaloids of *Cucumis metuliferus* isolated from the fruit pulp on some vital organs. *The Journal of Phytopharmacology*, 3(4), 259–263.

Anyanwu, A. A., Jimam, N. S., Omale, S., & Wannang, N. N. (2017). Antiviral activities of *Cucumis metuliferus* fruits alkaloids on Infectious Bursal Disease Virus (IBDV). *The Journal of Phytopharmacology*, 6(2), 98–101.

Arrieta, M. P., Garrido, L., Faba, S., Guarda, A., Galotto, M. J., & de Dicastillo, C. L. (2020). *Cucumis metuliferus* fruit extract loaded acetate cellulose coatings for antioxidant active packaging. *Polymers*, 12(6), 1–19.

Atif, R., Shyha, I., & Inam, F. (2016). Mechanical, thermal, and electrical properties of graphene-epoxy nanocomposites - A review. *Polymers*, *8*(8), 281.

Azmi, W. A., Samsuri, N., Hatta, M. F. M., Ghazi, R., & Seng, C. T. (2017). Effects of stingless bee (Heterotrigona itama) pollination on greenhouse cucumber (*Cucumis sativus*). *Malaysian Applied Biology*, 46(1), 51–55.

Barber, N. A., Adler, L. S., & Bernardo, H. L. (2011). Effects of above- and belowground herbivory on growth, pollination, and reproduction in cucumber. *Oecologia*, 165, 377–386.

Benzioni, A., Mendlinger, S., Ventura, M., & Huyskens, S. (2019). Effect of Sowing Dates, Temperatures on Germination, Flowering, and Yield of *Cucumis metuliferus*. *HortScience*, 26(8), 1051–1053.

Boissard, P., Martin, V., & Moisan, S. (2008). A cognitive vision approach to early pest detection in greenhouse crops. *Computers and Electronics in Agriculture*, 62(2), 81–93.

Brazaitytė, A., Duchovskis, P., Urbonavičiūtė, A., Samuolienė, G., Jankauskienė, J., Kasiulevičiūtė-Bonakėrė, A., Bliznikas, Z., Novičkovas, A., Breivė, K., & Žukauskas, A. (2009). The effect of light-emitting diodes lighting on cucumber transplants and after-effect on yield. *Zemdirbyste-Agriculture*, *96*(3), 102-118.

Brittain, C., Kremen, C., & Klein, A. M. (2013). Biodiversity buffers pollination from changes in environmental conditions. *Global Change Biology*, 19(2), 540–547.

Cakmak, I. (2002). Plant nutrition research: Priorities to meet human needs for food in sustainable ways. *Plant and Soil*, 247(1), 3–24.

Chamont, S., Strainchamps, D., & Thunot, S. (1995). Short- and long-term stomatal responses to fluctuations in environment in southern European greenhouses. *Annals of Botany*, 75(1), 39–45.

Demura, T., & Ye, Z. H. (2010). Regulation of plant biomass production. *Current Opinion In Plant Biology*, *13*(3), 298-303.

Descamps, C., Quinet, M., Baijot, A., & Jacquemart, A. L. (2018). Temperature and water stress affect plant–pollinator interactions in *Borago officinalis* (Boraginaceae). *Ecology and Evolution*, 8(6), 3443–3456.

Dris, R., Niskanen, R., & Jain, S. M. (2003). Crop management and postharvest handling of horticultural products. Volume II: Fruits and vegetables. *Crop management and postharvest handling of horticultural products. Volume II: Fruits and vegetables.*

Eifediyi, E. K., & Remison, S. U. (2010). Growth and yield of cucumber (*Cucumis sativus* L.) as influenced by farmyard manure and inorganic fertilizer. *Journal of Plant Breeding and Crop Science*, 2(7), 216–220.

Ekeke, C., Ogazie, C. A., & Agbagwa, I. O. (2018). Breeding biology and effect of pollinators on the fruit characteristics of cucumber (*Cucumis sativus* L.), cucurbitaceae. *Nigerian Journal of Botany*, *31*(2), 325-344.

