EFFECT OF 1-METHYLCYCLOPROPENE TREATMENT ON THE PHYSICO-CHEMICAL ATTRIBUTES AND POSTHARVEST GREEN LIFE OF UGANDAN INDIGENOUS AND HYBRID COOKING BANANAS

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A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN FOOD TECHNOLOGY OF KYAMBOGO UNIVERSITY

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DECLARATION

I Sarah Kisakye, declare that this dissertation is my original piece of work and has not been submitted to any University or institution of higher learning for the award of any degree and where other works have been included, it has been mentioned or cited.

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Sarah Kisakye

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Date…………………………

APPROVAL

This is to certify that the work presented in this dissertation titled "Effect of 1-Methylcyclopropene Treatment on the Physico-chemical Attributes and Postharvest Green Life of Ugandan Indigenous and Hybrid Cooking Bananas" by Sarah Kisakye is original. We therefore approve the submission of the dissertation for examination and subsequent award of the degree of Master of Science in Food Technology of Kyambogo University

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DEDICATION

This work is dedicated to my parents (Pr. Sebastian and Jennifer Ssekanyo) and siblings (Paul, Esther, Daniel, MaryAnn and Peter) for their continued support in my academic, professional and social life. I pray that God will satisfy you with a long life and continue to expand your territories.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1-MCP:	1-Methylcyclopropene
CIRAD:	French Agricultural Research Centre for International Development
CO_2:	Carbon dioxide
EAH:	East African Highland
FAO:	Food and Agricultural Organisation
IITA:	International Centre for Tropical Agriculture
NARL:	National Agricultural Research Laboratories
NARO:	National Agricultural Research Organization
O_2:	Oxygen
TA:	Titratable Acidity
TSS:	Total Soluble Solids

ABSTRACT

In this study, the efficacy of 1-methylcyclopropene (1-MCP), an ethylene inhibitor was evaluated in extending the green life of harvested mature green East African Highland (EAH) bananas including hybrid cooking bananas (*Matooke)*. The main objective was to lengthen the green life of the EAH cooking bananas while maintaining physico-chemical and sensory properties. Five cooking banana varieties, two indigenous (*Mpologoma* and *Nfuuka*), and three hybrids (NARITA 2, NARITA 4 and NARITA 16) were evaluated in this study. The choice of varieties was dependent on final consumer acceptability, availability of mature bunches, and ability to change color from green to yellow during ripening. *Mpologoma* is a popular local cooking variety grown by Ugandan farmers and produced for home consumption. Harvested bunches were declustered, fingers plucked and labelled. Thereafter, 100 fingers from each variety were treated with 1-MCP in sealed boxes for 24 hours, while 100 fingers were kept as a control. The bananas were observed for changes in the physico-chemical and sensory attributes, as well as green life during storage. Data was analyzed using XLSTAT (Student 2020.5.1.1063). The rate of respiration and ethylene production were significantly lower ($P<0.05$) in 1- MCP treated bananas than in the controls over the green life period. The rate of increase of total soluble sugars (TSS) was significantly higher ($P<0.05$) in the control than in treated bananas. 1-MCP treatment did not have a significant effect ($P<0.05$) on the dry matter content, titratable acidity and sensory attributes of the cooking bananas under study. For texture, no statistical differences ($P<0.05$) were obtained in the different treatments because according to the settings, no numerical values were obtained from the texture analyser on soft bananas yet 1-MCP treatment delayed softening of the banana peel and pulp especially the hybrids during storage by three to four day. Cooking bananas treated with 1-MCP displayed delayed ripening. Indigenous bananas treated with 1-MCP stayed green for 16 to 18 days while their controls stayed green for about 13 days. On the other hand, 1-MCP treated hybrid banana varieties stayed green for 12 to 13 days while their controls stayed green for about six days. However, no significant differences ($P<0.05$) were observed in the sensory attributes of the steamed bananas (both treated and un-treated green banana samples) during the storage period. Despite that, the sensory characteristics of the indigenous and hybrid cultivars remained significantly different ($P<0.05$). From the results of the study, it was observed that 1-MCP (at 5 ppm used in this study) can be used to extend postharvest green life of Ugandan indigenous and hybrid cooking bananas by about 5 days while maintaining their physico-chemical and sensory attributes.

KEY WORDS: 1-methylcyclopropene, Ethylene, Indigenous and hybrid cooking bananas, Physico-chemical attributes, Postharvest green life

CHAPTER ONE: INTRODUCTION

1.1 Background

1.1.1 Production Statistics

Around the world, many people use bananas as a staple food (Ssennoga et al., 2019). The crop is grown by more than 120 nations on about 10 million hectares. Bananas lead all other fruits globally with annual production of 155 million metric tons (FAOSTAT, 2020). The regions with the highest banana output include Asia, Latin America, and Africa, with China, India, Brazil, the Philippines and Uganda among the top producers (FAO, 2020b; FAO, 2018). Twenty million tons of bananas are produced in the East African region each year, which accounts for nearly a fifth of the region's total per-capita calorie intake (Tumuhimbise et al., 2016). With an annual production of about 9.2 and 9.7 million tons in 2020 and 2021, respectively, Uganda currently leads the world in both the production and consumption of cooking bananas (FAOSTAT, 2021).

1.1.2 Significance of bananas

Bananas are a major food and income security crop among Uganda's rural communities with per capita consumption of at least 250 kilograms annually (Ssennoga et al., 2019). According to Marimo et al., (2019), this is one of the highest banana utilization rates in the world. In Uganda, bananas are mostly grown by smallholder farmers in the Western, South Western, Central, and Eastern regions, on average sized plots of half an acre (Nyombi, 2013). Bananas are cultivated by 75% of Ugandan farmers on about 40% of the country's total arable area (Ariho, Makindara, Tumwesigye, and Sikira, 2015).

1.1.3 Cultivars

The East African Highland Cooking Banana (EAHCB) cultivars (matooke) are widely produced in Uganda. In the Great Lakes region of East Africa, matooke is consumed by more than 30 million people (NBRP, 2018; Nyombi, 2013). According to Akankwasa et al., (2016), notable clones include Nakitembe, Mpologoma, Nfuuka, and Kibuzi. Other cultivars of banana grown in Uganda include juice cultivars (Mbidde, Kayinja and Kisubi), dessert cultivars (Sukaali Ndiizi and Bogoya), and roasting cultivars (Gonja) (Byarugaba, Tumusiime, and Kimono., 2014; Nyombi, 2013). Numerous hybrid cooking bananas have been produced in Uganda as a result of technical innovation, shifting environmental conditions, and the desire for nutritional improvement. A few examples include M9, M7, and FHIA. Akankwasa et al., (2013) reports that while some hybrid cooking bananas have already been made available to the public, others are currently being tested.

1.1.4 Marketing and Distribution

Although banana is widely produced and consumed in Uganda, marketing and distribution channels constitute a significant difficulty. While some bananas are sold within the East African region (Kenya and Southern Sudan), and a small amount of desert bananas is exported to European markets, banana markets in Uganda are located in metropolitan areas. According to Akankwasa et al., (2013), bananas are primarily sold in bunches, clusters, and fingers. However, the banana crop is highly perishable, leading to severe postharvest losses despite the advancements and innovations that have led to the high domestic production (Muranga et al., 2010).

1.1.5 Strategies for Reducing Postharvest Losses

Due to their high perishability, fruits and vegetables farmers experience significant postharvest losses worldwide. Therefore, extension of postharvest shelf life has been the focus of technological development (Valero et al., 2016; Guan et al., 2015; Wongs-Aree et al., 2011). One such example is the application of 1-methylcyclopropene, a potent ethylene inhibitor that extends fruit ripening. The use of controlled atmospheric storage, which involves increasing CO_2 generation and decreasing O_2 levels in airtight containers or rooms at the ideal storage temperature. These technologies have been examined on fresh fruits and vegetables and found to be effective (Jalali et al., 2017).

Various horticultural crops require varying amounts of O_2 and CO_2 to maintain quality and extend shelf life. It is possible to utilize passive or active "Modified Atmosphere Packaging (MAP)" by wrapping whole fruits and vegetables or other fresh foods in plastic films (Jalali et al., 2017). The equilibrium concentrations of O_2 and CO_2 in passive modified atmospheric packaging rely on the product weight and respiration rate, which is influenced by a number of variables including temperature, surface area, and the gas permeability of the film (Jalali et al., 2017). Before sealing, the appropriate environment is introduced into the package headspace as part of active modified atmospheric packaging. Still, product weight and respiration rate affect the ultimate environment (Jalali et al., 2017). Other techniques include chemical treatments with antimicrobials and antioxidants as well as physical treatments using heat, radiation, and edible coatings.