El-Mageed, T. A., & Semida, W. M. (2015). Effect of deficit irrigation and growing seasons on plant water status, fruit yield and water use efficiency of squash under saline soil. *Scientia Horticulturae*, *186*, 89-100.

Erdem, Y., Erdem, T., Orta, A. H., & Okursoy, H. (2006). Canopy-air temperature differential for potato under different irrigation regimes. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science*, *56*(3), 206-216.

Fageria, N. K. (2014). Nitrogen harvest index and its association with crop yields. *Journal of Plant Nutrition*, *37*(6), 795-810.

Fan, R., Maximov, T. C., Sugimoto, A., & Chikaraishi, Y. (2019). Refinement of Isotopic Fractionation in Plants: A New Insight into Physiological Responce to Dry-Wet Conditions. In *29th International Meeting on Organic Geochemistry* (Vol. 2019, No. 1, pp. 1-2). European Association of Geoscientists & Engineers.

Ferreira, I. M. P. L. V. O., Pinho, O., Vieira, E., & Tavarela, J. G. (2010). Brewer's Saccharomyces yeast biomass: characteristics and potential applications. *Trends in food science and technology*, *21*(2), 77-84.

Friedman, J., & Barrett, S. C. H. (2009). Wind of change: New insights on the ecology and evolution of pollination and mating in wind-pollinated plants. *Annals of Botany*, 103(9), 1515–1527.

Gajdová, J., Navrátilová, B., Smolná, J., & Lebeda, A. (2012). Factors affecting protoplast isolation and cultivation of *Cucumis spp*. *Journal of Applied Botany and Food Quality*, *81*(1), 1-6.

Gallagher, M. K., & Campbell, D. R. (2017). Shifts in water availability mediate plant–pollinator interactions. *New Phytologist*, 215(2), 792–802.

Galpaz, N., Wang, Q., Menda, N., Zamir, D., & Hirschberg, J. (2008). Abscisic acid deficiency in the tomato mutant high-pigment 3 leading to increased plastid number and higher fruit lycopene content. *The Plant Journal*, *53*(5), 717-730.

Garratt, M. P. D., Breeze, T. D., Jenner, N., Polce, C., Biesmeijer, J. C., & Potts, S. G. (2014). Avoiding a bad apple: Insect pollination enhances fruit quality and economic value. *Agriculture, Ecosystems and Environment*, 184, 34–40.

Gevens, A. J., Ando, K., Lamour, K. H., Grumet, R., & Hausbeck, M. K. (2006). A detached cucumber fruit method to screen for resistance to *Phytophthora capsici* and effect of fruit age on susceptibility to infection. *Plant Disease*, 90(10), 1276–1282.

Golabadi, M., Golkar, P., & Ercisli, S. (2017). Estimation of gene action for fruit yield and morphological traits in greenhouse cucumber by mating designs. *Acta Scientiarum Polonorum, Hortorum Cultus*, 16(4), 3–12.

Guner, N., & Wehner, T. C. (2004). The genes of watermelon. *HortScience*, *39*(6), 1175-1182.

Hao, X., & Papadopoulos, A. P. (1999). Effects of supplemental lighting and cover materials on growth, photosynthesis, biomass partitioning, early yield and quality of greenhouse cucumber. *Scientia Horticulturae*, 80(1–2), 1–18.

Hochmuth, R. C. (2015). Greenhouse cucumber production-Florida greenhouse vegetable production handbook, vol. 3. *IFAS Extension, University of Florida. Florida, EEUU. HS790*.

Holzschuh, A., Dudenhöffer, J. H., & Tscharntke, T. (2012). Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry. *Biological Conservation*, *153*, 101-107.

Hovi-Pekkanen, T., & Tahvonen, R. (2008). Effects of interlighting on yield and external fruit quality in year-round cultivated cucumber. *Scientia Horticulturae*, 116(2), 152–161.

Jäger, A. K., & Van Staden, J. (2000). The need for cultivation of medicinal plants in southern Africa. *Outlook on Agriculture*, 29(4), 283–284.

Jiang, B., Liu, W., Xie, D., Peng, Q., He, X., Lin, Y. E., & Liang, Z. (2015). High-density genetic map construction and gene mapping of pericarp color in wax gourd using specific-locus amplified fragment (SLAF) sequencing. *BMC genomics*, *16*(1), 1-10.