1.2 Problem Statement

The East African region’s food security is seriously threatened by postharvest losses, which rank among the highest globally and account for 20 to 60% of the food output (Whitney et al., 2016). In Uganda, ripening of bananas accounts for the biggest percentage of the loss, particularly during peak seasons (Kikulwe et al., 2018), with around 40% of the green harvested cooking bananas going to waste each year. At the farm, local, and global market levels, ripening is one of the significant factors that contributes to the physical and monetary losses of cooking bananas.

Four to five days after harvest, cooking bananas begin to ripen (Nalunga et al., 2015). Consumers reject them once they start to ripen. Before being sold, bananas ripen on the farm, in transit, and at market stands. Because households only purchase bananas that can be consumed within a few days, the short green life also limits consumption at the consumer level (Kikulwe et al., 2018). To ensure a longer postharvest green life, farmers therefore harvest bananas at a somewhat younger stage.

However, selling immature bananas also incurs economic losses due to their perceived low quality leading to low buying prices in comparison to mature bunches. The physical and economic losses of the harvested bananas during the peak season are projected at 3.4% and 2.8% respectively hence lower selling value (Kikulwe et al., 2018). As a result of these difficulties, there is a high demand for banana varieties with a long green life which has necessitated the development of green life extension technologies.

Induction of ripening in climacteric fruits like bananas is linked to the generation of ethylene. Some banana types and other fruits have been exposed to 1-methylcyclopropene to prevent the effects of ethylene and increase the fruit postharvest shelf life (Ma et al., 2017). However, there is little information available regarding the use of 1-methylcyclopropene on Uganda's native and hybrid cooking banana species. The purpose of this study therefore, was to evaluate the effects of 1-methylcyclopropene treatment on the physico-chemical attributes and postharvest green life of selected indigenous and hybrid cooking banana varieties in Uganda.

1.3 Justification

Given the great importance attached to addressing the problem of ripening in harvested green cooking bananas in Uganda, a breakthrough technology is required to extend banana green life. 1-

methylcyclopropene has undergone testing and is currently being utilized commercially as an ethylene inhibitor that greatly slows down the ripening of sugar apples, Cavendish bananas (Manigo and Limbaga, 2019), avocados, and pears (Feng et al., 2018; Yu and Wang, 2017).

Treatment with 1-methylcyclopropene significantly controls the stay-green disorder of the peel, inhibits fruit softening enzyme activity, and delays sugar accumulation (Zhu et al., 2020). The ethylene inhibitor has a negligible negative effect on the environment while delaying banana ripening after harvest (Manigo and Limbaga, 2019; Pongprasert and Srilaong, 2014; Krishnakumar and Thirupathi, 2014). Embracing this technology on Uganda's indigenous and hybrid cooking bananas will potentially delay ripening hence increasing their green life and overall quality, thereby enhancing the utilisation, marketing and export quality thereof.

1.4 Significance of the study

Increasing *Matooke* green life with 1-methylcyclopropene treatment will significantly contribute to the reduction of the high *Matooke* postharvest losses in Uganda thereby increasing access to food as well as income security for poor rural farmers. Similarly, extending green life of bananas will potentially boost banana trade especially export in Uganda and East Africa. The study is also in line with the objectives and aspirations of NDP III targeted at increasing household income and enhancing the quality of life. The study also conforms to the sustainable development goals including; hunger reduction, improvement of food and nutrition security, promotion of sustainable agriculture, and warranting sustainability of consumption and production.

1.5 Objectives

1.5.1 General objective

To investigate the effects of 1-methylcyclopropene (1-MCP)) on the physico-chemical attributes of selected Ugandan indigenous and hybrid cooking banana varieties.

1.5.2 Specific objectives

1. To determine the effect of 1-MCP treatment on ethylene production and respiration rate in the selected banana varieties during postharvest storage.
2. To determine the effect of 1-MCP treatment on the textural, chemical and sensory properties of the selected banana varieties grown in Uganda.
3. To evaluate the effect of 1-MCP treatment on the green life of the selected banana varieties grown in Uganda.

1.6 Hypotheses

1) 1-MCP treatment on Ugandan indigenous and hybrid cooking bananas has no effect on ethylene production and respiration rates during storage.
2) 1-MCP treatment of Ugandan indigenous and hybrid cooking bananas has no effect on textural, chemical and sensory properties during storage.
3) 1-MCP treatment of Ugandan indigenous and hybrid cooking bananas has no effect on green life during storage.

CHAPTER TWO: LITERATURE REVIEW

2.1 History of bananas

In the developing world, bananas (Musa spp.) constitute a highly valued staple food and they come in a variety of forms, including the cooking, dessert, roasting, and beer types (Dadzie and Orchard, 1997). Bananas are monocotyledonous flowering plants under the genus Musa, family Musaceae, order Scitamineae, and species Musa acuminata Colla (Blomme et al., 2013). They are a part of the section Eumusa. According to Dufour and Gibert (2009), the genus Musa produces edible fruits known as fingers arranged in clusters. Musa species are not native to Africa. They are said to have tropical Asian ancestry, stretching from South West India east to the island of New Guinea. African tropical lowland plantain banana and East African highland banana cultivation is said to have begun in 1 AD (Blomme et al., 2013). During the colonial era, Arab traders introduced the majority of the cooking and desert bananas to Africa from India. Through vegetative multiplication, natural crossing, and human management of chosen wild subspecies, these variants were dispersed throughout the East African region.

Bananas are currently the fourth-largest food crop in the world with annual production of 155 million metric tons. The crop is cultivated in a variety of humid tropical locations, with 27% of the production coming from sub-Saharan Africa (FAOSTAT, 2020). Sequentially, bananas have a high export value compared to other exported fruits (FAO, 2021). Global exports of bananas, excluding plantains, reached 22.2 million tons in 2020, representing a 1.7% increase, according to the FAO. Bananas provide a source of income for more than 70 million people in Africa (InAfrica24, 2016). The banana has regularly been regarded as Uganda's most significant food and economic security crop by the farming community over the years (Lescot, 2015).

According to FAO (2018), the annual production of East African highland cooking bananas is predicted to be 4.3 million tons, contributing 10% to the nation's GDP and 17% of Uganda's daily energy requirements (Fiedler et al., 2013). Therefore, the banana business is crucial for nations like Uganda that produce bananas.

2.2 Banana breeding in Uganda

Several hybrids have been introduced into the banana production chain. NARO, in collaboration with IITA and Bioversity International have focussed efforts in breeding hybrid bananas. These hybrids include; NARITA 23, NARITA 14, NARITA 21, and NARITA 7. Breeding efforts are aimed at dealing with the environmental and biotic aspects affecting banana production including; drought, low soil fertility, pests and diseases (Tumuhimbise et al., 2018). The breeding program focusses on enhancing yield characteristics, abiotic and biotic stress resistance together with postharvest and market attributes (Batte et al., 2017; Heslop-Harrison and Schwarzacher, 2011)

Banana breeding employing traditional techniques that find valuable genes, combine desirable features or resistance genes, and speed up selection using genetic maps and DNA markers (Heslop-Harrison and Schwarzacher, 2011). The resulting hybrids typically have higher agronomic yields and host tolerance to pests and diseases that affect bananas (Tumuhimbise et al., 2018; Arinaitwe et al., 2014). However, despite their large bunch yields, several varieties, including N23, FHIA 03, and N21, have low consumer acceptability due to poor eating characteristics and may be rejected as food crops (Tumuhimbise et al., 2018; Nowakunda et al., 2015; Nowakunda and Tushemereirwe, 2004)

2.3 Postharvest handling and losses in cooking bananas

Uganda's harvested bananas frequently rot and go to waste for a variety of reasons, including transit delays, ripening, inadequate conveyance, and storage conditions. Bananas should go faster to the market because of their perishable nature. However, numerous postharvest losses happen as a result of the large number of supply chain operators (Nalunga et al., 2015). The product quality declines at each exchange location along the supply chain. Poor handling and packaging facilities also cause quality to decline. Commercial bananas lose their freshness and quality since they are typically loaded by hand for truck transportation (Ssennoga et al., 2019). However, there isn't much published data available regarding the losses incurred during banana production in Uganda.

Postharvest losses are correspondingly higher during the high production (surplus) season than they are during the low production (scarce) season. In periods of scarcity, 1.2% and 1.9% of the bananas harvested on farms respectively suffer physical and financial losses. A bunch is sold at a discount rate of about 25% during the lean season at the farm level because of quality decline (economic losses). Farm-level physical losses are mostly caused by theft, improper handling, and ripening; on the other hand, sales of underripe bananas together with subpar postharvest treatment are the main causes of economic losses (Kikulwe et al., 2018). The main cause of postharvest (financial and physical) losses during the peak season is ripening. During the surplus season, a large number of farmers supply bananas to the market, but few buyers are present. As a result, some farmers choose not to sell their bananas, while others store their fruit longer, increasing the likelihood that it will ripen. The main reasons for physical and financial losses during both the surplus and scarcity seasons are bruising, ripening, and overstaying.

2.4 Marketing of cooking bananas

The majority of Uganda's banana markets are located in its urban areas, although some are transported on trucks and sold in other East African nations while others are flown to markets in Europe (Kiiza et al., 2004). The marketing for the bananas focuses on bunches, clusters, or fingers (Akankwasa et al., 2013). Some traders prefer to trade in landrace types known to have relatively intrinsic longer shelf lives such as "landrace cultivar "Kibuzi". Banana farmers and traders sometimes use the slightly younger harvest age to achieve longer postharvest green life.

2.5 Postharvest physiology of bananas

2.5.1 Ethylene production

Fruits release ethylene, a ripening hormone, to speed up the natural process of fruit senescence and maturation. The ripening process of climacteric fruits depends on the action of ethylene, which also causes changes in colour, texture, and flavour. Delaying ripening by inhibiting ethylene action could help retain the post-harvest quality of mature green bananas. Ethylene production rates increase with harvest maturity, physical damage, disease occurrence, greater temperatures up to 30°C, and water stress (Li et al., 2016). Conversely, ethylene synthesis rates in fresh horticultural commodities are decreased by low temperature storage, low oxygen levels, and high CO_2 levels surrounding the commodity (Jalali et al. 2017). When climacteric fruits are exposed to ethylene, they quickly ripen and begin an irreversible rise in respiration rate (Brat et al., 2020; Irtwange, 2006). Until the onset of ripening, unripe bananas continuously produce ethylene, albeit at a low level. After then, there is an increase in the rate of respiration and ethylene synthesis (Mariah et al., 2022; Hailu et al., 2013). Nonetheless, by reducing ethylene production and sensitivity, alternative packaging can postpone the onset of fruit ripening and extend the fruits' green life.

2.5.2 Respiration

After harvest, fresh produce continues to lose moisture as a result of evaporation and respiration (Bovi et al., 2016). When bananas are harvested, they take in in oxygen and exhale heat, moisture, and carbon dioxide (Xu et al., 2018). When stored the carbohydrates, proteins, and lipids are metabolised during respiration and energy is released. This process makes use of oxygen and generates carbon dioxide. Due to the depletion of energy reserves, senescence is accelerated. This leads to loss of taste, particularly sweetness. Therefore, the respiration rate and the rate of deterioration of harvested goods are often proportionate (Irtwange, 2006). Bananas are climacteric fruits, thus when they are harvested and kept at 20°C, they reach their peak of respiration during ripening. In a few days, the hard-green banana fruit's respiration rate, which is typically 20 mg/kg/h, may be multiplied at the climacteric peak before declining as ripening progresses.

2.5.3 Relationship between ethylene production and respiration

When climacteric fruits are exposed to ethylene, an unalterable rise in respiration rate and rapid ripening occur (Brat et al., 2020; Irtwange, 2006). Peak ethylene production often occurs during the ripening process when respiration is still coming up. With decreasing ethylene production, the rate of respiration peaks at around 125 mg/kg/h, then slightly drops but stays high (Irtwange, 2006).

2.5.4 Titratable acidity

According to Atkinson et al. (2014), the titratable acidity of bananas is a key predictor of their suitability for eating as well as a potential signal of fruit development. It has to do with the fruit's organic acid concentration. According to a 2016 study by González-agüero et al., titratable acidity often rises during ripening until the latter stages of ripening, at which point it falls. The decrease is linked to the respiration of starch, or its conversion to sugars, which requires the consumption of organic acids. In order to achieve the correct sugar/acid balance during fruit ripening, which results in a tasty fruit flavour, organic acids are crucial. A study by Sakyi-Dawson et al., (2008) found that the titratable acidity of cooking banana hybrids varied within varieties and was higher than that of plantain hybrids (Dadzie and Orchad, 1997). The reduction in titratable acidity in fruits has been found to be affected by respiration-delaying techniques including the application of methyl cellulose coating.

2.5.5 Sugars

Total soluble solid content is a crucial measure of fruit maturation because as it is indicative of fruit ripening (Yan et al., 2019). It has to do with how fruits develop and respire, which causes complex carbohydrates to break down into soluble solids (Narayanapurapu, 2012). The hydrolysis of starch and the accumulation of sugars, specifically sucrose, glucose, and fructose, which are responsible for the fruit sweetness as it ripens, are the two most noticeable chemical changes that take place during postharvest ripening of bananas. About 20 to 25% of the fresh weight of unripe banana pulp is made up of starch. The starch degrades quickly when the fruit ripens, resulting in the accumulation of the sugars sucrose, glucose, and fructose; traces of maltose may also be present (Cordenunsi-lysenko, 2019).

On average sugar content in the fresh pulp of the green fruit ranges between 1 and 2%; during ripening, it rises to 15 to 20%, the start of the increase occurs at the top of the respiratory climacteric wave. Starch also vanishes simultaneously, decreasing from 20–25% in green fruit to 1–2% in ripe fruit. It is more in mature plantains (6% than dessert bananas) than in the latter (Simmonds, 1959). Sucrose is the predominant sugar in the banana pulp at the beginning of ripening due to the activity of amylases, starch phosphorylase, and 1,6-glucosidase enzymes. Its formation occurs before the accumulation of glucose and fructose (Cordenunsi-lysenko, 2019;

Narayanapurapu, (2012). During ripening, these distinctive patterns of carbohydrate metabolism can change (Hailu et al., 2013). Fruit ripening delaying techniques, such as the use of edible coatings, are utilized to delay accumulation of TSS content in fruits (Narayanapurapu, 2012)

2.5.6 Dry matter

Given that the shelf life and freshness of food products are related to level of moisture, the significance of dry matter content in product quality screening has been paramount (Annor et al., 2016). According to Baiyeri et al. (2015), food deterioration increases with increasing moisture content due to increased susceptibility to microbial harm. According to sensory assessment reports of cooked bananas, a higher dry matter content results in better eating quality (Belayneh et al., 2014). Additionally, a high dry matter content has been associated with superior cooking quality in cooking bananas (Dzomeku et al., 2006). There is evidence of a favourable link between dry matter and other fruit quality characteristics. For instance, a study conducted by Bugaud et al., (2009) found a correlation between the total soluble solids in ripe fruits and the dry matter content of immature fruits. Due to starch being their primary component, dry matter also impacts how firm green bananas are (Gibert et al., 2010). Bananas typically have a high-water content. When a banana is green, its dry matter is primarily made up of starch (72%). Starch transforms into simple sugars as it ripens. This process involves moisture release, thereby lowering the amount of dry matter present and significantly reduces the firmness of the fruit (Cordenunsi-lysenko, 2019; Adi et al., 2019). A reduction in the dry matter of bananas during ripening could potentially be caused by the moisture migration from the peel to the pulp during storage (Adi et al., 2019). Notably, many studies reveal variances in moisture levels of specific banana cultivars and the dry matter content of bananas varies with variety and growth conditions (Thompson, 2011). Cooking bananas also reportedly have lower dry matter content values than hybrids. (Annor et al., 2016; Dufour et al., 2009).

2.5.7 Texture

As they ripen in storage, fruits get softer due to the action of Pectinase enzyme which breaks down he banana fruit's cell walls. Pulp firmness is one of the key elements affecting postharvest quality of mature harvested green bananas (Manigo and Limbaga, 2019). According to Morris et al. (2014), this is a crucial qualitative trait that usually determines consumer acceptability and the green life. Marapana (2019) identifies three possible reasons for fruit softening: turgor loss, starch deterioration, or fruit cell wall collapse. Turgor loss can become economically significant during storage because it is mostly a non-physiological process associated with the fruit's postharvest dehydration (Hailu et al., 2013). Some fruits, such as bananas, contain a significant amount of starch, therefore its degradation may cause a texture change (Turner, 2001; Tucker, 1993).