Kaiser, E., Ouzounis, T., Giday, H., Schipper, R., Heuvelink, E., & Marcelis, L. F. M. (2019). Adding blue to red supplemental light increases biomass and yield of greenhouse-grown tomatoes, but only to an optimum. *Frontiers in Plant Science*, 9, 2002.

Kevan, P. G., Clark, E. A., & Thomas, V. G. (1990). Insect pollinators and sustainable agriculture. *American Journal of Alternative Agriculture*, 5(1), 13–22.

Klatt, B. K., Holzschuh, A., Westphal, C., Clough, Y., Smit, I., Pawelzik, E., & Tscharntke, T. (2013). Bee pollination improves crop quality, shelf life and commercial value. *Proceedings of the Royal Society B: Biological Sciences*, 281(1775): 20132440.

Knapp, E. E., Goedde, M. A., & Rice, K. J. (2001). Pollen-limited reproduction in blue oak: Implications for wind pollination in fragmented populations. *Oecologia*, 128(1), 48–55.

Lee, S. K., & Kader, A. A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology*, *20*(3), 207-220.

Li, G., Lin, L., Dong, Y., An, D., Li, Y., Luo, W., Yin, X., Li, W., Shao, J., Zhou, Y. & Dai, J. (2012). Testing two models for the estimation of leaf stomatal conductance in four greenhouse crops cucumber, chrysanthemum, tulip and lilium. *Agricultural and Forest Meteorology*, 165, 92–103.

Lin, Y. T., Lin, C. W., Chung, C. H., Su, M. H., Ho, H. Y., Yeh, S. D., Jan, F.J. & Ku, H.M. (2011). In vitro regeneration and genetic transformation of *Cucumis metuliferus* through cotyledon organogenesis. *HortScience*, 46(4), 616–621.

Liu, Z., Zhang, Z., Wang, Z., & Shu, Q. (2008). Measuring and modelling stomatal conductance of cucumber crop in solar greenhouse in Northeast China. *Scientia Horticulturae*, 117(2), 103–108.

Maltsoglou, I., Koizumi, T., & Felix, E. (2013). The status of bioenergy development in developing countries. *Global Food Security*, 2(2), 104–109.

Maluleke, M. K., Moja, S. J., Nyathi, M., & Modise, D. M. (2021). Nutrient Concentration of African Horned Cucumber (Cucumis metuliferus L) Fruit under Different Soil Types, Environments, and Varying Irrigation Water Levels. *Horticulturae*, *7*(4), 76.

Manzoni, S., Vico, G., Palmroth, S., Porporato, A., & Katul, G. (2013). Optimization of stomatal conductance for maximum carbon gain under dynamic soil moisture. *Advances in Water Resources*, *62*, 90-105.

Motzke, I., Tscharntke, T., Wanger, T. C., Klein, A., & Mall, S. (2015). Pollination mitigates cucumber yield gaps more than pesticide and fertilizer use in tropical smallholder gardens. *Journal of Applied Ecology*, 52, 261–269.

Moyo, M., Amoo, S. O., Aremu, A. O., Gruz, J., Šubrtová, M., Jarošová, M., Tarkowski, P. & Doležal, K. (2018). Determination of mineral constituents, phytochemicals and antioxidant qualities of *Cleome gynandra*, compared to *Brassica oleracea* and *Beta vulgaris*. *Frontiers in Chemistry*, *5*, 128.

Nambi, V. E., Thangavel, K., & Jesudas, D. M. (2015). Scientific classification of ripening period and development of colour grade chart for Indian mangoes (*Mangifera indica* L.) using multivariate cluster analysis. *Scientia Horticulturae*, 193, 90-98.

Nerson, H. (2015). Does fruit number per plant, or fruit-set order affect seed yield and quality in cucumber? *Journal of Horticultural Science and Biotechnology*, 83(2), 160–164.

Nicodemo, D., Malheiros, E. B., Jong, D. De, & Couto, R. H. N. (2013). Incremento da produção de pepino partenocárpico com abelhas sem ferrão e Africanizadas em casas de vegetação. *Semina:Ciencias Agrarias*, 34(6 Suppl. 1), 3625–3634.

Nowak, J. S. (2002). Effect of different soil water potential on leaf transpiration and on stomatal conductance in poinsettia. *Acta Agrobotanica*, *55*(2), 27-36.

Nunes, M. C. N., Emond, J. P., Rauth, M., Dea, S., & Chau, K. V. (2009). Environmental conditions encountered during typical consumer retail display affect fruit and vegetable quality and waste. *Postharvest Biology and Technology*, 51(2), 232–241.

Nweke, I. A., Ijearu, S. I., & Igili, D. N. (2013). Effect of different sources of animal manure on the growth and yield of okra (Abelmoschus esculentus L. Moench) in Ustoxic Dystropept at Enugu South Eastern, Nigeria. *Journal of Scientific and Technology Research*, *2*(3), 135-137

Nyathi, M. K., Mabhaudhi, T., Halsema, G. E. Van, Annandale, J. G., & Struik, P. C. (2019). Benchmarking nutritional water productivity of twenty vegetables - A review. *Agricultural Water Management*, 221(1), 248–259.

Pettersen, R. I., Torre, S., & Gislerød, H. R. (2010). Effects of intracanopy lighting on photosynthetic characteristics in cucumber. *Scientia Horticulturae*, 125(2), 77–81.

Premanandh, J. (2011). Factors affecting food security and contribution of modern technologies in food sustainability. *Journal of the Science of Food and Agriculture*, *91*(15), 2707-2714.

Rahil, M. H., & Qanadillo, A. (2015). Effects of different irrigation regimes on yield and water use efficiency of cucumber crop. *Agricultural Water Management*, 148, 10–15.

Rani, V., Deep, G., Singh, R. K., Palle, K., & Yadav, U. C. (2016). Oxidative stress and metabolic disorders: Pathogenesis and therapeutic strategies. *Life Sciences*, *148*, 183-193.

Reinten, E. Y., Coetzee, J. H., & Van Wyk, B. E. (2011). The potential of South African indigenous plants for the international cut flower trade. *South African Journal of Botany*, *77*(4), 934-946.

Russo, V. M., & Schatzer, R. J. (1991). Feasibility of Trellised Cucumber Production. *HortScience*, 26(9), 1156–1158.

Salehi, B., Sharifi-Rad, J., Capanoglu, E., Adrar, N., Catalkaya, G., Shaheen, S., Jaffer, M., Giri, L., Suyal, R., Jugran, A.K., & Cho, W. C. (2019). Cucurbita plants: From farm to industry. *Applied Sciences*, *9*(16), 3387.

Sanzol, J., & Herrero, M. (2001). The “effective pollination period” in fruit trees. *Scientia Horticulturae*, 90(1–2), 1–17.

Sarwar, G., Aslam, M., Munawar, M. S., Raja, S., & Mahmood, R. (2008). Effect of honey bee (Apis mellifera L.) pollination on fruit setting and yield of cucumber (Cucumis sativus L.). *Pakistan Entomologist*, *30*(2), 185-191.

Savvas, D., Ntatsi, G., & Passam, H. C. (2008). Plant Nutrition and Physiological Disorders in Greenhouse Grown Tomato, Pepper and Eggplant. *The European Journal of Plant Science and Biotchnology*, 2(Special Issue 1), 45–61.

Savvides, A., Fanourakis, D., & Van Ieperen, W. (2012). Co-ordination of hydraulic and stomatal conductances across light qualities in cucumber leaves. *Journal of Experimental Botany*, 63(3), 1135–1143.

Shah, A. H., Muhammad, S., Wazir, F. K., & Shah, S. H. (2009). Comparison of two nutrient solution recipes for growing cucumbers in a non-circulating hydroponic system. *Sarhad Journal of Agriculture (Pakistan)*, 25(2), 179-185.

Shahak, Y., Gal, E., Offir, Y., & Ben-Yakir, D. (2008). Photoselective shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. *Acta Horticulturae*, 797(2014), 75–80.