2.5.8 Green life of cooking bananas

The period of time between harvest and the beginning of natural ripening or the climacteric phase has been referred to as the "banana green life." It is one of the key quality factors determining a fruit's suitability for selling and export (Brat et al., 2019). The green life cycle is characterized by a low respiration rate and hardly perceptible ethylene generation in mature green bananas (Hailu et al., 2013). During this period, green bananas have a low sugar content close to 0% and a low carbon dioxide production rate of 4mg/kg/hr. (Mees et al., 2017). According to Brat et al. (2019), autocatalytic ethylene generation in bananas is a crucial sign of the fruit's end of green life. A prominent visual signal of the end of the green life of cooking bananas is a gradual decline in chlorophyll that causes the yellowing of the peel (Chillet et al. 2008). By regulating ethylene action, lowering storage temperature, and storing bananas in an environment with high carbon dioxide production and low oxygen consumption, banana green life can be prolonged (Park et al., 2021: Zhang et al., 2017).

2.5.8.1 Green life extension technologies

Ethylene, a fruit ripening hormone, is connected to spoiling and the activation of ripening in climacteric fruits. Therefore, efforts to delay ripening and extend postharvest green life of such fruits after harvest have been focused on reducing ethylene action (Zhang et al., 2017).

2.5.8.2 1-Methylcyclopropene

The quality and green life of plant products, such as fruits, vegetables, and floriculture crops, is greatly enhanced by the new ethylene activity inhibitor 1-MCP. In addition to enhancing product post-harvest quality, 1-MCP is helpful in the laboratory for researching the effects of ethylene on fruit ripening and ageing. 1-MCP gas has a weight of 54 and the chemical formula C_4H_6 at standard pressure and temperature. 1-MCP is sold commercially in Europe and the US under the brands Smart Fresh and Ethyl Bloc. 1-MCP is utilised at very low doses with minimal residual levels and no toxicity, according to Blankenship et al. (2003). It has been extensively used in fruit processing because of its potent abilities to prevent fruit softening, browning, rot, and peel yellowing, hence maintaining fruit quality during storage (Cheng et al., 2012; Watkins 2006).

2.5.8.3 Preservation mechanism of 1- MCP

1-MCP suppresses the respiration process induced by ethylene by interacting with ethylene receptors and outcompeting ethylene for the binding sites in the receptor. According to Merisko and Liversidge (2011), the gas binds to the ethylene receptors and stays locked up hence blocking the development of ethylene receptor complexes that induce ripening. In this way, 1-MCP prolongs the green life and enhances the quality of plant products. 1-MCP is effective at far lower doses than ethylene because its affinity for the ethylene receptor is roughly ten times greater than ethylene's. According to Golding et al. (1999), climacteric fruits treated with 1-MCP exhibit delayed respiration rates. Hu et al. (2017) states that preharvest circumstances, ripeness, cultivar, and postharvest techniques all affect 1-MCP action.

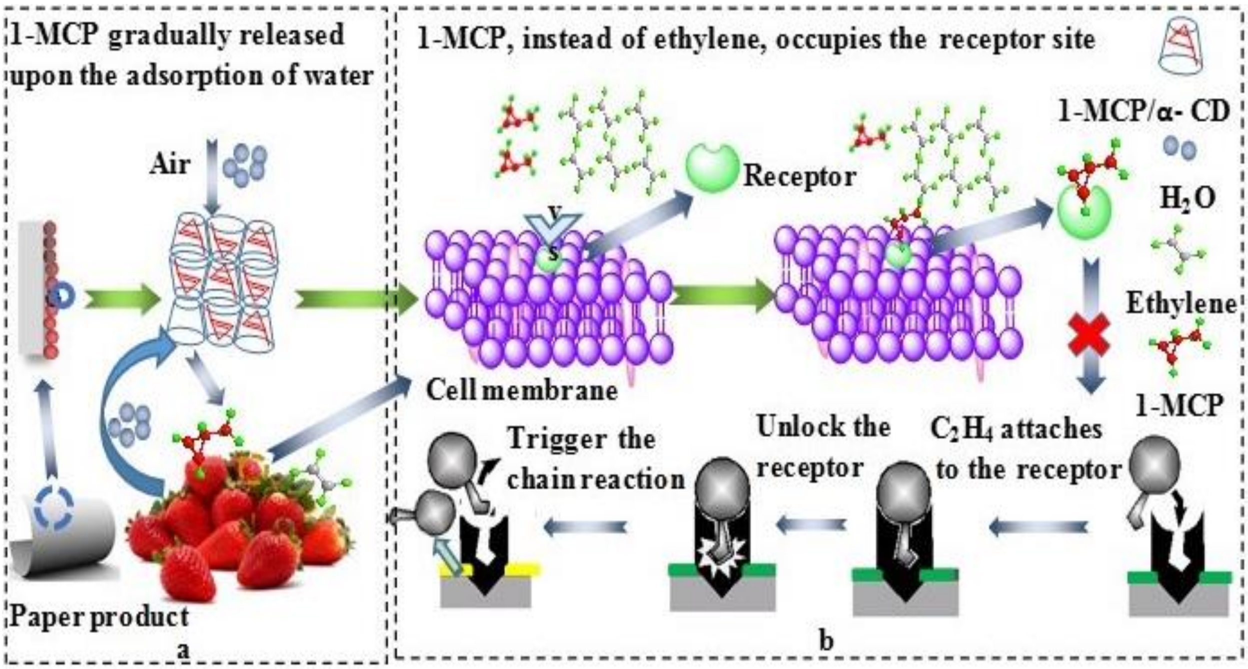

Figure 2.1: Preservation mechanism of 1-Methylcyclopropene

*a: Application of 1-MCP on the fruit; *b: Action of 1-MCP on the fruit

Source: Hu et al., 2017

2.5.8.4 Other Green Life Extension Technologies

In addition to 1-MCP, postharvest technologies like controlled atmosphere storage, which regulate carbon dioxide (CO_2) and oxygen (O_2) levels in gas-tight stores at the ideal storage temperature, have been used (Jalali et al. 2017). Related to this is modified atmosphere packaging, which can be passive or active and comprises the packing of a whole or freshly cut product in plastic film bags (Jalali et al. 2017). Strawberry respiration rates have been found to be effectively reduced by an edible coating made of sodium alginate and calcium chloride (Jalali et al. 2017). Other techniques include chemical and physical treatments using antimicrobial and antioxidant agents, as well as physical treatments using heat, radiation, and edible coatings (Jalali et al. 2017).

2.6 Processing of Cooking Bananas

Processing of harvested green matooke in Uganda entails peeling, wrapping, steaming or boiling, and mashing. The cooked product may be consumed as part of a meal or as a snack (Marimo et al., 2019; Nowakunda et al., 2019; FAO, 2018). Steamed matooke is a delicacy in the Great Lakes countries. It is soft with a distinct bland flavour and bright yellow colour. These traits make up for the "tookeness" attribute which consumers prefer in matooke varieties (NBRP, 2016; Akankwasa et al., 2013). *Matooke* farmers and dealers in western Uganda pay attention to consumer preferred traits. A survey by Akankwasa et al., 2013 revealed men and women to report preference for the same traits including softness, good flavour, yellow colour, and mouldability. Undesirable traits include paleness, hardness, wateriness and sogginess which account for rejection of some matooke varieties ((Marimo et al., 2019; Akankwasa et al., 2013).

CHAPTER THREE: METHODOLOGY

3.1 Experimental design

The banana varieties used in the study were harvested from the fields at National Agricultural Research Laboratories, Kawanda. Green mature banana bunches were harvested at 91 to 119 days (Table 3.2) depending on the variety. The bananas were declustered, sorted, cleaned and the fingers labelled. The middle clusters of each bunch and the middle fingers of each cluster were used for the experiments to ensure evenness of banana maturity. Immediately after harvest (day 0), 100 banana fingers from each variety were treated with 1-MCP while 100 banana fingers were used as a control. Treatment with 1-MCP was done at 0 and 5 ppm levels in sealed boxes equipped with fans to ensure proper circulation of the gas. Bananas were left in the boxes for 24 hours after which they were removed and stored under ambient conditions (24 to 26^{o}C) for 15 days while being observed. Changes in physico-chemical attributes and sensory parameters were evaluated every two days. The experiments were terminated when the bananas reached the end of their green life. This was marked by change of the colour of the fingers from green to yellow on visual observation, softening of the banana, and the peak in ethylene and carbon dioxide production as measured by the gas analyser. Softening of the banana was tested by hand pressing and by the texture analyser. The texture analyser used during the experiments measured bananas within the normal range of hardness of green cooking bananas and read "N/A" when the banana was soft. Other dependent variables tested included; dry matter content, titratable acidity, total soluble solids, and sensory characteristics. All experiments were carried out in replicates of three.