Shetty, N. V., & Wehner, T. C. (1998). Evaluation of oriental trellis cucumbers for production in North Carolina. *HortScience*, *33*(5), 891-896.

Shu, S., Yuan, L. Y., Guo, S. R., Sun, J., & Yuan, Y. H. (2013). Effects of exogenous spermine on chlorophyll fluorescence, antioxidant system and ultrastructure of chloroplasts in *Cucumis sativus* L. under salt stress. *Plant Physiology and Biochemistry*, 63, 209–216.

Sigüenza, C., Schochow, M., Turini, T., & Ploeg, A. (2005). Use of *Cucumis metuliferus* as a Rootstock for Melon to Manage *Meloidogyne incognita*. *Journal of Nematology*, 37(3), 276–280.

Sinclair, T. R. (1998). Historical changes in harvest index and crop nitrogen accumulation. *Crop Science*, *38*(3), 638-643.

Slaa, E. J., Sánchez Chaves, L. A., Malagodi-Braga, K. S., & Hofstede, F. E. (2006). Stingless bees in applied pollination: Practice and perspectives. *Apidologie*, 37(2), 293–315.

Smitha, K., & Sunil, K. M. (2017). Influence of growing environment on growth characters of cucumber (*Cucumis sativus*). *Journal of Tropical Agriculture*, 54(2), 201.

Steslow, J. (2012). Testing Health of *Baptisia alba* Growing in a Reconstructed Tallgrass Prairie to Investigate How Lawn Watering Affects Plants. *ESSAI*, 10(1), 33.

Tardieu, F. (2013). Plant response to environmental conditions: assessing potential production, water demand, and negative effects of water deficit. *Frontiers in Physiology*, 4, 17.

Thakur, M., & Rana, R. S. (2008). Studies on the role of insect pollination in cucumber yield. *Pest Technology*, 2(2), 130–133.

Toledo-Hernández, M., Wanger, T. C., & Tscharntke, T. (2017). Neglected pollinators: Can enhanced pollination services improve cocoa yields? A review. *Agriculture, Ecosystems and Environment*, 247(May), 137–148.

Torres-Olivar, V., Valdez-Aguilar, L. A., Cárdenas-Flores, A., Lira-Saldivar, H., Hernández-Suárez, M., & Ibarra-Jiménez, L. (2016). Effect of colored plastic mulch on growth, yield and nutrient status in cucumber under shade house and open field conditions. *Journal of Plant Nutrition*, *39*(14), 2144-2152.

Tucker, M. R. (1999). *Essential plant nutrients: their presence in North Carolina soils and role in plant nutrition*. Department of Agriculture and Consumer Services, Agronomic Division.

Tuell, J. K., & Isaacs, R. (2010). Weather during bloom affects pollination and yield of highbush blueberry. *Journal of Economic Entomology*, 103(3), 557–562.

Usman, J. G., Sodipo, O. A., Kwaghe, A. V., & Sandabe, U. K. (2015). Uses of *Cucumis metuliferus*: A review. *Cancer Biology*, 5(1), 24-34.

Uusiku, N. P., Oelofse, A., Duodu, K. G., Bester, M. J., & Faber, M. (2010). Nutritional value of leafy vegetables of sub-Saharan Africa and their potential contribution to human health: A review. *Journal of Food Composition and Analysis*, 23(6), 499–509.

Van Kooten, O., & Snel, J. F. (1990). The use of chlorophyll fluorescence nomenclature in plant stress physiology. *Photosynthesis Research*, 25(3), 147-150.

Van Wyk, B. E. (2005). Food plants of the word (First edit). Pretoria: Briza Publications. Timber Press, ISBN 978-0881927436.

Walters, S. A., & Wehner, T. C. (2002). Incompatibility in diploid and tetraploid crosses of *Cucumis sativus* and *Cucumis metuliferus*. *Euphytica*, 128(3), 371–374.

Wang, X., Christensen, S., Svensgaard, J., Jensen, S. M., & Liu, F. (2020). The effects of cultivar, nitrogen supply and soil type on radiation use efficiency and harvest index in spring wheat. *Agronomy*, *10*(9), 1391.