3.2 Raw materials selection

Five cooking banana (*Matooke*) varieties were selected. They included two indigenous varieties i.e. *Mpologoma* (one of the most preferred landraces) and *Nfuuka* (which is a less preferred landrace); and three hybrid varieties namely NARITA 2 and NARITA 4 (the moderately preferred); and NARITA 16 (one of the least preferred hybrids). The choice of varieties was based on end-user acceptance (Akankwasa et al., 2020), availability and ability to change color during ripening. The local varieties were sourced from farmers in Kawanda and the hybrids obtained from National Agricultural Research Laboratories, Kawanda.

Table 3.1: Characterization of the matooke varieties used for the experiments.

Name	Quality	Type	Source
Mpologoma	Good	Landrace	NARL Banana Programme field reports
NARITA 4	Good	Hybrid (AAA)	http://www.promusa.org/NARITA+4
NARITA 2	Moderate	Hybrid (AAA)	http://www.promusa.org/NARITA+2
NARITA 16	Worst	Hybrid (AAA)	http://www.promusa.org/NARITA+16
Nfuuka	Worst	Landrace	NARL Banana Programme field reports

3.3 Sample harvesting and preparation

Three bunches per variety were harvested according to their physiological maturity stage ranging from 91 to 119 days. Each bunch was declustered, sorted, cleaned and fingers were coded according to variety (V), harvest session (Hn) and treatment concentration administered i.e., VHnTc. The fingers were pooled according to the variety and divided into control and treatment portions each portion containing 100 fingers.

Table 3.2: Physiological maturity indices for the matooke varieties used

Name	Minimum harvest age (days)	Appearance of fully mature fruit	Source
Mpologoma	91	Light green colour Few or no ridges	NARL Banana Programme field reports
NARITA 4	119	Maintains a deep green colour Ridges remain	NARL Banana Programme field reports
NARITA 2	119	Maintains deep green colour Splitting of fingers on the first cluster of the bunch	NARL Banana Programme field reports
NARITA 16	119	Shiny surfaced fingers Splitting of fingers on the first cluster of the bunch No ridges on the fingers	NARL Banana Programme field reports
Nfuuka	112	Few or no ridges on fingers Maintains deep green colour	NARL Banana Programme field reports

3.4 Preparation of 1- MCP

1-methylcyclopropene was prepared 24 hours prior the experiment as described by Dan et al. (2017). 50 ml of distilled water were added to 0.82 grams of 1-MCP powder in sealed jars in order to generate 5 ppm of 1-MCP gas. Distilled water was added using a syringe through the septum on the lid of the jar. The mixture was then left to stand at ambient conditions for 24 hours to allow complete dissolution and formation of 1-MCP gas.

3.5 Sample treatment

Banana fingers were treated according to Amoateng et al. (2019) with modifications in equipment used. The banana fingers were treated with 0 ppm (control) and 5 ppm of 1-MCP (independent variables) at ambient temperature conditions (24 -26ºC) in sealed boxes with a small fan attached to the lid to ensure even distribution of the gas. The gas was introduced into the treatment boxes using syringes to avoid gas loss for a period of 24 hours. Both the treated and control samples were placed on the shelf in a well-ventilated place at ambient conditions for 15 days.

3.6 Evaluation of changes in physico-chemical attributes

The physico-chemical attributes measured included; ethylene production, carbon dioxide production, oxygen consumption, peel and pulp firmness, dry matter content, titratable acidity, total soluble solids, and green life (dependent variables).

3.6.1 Determination of ethylene production

Ethylene production was determined as described by Dadzie and Orchad, (1997). The ethylene production rate of the banana fruits was measured by using a portable three-gas analyzer (F-950 ES-France). The sample was weighed and then placed inside an airtight container for one hour. The three-gas analyzer measuring ethylene production, carbon dioxide production and oxygen uptake was connected to the ethylene containers by a needle attached to a tube through which the gas was transferred to the equipment. The initial ethylene levels were measured and the percentage ethylene reading obtained from the three-gas analyzer. A final reading was taken and recorded after incubation for one hour. The ethylene production rates were calculated and determined by getting the difference between the initial and final ethylene values and were expressed as mg/kg/hr. The Three gas analyzer was calibrated weekly using Potassium permanganate, soda lime and Oxygen in the air according to the instructions in the user's manual.

3.6.2 Determination of respiration rate

3.6.2.1 Determination of carbon dioxide production

Carbon dioxide production was measured using the same method as for ethylene determination elaborated in section 3.6.1. The readings for the percentage carbon dioxide values were obtained by using the three-gas analyzer.

3.6.2.2 Determination of oxygen consumption

Oxygen production was measured by using the same method as for ethylene determination discussed in section 3.6.1. The readings for the percentage oxygen values were obtained from the three-gas analyzer.

3.6.3 Determination of peel and pulp hardness

The hardness of raw banana fingers was measured by penetration with modifications using a texture analyzer (TMS- Pilot Texture analyzer ILC 500 N, Mecmesin, Virginia) (Gafuma et al., 2018). The specifications were; a cylindrical probe (2 mm); mode (*Return to start* position); sample penetration distance (5 mm): pre-test speed (60 mm/min); trigger force (1 N); calibration (2 kg load cell). Samples were mounted on the instrument's platform for texture analysis. Five samples per treatment were analyzed and the texture profile (force vs distance) observed on a Personal Computer connected to the instrument. The sample penetration force was recorded as the first peak under the force-time curves and was taken as the hardness of the sample (Gafuma et al., 2018).

3.6.4 Determination of total soluble solids (TSS) content

TSS was measured using a refractometer (Leica Buffalo, NY 14215 0-50 °Brix, USA) (Dadzie and Orchad, 1997). Pulp tissue (50 g) was crushed in a kitchen blender (Snijders Scientific 8011 E Wl 102-295, Holland) in 100 ml of distilled water for 2 minutes and filtered using a cheese cloth. The surface of the refractometer was calibrated using distilled water and rinsed with filtrate solution. A single drop of the filtrate was placed on the prism of the refractometer, the refractometer pointed towards a light source, and the reading taken as ^{o}Brix (1^{o}Brix = 1% TSS) (Dadzie and Orchad, 1997).

3.6.5 Determination of titratable acidity

Total titratable acidity of the banana samples was measured according to Garner et al. (2005). Pulp tissue (50 g) was weighed into a kitchen blender and 100 ml of distilled water added, and the pulp tissue crushed in the blender for 2 minutes until a fine juice was obtained which was then filtered. The resulting juice amounting to 6 ml was transferred into a 250 ml conical flask and 50 ml of distilled water added. Then 3 drops of phenolphthalein indicator were added. A 50 ml burette was filled with 0.1 N sodium hydroxide (NaOH) solution and adjusted to the zero mark after eliminating air bubbles. The sample was then titrated against 0.1 N sodium hydroxide standardised using hydrochloric acid until the solution turned pink and the titre volume of NaOH was read and recorded. The titratable acidity (TA) was calculated according to the formula (1) below and the results expressed as milli-equivalent of malic acid per 100 g sample.

% TA = (ml of NAOH) *(0.1N NAOH) *0.067 (Milli-equivalent Factor) *100)/6 grams of sample …………………1

3.6.6 Determination of changes in dry matter content

The dry matter content of the bananas was determined according to AOAC (2000) standard method no. 44-l 5A. An aluminium dish was weighed (W1). Fifty grams of chopped fresh banana peel or pulp were added to weighed aluminium crucibles. The weight (W2) of the sample was measured using a using a digital analytical balance (Model: MS204S/01 New classic MF) and recorded. The samples were placed in a hot air oven at 105^0C for 6 hours. They were removed from the oven and directly transferred into a desiccator for 30 minutes to cool at room temperature.