Wei, Q. Z., Fu, W. Y., Wang, Y. Z., Qin, X. D., Wang, J., Li, J., Lou, Q.F., & Chen, J. F. (2016). Rapid identification of fruit length loci in cucumber (*Cucumis sativus* L.) using next-generation sequencing (NGS)-based QTL analysis. *Scientific Reports*, *6*(1), 1-11.

Weng, Y. (2010). Genetic diversity among *Cucumis metuliferus* populations revealed by cucumber microsatellites. *HortScience*, 45(2), 214–219.

Wood, B. W. (1997). Source of pollen, distance from pollinizer, and time of pollination affect yields in block-type pecan orchards. *HortScience*, *32*(7), 1182-1185.

Wragg, P. D., & Johnson, S. D. (2011). Transition from wind pollination to insect pollination in sedges: Experimental evidence and functional traits. *New Phytologist*, 191(4), 1128–1140.

Yang, W., Matsushita, B., Chen, J., Fukushima, T., & Ma, R. (2010). An enhanced three-band index for estimating chlorophyll-a in turbid case-II waters: case studies of Lake Kasumigaura, Japan, and Lake Dianchi, China. *IEEE Geoscience and Remote Sensing Letters*, *7*(4), 655-659.

Yeasmin, F. (2016). *Role of insect pollinator on cucumber (Cucumis sativus L.) yield* (Doctoral dissertation, Department of Entomology, Sher-Bangla Agriculture University, Dhaka.).

Zhang, S., Raza, W., Yang, X., Hu, J., Huang, Q., Xu, Y., Liu, X., Ran, W. & Shen, Q. (2008). Control of Fusarium wilt disease of cucumber plants with the application of a bioorganic fertilizer. *Biology and Fertility of Soils*, 44(8), 1073-1080.

Zhao, J., Jiang, L., Che, G., Pan, Y., Li, Y., Hou, Y., Zhao, W., Zhong, Y., Ding, L., Yan, S., & Sun, C. (2019). A functional allele of CsFUL1 regulates fruit length through repressing CsSUP and inhibiting auxin transport in cucumber. *The Plant Cell*, *31*(6), 1289-1307.

7. APPENDICES

APPENDIX I: COLLEGE ETHICS APPROVAL

UNISA university of south africa

UNISA-CAES HEALTH RESEARCH ETHICS COMMITTEE

Date: 22/01/2021

NHREC Registration # : REC-170616-051
REC Reference # : 2021/CAES_HREC/001
Name : Mr NG Magwaza
Student #55874444

Dear Mr Magwaza

Decision: Ethics Approval from 21/01/2021 to 31/01/2024

Researcher(s): Mr NG Magwaza
nkocgoodman@gmail.com

Supervisor (s): Mr MK Maluleke
malulm@unisa.ac.za; 011-471-3838

Working title of research:

Investigation of the impact of hand pollination on fruit yield of *Cucumis metuliferus* L. (African horned cucumber) under protected sturctures

Qualification: MSc Ornamental Horticulture

Thank you for the application for research ethics clearance by the Unisa-CAES Health Research Ethics Committee for the above mentioned research. Ethics approval is granted for three years, **subject to submission of yearly progress reports. Failure to submit the progress report will lead to withdrawal of the ethics clearance until the report has been submitted.**

The researcher is cautioned to adhere to the Unisa protocols for research during Covid-19.

Due date for progress report: 31 January 2022

Please note the points below for further action:

1. More detail is required on the experimental design and statistical analysis. The researcher should first describe how the research materials/treatments will be arranged, and then link the statistical analysis to the design.

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

2. What is the motivation for using two-way Anova? What are the variables that will be applied?
3. What is the motivation for using Duncan's multiple range test? The research will be strengthened if the researcher can substantiate the use of these statistical approaches.