The samples were again weighed and the weight recorded (W3). Dry matter was calculated and expressed as a percentage of the original sample weight using the following formular.

Moisture (%) = $\frac{W2-W3}{W2-W1} x\ 100$Where: W1 = crucible; W2 = sample + crucible; W3 = sample + crucible after drying

3.7 Determination of the green life

Green life of the bananas was determined by detecting the carbon dioxide and ethylene peak (Brat et al., 2022). The sharp increase in ethylene and Carbon dioxide production was measured by the three-gas analyser (Model F-950 ES-France). Other methods used included visual observation of physical attributes (Dadzie and Orchard, 1997) such as change of whole finger colour and a soft texture by hand pressing as well as using a texture analyser (Brat et al., 2022).

3.8 Determination of sensory characteristics

Consumer evaluation was performed on the indigenous and hybrid cooking bananas excluding *NARITA 16* which reportedly has poor sensory attributes. A *Matooke* sensory lexicon was generated and the diversity of sensory quality traits were profiled in the laboratory using quantitative descriptive sensory analysis with a trained sensory panel (Khakasa et al, 2022, Nowakunda et al, 2022). Samples were prepared by steaming the bananas in banana leaves for two hours, then mashing and simmering for 30 minutes. The samples were coded with three digits and a table spoonful of the steamed product was served to each of the panellists. The sample was evaluated in booths equipped with a sink, running water and a bulb for light. Panellists were provided with an evaluation form, a pencil and bottled water for palate cleansing in-between sample testing. Panellists assessed the intensity of the sensory attributes according to a 10-point scale presented in the lexicon (Annex 5). The sensory attributes evaluated included homogeneity of color, firmness, moistness, smoothness, hardness, moldability, stickiness, sweetness, astringency, sourness and *Matooke* aroma.

3.9 Statistical analysis

Data analysis involved the use of One-Way Analysis of Variance (ANOVA) in XLSTAT (Student 2020.5.1.1063) to detect significant differences among samples. Principal component analysis was also done using XLSTAT to determine whether correlations existed between the physico-chemical parameters of the different cultivars and treatments as well as the sensory attributes. Tukey's test was used to compare means among treatments and varieties and statistical differences were considered to be significant at $p < 0.05$. All results were expressed as means ± *SD*.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Effect of 1-MCP on ethylene production and respiration rate

4.1.1 Ethylene production

Ethylene production was generally higher in the control than in the 1-MCP treated bananas (Figure 4.1). The peak ethylene values in the controls for *Nfuuka*, NARITA 2 and NARITA 4 were 1593.78 mg/kg/h, 1373.06 mg/kg/h and 1512.64 mg/kg/h respectively. *Mpologoma* had the lowest ethylene production of 286.02 mg/kg/h while NARITA 16 had the highest ethylene production (2374.02 mg/kg/h) among the control samples as recorded on day 7 and 13 respectively. A decline in ethylene production was observed in treated and control bananas of *Mpologoma* and *Nfuuka* varieties after days 7 and 13. The ethylene production trend observed in the controls of *Mpologoma* and *Nfuuka* is similar to trend shown by graphs with one peak commonly observed in bananas (Moreno et al., 2021; Xu et al., 2018). For other genotypes, a double peak curve for ethylene production was observed suggesting a second induction of ethylene synthesis. Overall, the rate of ethylene production over the storage period in the treated and control samples was generally not significantly different ($P<0.05$) mainly during early storage. However, differences were observed towards the end of the green life in the control banana samples. Significant differences ($P<0.05$) in ethylene production by control and 1-MCP treated bananas were observed in NARITA 2 bananas on day 7; *Nfuuka* on day 13 and 15; and NARITA 4 on day 7; and NARITA 16 on day 11 and 13 (Annex 3). The controls reached peak ethylene production earlier than the 1-MCP treated samples signifying that the treatment of 1- MCP delays ripening. Similar patterns have been reported by Jiang et al., (2004) where 1-MCP treatment on Chinese green bananas from Musa sp., AAA group significantly ($P<0.05$) delayed the ethylene peaks. Ethylene production was also more pronounced in the hybrid than in the indigenous varieties irrespective of the treatment. This is probably due to the fact that the action of 1-MCP on fruits is dependent on the cultivar. Yoo et al., 2021 also reported a similar observation where the treated fruit traits affected by 1-MCP varied depending on the cultivars used. Similarly, 1-MCP treatment applied to fruits during postharvest storage has been reported to reduce the rate of ethylene synthesis.

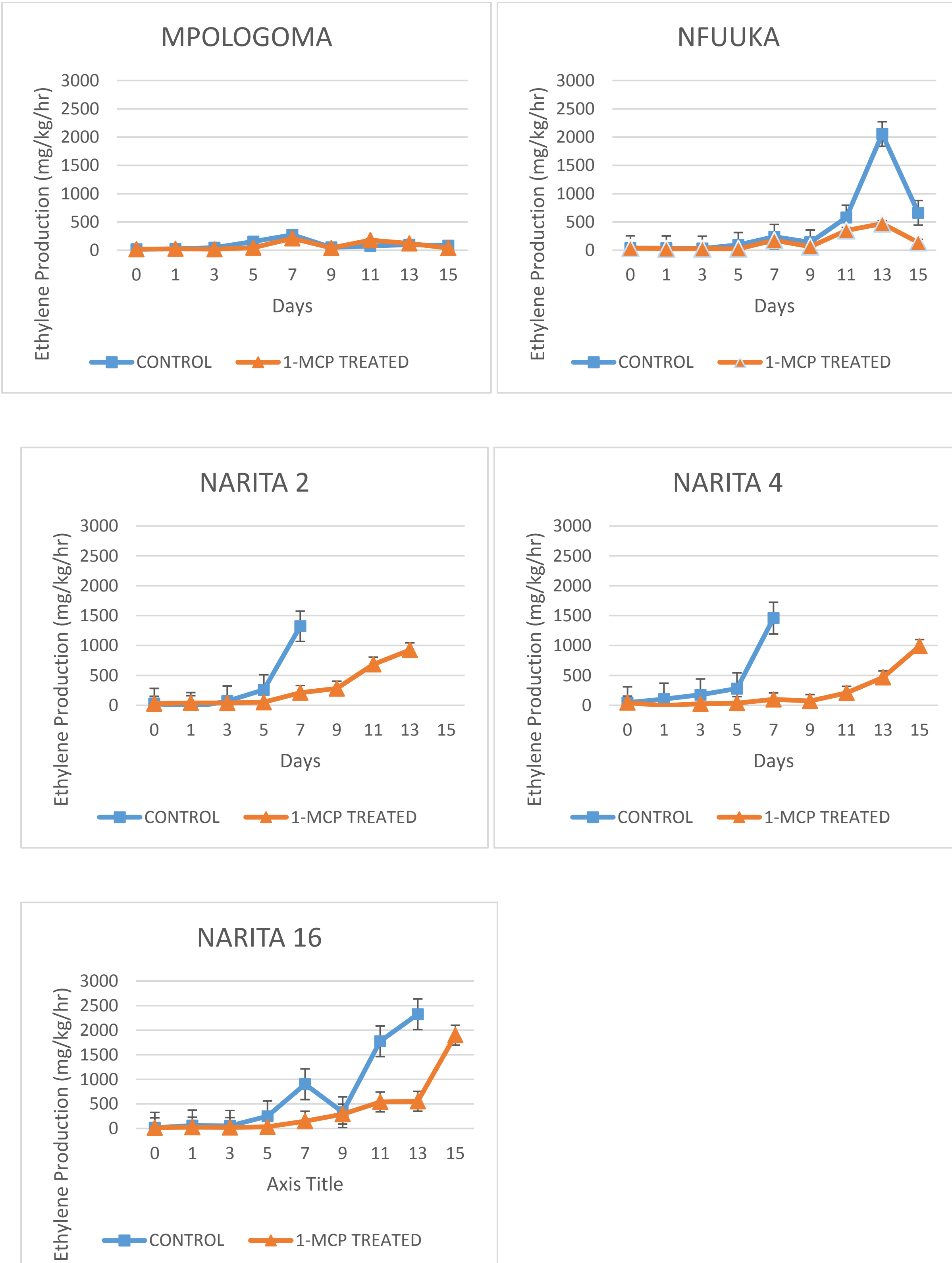

Figure 4.1: Changes in ethylene production among 1-MCP treated bananas during storage