The minimal ***risk application*** *was* ***reviewed*** *by the UNISA-CAES Health Research Ethics Committee on 21 January 2021 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.*

The proposed research may now commence with the provisions that:

1. The researcher will ensure that the research project adheres to the relevant guidelines set out in the Unisa Covid-19 position statement on research ethics attached.
2. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
3. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the Committee.
4. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
5. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
6. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.
7. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
8. No field work activities may continue after the expiry date. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

Note:
*The reference number **2021/CAES_HREC/001** should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

Prof MA Antwi
Chair of UNISA-CAES Health REC
E-mail: antwima@unisa.ac.za
Tel: (011) 670-9391

Prof SR Magano
Acting Executive Dean : CAES
E-mail: magansr@unisa.ac.za
Tel: (011) 471-3649

APPENDIX II: TURNITIN SIMILARITY REPORT MEMO OF ACCEPTANCE

TO WHOM IT MAY CONCERN

Mr. N.G Magwaza's dissertation, titled "**Investigation of the impact of hand pollination on the yield of African horned cucumber (*Cucumis metuliferus* E. Mey. Ex Naudin) under protected structures,**" has a similarity score of 41 percent on Turnitin.

This similarity percentage stemmed from the fact that his research was intended to fill a gap discovered in his supervisor's study, **"Investigating the performance and quality of the *Cucumis metuliferus* E. Mey. Ex Naudin (African horned cucumber) under different growing environments for potential commercialization."**

As a result, due to the limited literature available for this crop, the percentage of similarity is accepted.

Regards

Dr. Maluleke M.K

Supervisor | Date

10-May-2022

APPENDIX III: TURNITIN ORIGINAL REPORT

Turnitin Originality Report

MSc Ornamental Horticulture dissertation by Ng Magwaza

From DES 2022 (DES 2022)

- Processed on 10-May-2022 08:13 SAST
- ID: 1832766120
- Word Count: 11508

Similarity Index
41%
Similarity by Source

Internet Sources:
40%
Publications:
25%
Student Papers:
20%

APPENDIX IV: PROOF OF LANGUAGE EDITING

John Dewar Tel: +27833210844

PhD, DAHM Email: johndewar65@gmail.com

Dear Dr Maluleke,

This letter is to confirm that I completed a language and content edit of a dissertation entitled: **Investigation of the impact of hand pollination on the yield of African horned cucumber (*Cucumis metuliferus* E. Mey. Ex Naudin) under protected structures.**

This dissertation describes a research study under your and Mr Koopa's supervision and will be presented to the Department of Environmental Sciences, College of Agriculture and Environmental Sciences, University of South Africa in fulfilment for the requirements for the degree Master of Science in Ornamental Horticulture. The dissertation was prepared by Mr Nkosikhona Magwaza.

My edit included the following:

- Spelling and grammar
- Vocabulary and punctuation
- Sentence structure and word usage
- Checking of in text references

Text formatting included:

- Reformatting frontis page and correcting the order of initial pages of dissertation
- Repaginating dissertation
- Requesting inclusion of in text references in Reference list
- Transferring description of figures and tables to above same
- Suggesting the inclusion of theory behind the various tests conducted in the study