4.1.2 Respiration rate

4.1.2.1 CO_2 production

Results from the laboratory experiments showed increasing trends in the respiration rates of both control and treated bananas during storage. It was observed that bananas treated with 1-MCP had lower respiration rates than the controls. This is attributed to the action of 1-MCP inhibiting ethylene activity on ripening enzymes. In general, the CO_2 production varied from 49.18 to 939.04 mg/kg/hr. (Figure 4.2). For *Mpologoma*, CO_2 production ranged from 60.23 to 159.45 mg/kg/hr. in the control and from 49.18 to 119.54 mg/kg/hr. in the treated samples. For *Nfuuka,* CO_2 production ranged from 64.11 to 539.09 mg/kg/hr. in the control and from 64.11 to 175.84 mg/kg/hr. in the treated samples. In NARITA 2, CO_2 production ranged from 75.46 to 823.05 mg/kg/hr. in the control and from 58.56 to 346.25 mg/kg/hr. in the treated samples. In NARITA 4, CO_2 production ranged from 65.51 to 939.04 mg/kg/hr. in the control and from 54.65 to 185.98 mg/kg/hr. in the treated samples. In NARITA 16, CO_2 production ranged from 67.29 to 749.59 mg/kg/hr. in the control and from 67.29 to 315.73 mg/kg/hr. in the treated samples. The results are similar to those commonly observed in bananas except for the *Nfuuka* variety (Moreno et al., 2021). It was observed that at the beginning of the storage period, CO_2 production was not significantly different ($P<0.05$) between the treated and control bananas. However, differences ($P<0.05$) were observed at 5 to 7 days towards the end of the green life of bananas ($P<0.05$) except for *Mpologoma* where significant differences were observed on day 15. Carbon dioxide production in NARITA 4 was significantly higher than in rest of the cooking banana cultivars, while the lowest value was observed in *Mpologoma*. NARITA 4 had the highest respiration rate during the storage period which possibly explains the early end of its green life compared to the rest of the cultivars. The differences in the respiration rate among the banana varieties are a possible explanation for the difference in green life of the local cultivars and hybrid varieties.

The respiration rates of *Nfuuka, Mpologoma* and NARITA 16 were observed to decline after 7 days. This observation was not possible in NARITAs 2 and 4 whose experiments were stopped at 7 days after ripening. The bananas in the control had significantly higher respiration rates than the 1-MCP treated samples ($p < 0.05$). According to the current results, NARITA 4 recorded the highest respiration rate (on day 7), followed by NARITA 2 (also on day 7), NARITA 16 (on day 7), *Nfuuka* (on day 15) and lastly *Mpologoma* (on day 7). Among all varieties studied, *Mpologoma* recorded the lowest respiration rate of 49.18 mg/kg/hr. followed by NARITA 4 (54.65 mg/kg/hr.). The respiratory climacteric peak appeared on day 7 in almost all controls while the respiratory rates of 1-MCP treated bananas remained (both hybrid and local) lower throughout the experiment. All hybrid bananas appear to reach their climacteric peak at around 11 days. Moreover, 1-MCP treatment delayed the peak in hybrid bananas by 4 days which is in close agreement with Xu et al., (2018) who reported that the climacteric peak in MCP-treated mature green bananas (Musa acuminata L. AAA group cv. Brazil) was delayed by two days. Zhu et al. (2020) showed that 1-MCP treatment can effectively delay the respiration rate because treatment of Chinese Fenjiao bananas (Musa ABB Pisang Awak) with 1-MCP strictly suppressed fruit respiration at critically lower levels than the control fruits during storage.

The production of carbon dioxide (CO_2) clearly reflects physiological evolution in fruits (Yan et al., 2019). The low production of CO_2 in 1-MCP treated bananas reflects a slowing down of the physiological processes due to the inhibitory activity of 1-MCP towards the respiratory enzymes unlike in the controls.

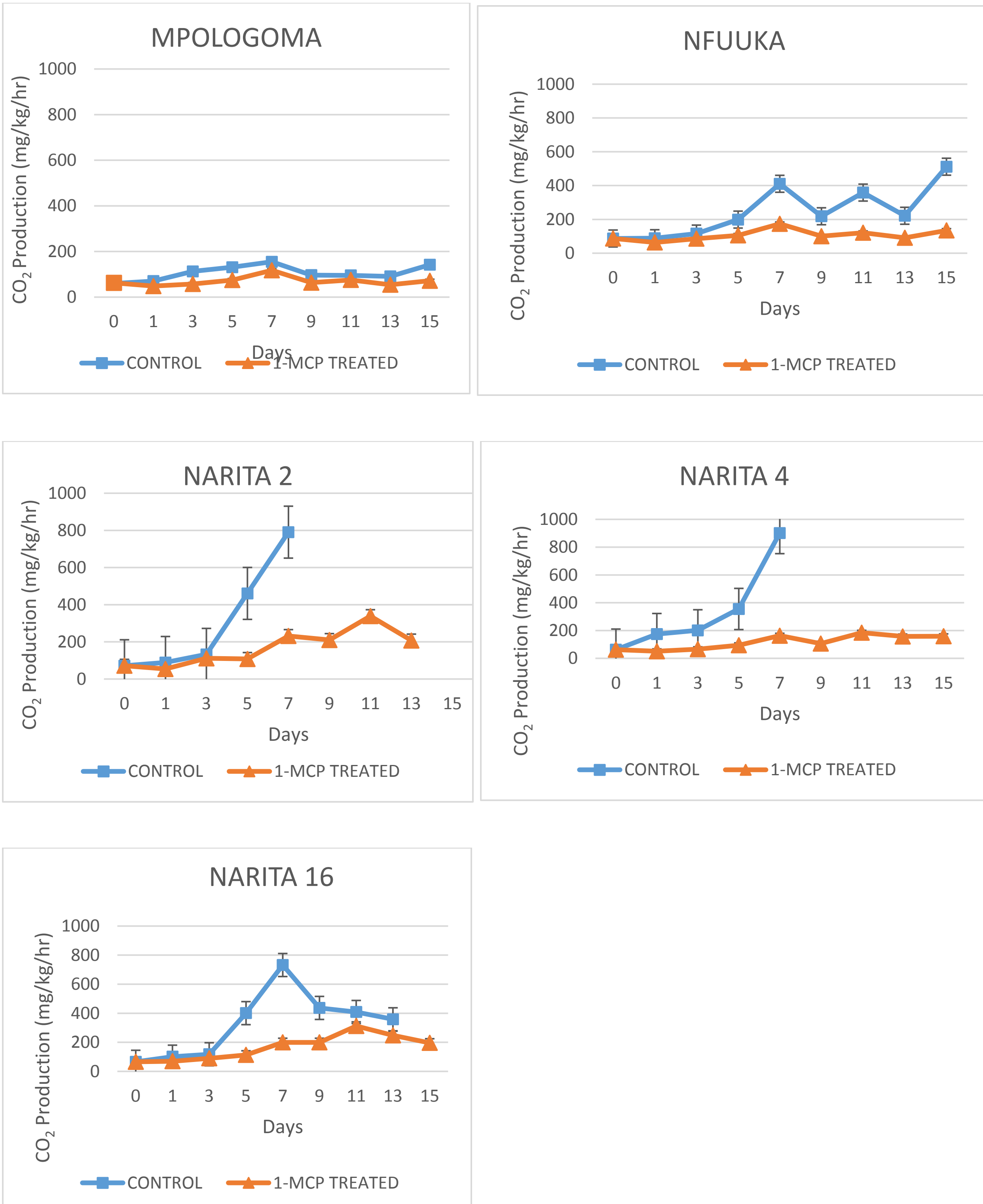

Figure 4.2: Changes in CO_2 consumption among 1-MCP treated bananas during storage

4.1.2.2 O_2 consumption

In comparison to CO_2 production, a similar pattern was obtained in the oxygen depletion rates (Figure 4.3). The rate of change in carbon dioxide production was directly proportional to the rate of change in oxygen consumption, hence an increase in carbon dioxide production resulted in a decline in oxygen consumption and vice versa. The rate of oxygen depletion was higher in hybrid varieties than in local varieties. The same was higher in control fruits than in 1-MCP treated fruits. Significant differences ($p < 0.05$) in oxygen values of control and 1-MCP treated fruits were obtained in NARITA 2 bananas on day 5 and 7; *Nfuuka* on day 13 and 15; and NARITA 4 on day 7 (Annex 2). This same pattern was observed in CO_2 production by the banana cultivars during storage except for NARITA 16. 1-MCP treatment was able to lower the respiration rates in Ugandan cooking bananas during postharvest storage implying it could be used in maintaining the quality and green life of indigenous fresh bananas.

In summary, 1- MCP treatment decreased respiration rates in both indigenous and hybrid bananas, with a greater impact in the hybrid than the indigenous bananas. This can be explained by the inter varietal variation between bananas.

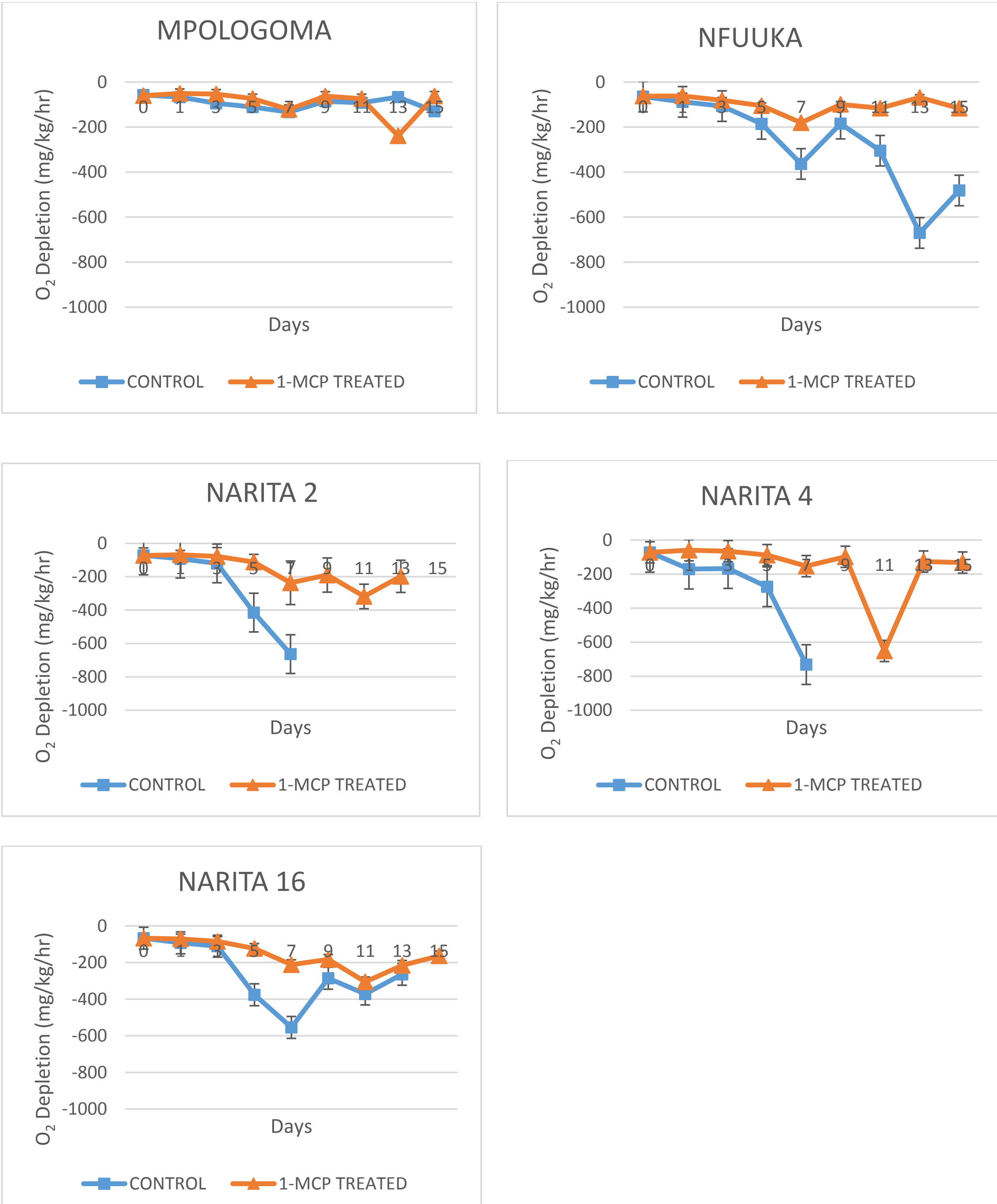

Figure 4.3: Changes in O_2 consumption among 1-MCP treated bananas during storage

4.2 Effect of 1-MCP treatment on textural, chemical and sensory attributes

4.2.1 Textural attributes

4.2.1.1 Peel hardness

Banana peel hardness was determined to assess whether it's affected by 1-MCP treatment since 1-MCP has been shown to delay softening of bananas (Xu et al, 2018; Jiang et al, 2004), and other fruits (Guan et al., 2015). There was an increasing trend in peel hardness of the banana peel during storage (Table 4.1). Peel hardness in both treated and control banana samples increased over time peaking at the end of the treatment period as observed for *Mpologoma, Nfuuka,* NARITA 4 and NARITA 16. This can be attributed to the increasing tensile strength of the peel resulting from evapo transpiration. Results indicate that there were no significant differences ($P<0.05$) in peel hardness between the treated and control banana samples. However, significant differences ($P<0.05$) were observed across varieties (Table 4.1). These could be attributed to the inter varietal variations present within bananas. The control and treated banana samples of NARITA 2 had the highest peel hardness values on day 3 and day 9 respectively, after which it declined towards the end of green life. Overall, NARITA 16 had the lowest peel hardness (11.61 N) at harvest time (day 0), while *Mpologoma* had the highest of 15.23 N at harvest time. *Mpologoma* and *Nfuuka* were generally observed to have the highest peel hardness from the beginning to the end ranging from 15.23 to 19.41 N and 14.69 to 20.78 N respectively.

It can be noted that even though the statistical analysis showed no significant differences in the 1-MCP treated and control bananas in terms of peel hardness, physical differences were observed. No numerical data was obtained from soft bananas because the texture analyser used during the experiments measured bananas within the normal range of hardness of green cooking bananas and read N/A when the banana softens. Therefore, 1-MCP treatment delayed softening of the banana peel especially the hybrids during storage by three to four days.

Table 4.1: Changes in peel hardness (N) among 1-MCP treated bananas during storage

STORAGE DAYS	VARIETIES									
	MPOLOGOMA		NFUUKA		NARITA 2		NARITA 4		NARITA 16	
	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm
0	15.2±1.4^{c}	15.2±1.4^{c}	14.7±1.6^{c}	14.7±1.6^{c}	14.0±2.1^{b}	14.0±2.1^{b}	13.1±1.5^{f}	13.1±1.5^{f}	11.6±1.3^{a}	11.6±1.3^{a}
1	17.06±1.5^{abc}	15.6±2.1^{bc}	17.2±2.0^{abc}	16.2±1.8^{bc}	16.0±2.6^{ab}	14.7±2.1^{ab}	14.7±1.8^{def}	14.5±0.9^{ef}	12.4±0.4^{a}	12.56±0.9^{a}
3	17.±1.4^{abc}	16.9±1.7^{abc}	17.8±2.1^{abc}	17.2±1.2^{abc}	16.4±2.2^{ab}	15.6±2.0^{ab}	14.6±1.7^{def}	15.1±2.0^{cdef}	12.5±1.2^{a}	12.6±1.1^{a}
5	16.7±1.1^{abc}	16.8±2.4^{abc}	18.4±2.9^{abc}	17.0±2.2^{abc}	15.5±1.9^{ab}	15.7±2.2^{ab}	15.5±0.7^{bcde}	15.5±1.4^{bcdef}	13.2±1.3^{a}	11.9±0.9^{a}
7	17.2±2.3^{abc}	17.9±2.9^{abc}	17.4±1.6^{abc}	18.2±3.3^{abc}	16.04±2.5^{ab}	17.4±2.1^{a}	17.7±1.7 ^{ab}	15.8±14^{abcde}	13.3±1.3^{a}	13.4±1.0^{a}
9	17.3±1.3^{abc}	16.7±1.6^{abc}	18.3±2.0^{abc}	17.9±1.0^{abc}	N/A	17.9±1.6^{a}	N/A	14.7±1.7^{def}	12.8±0.2^{a}	12.7±1.3^{a}
11	19.2±1.1^{ab}	18.0±3.7^{abc}	19.3±1.3^{ab}	