Yours sincerely,

John Dewar

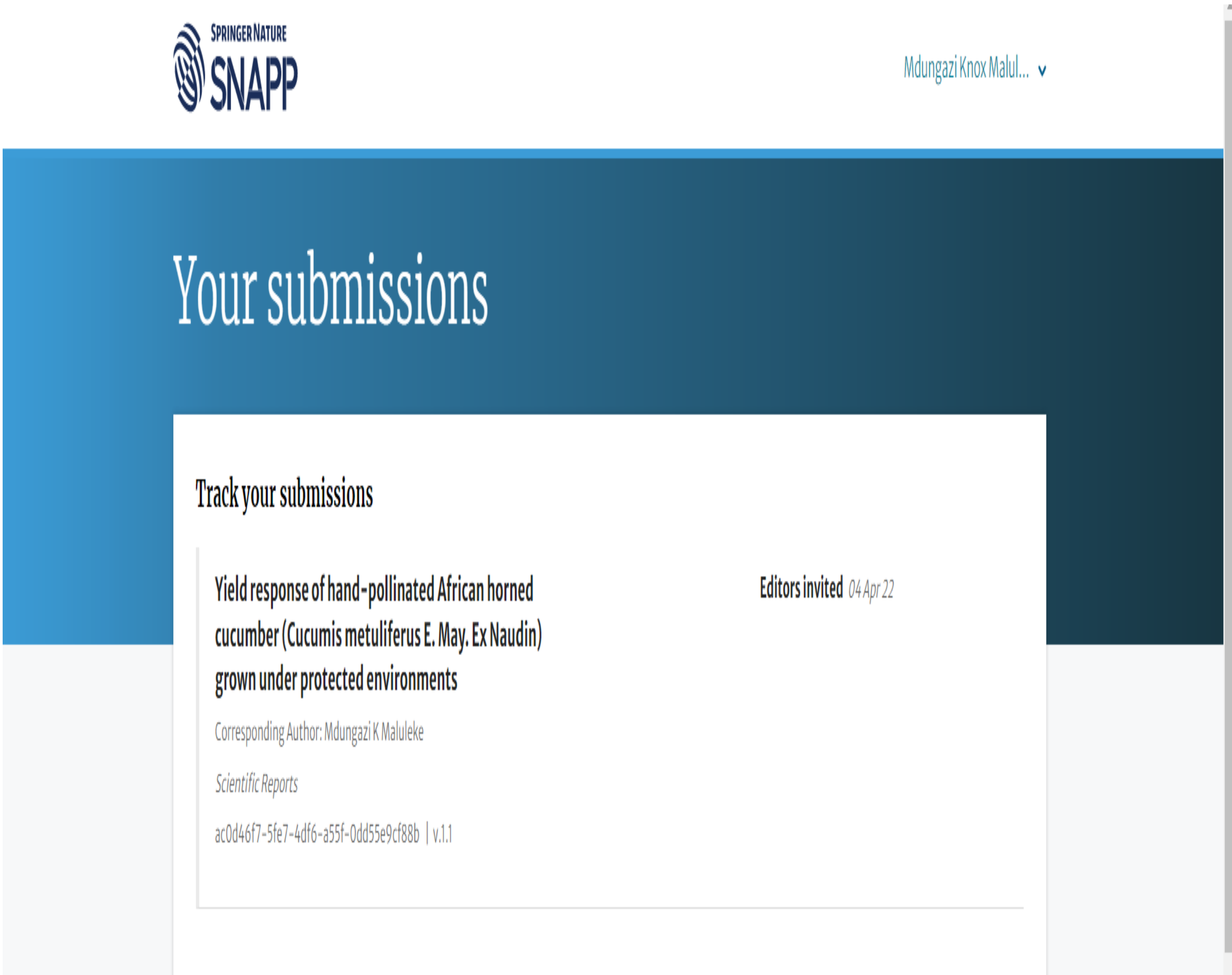
15st May 2022

APPENDIX V: ARTICLE/MANUSCRIPT SUBMISSION

Title: Yield response of hand-pollinated African horned cucumber (*Cucumis metuliferus* E. May. Ex Naudin) grown under protected environments.

Authors: Nkosikhona G Magwaza[1]. Mdungazi K Maluleke[2]. Katlego G Koopa[3].

Name of the Journal: Scientific Reports



Re: Scientific Reports: Amendment required

Harshad Kulkarni <scientific.reports@springernature.com>
To Maluleke, Mdungazi

Reply | Reply All | Forward | ...

Fri 2022/04/22 17:34

If there are problems with how this message is displayed, click here to view it in a web browser.
Click here to download pictures. To help protect your privacy, Outlook prevented automatic download of some pictures in this message.

Dear **Dr. Mdungazi Knox Maluleke**

Thank you for contacting us about the progress of your manuscript.

Unfortunately, we haven't yet been able to secure an Editor to handle the submission, despite having sent out 10 invitations.

We will therefore assign a Senior Editorial Board Member to handle your paper, as soon as one becomes available. In the meantime, we will continue inviting Editors who we feel are appropriate.

I do apologise for the unexpected delay and would like to stress that we're doing everything we can to move things forward and provide you with a decision.

Kind regards,
Harshad Kulkarni
Editorial Support at Scientific Reports

On Tue, 19 Apr at 8:10 AM , Malulm <malulm@unisa.ac.za> wrote: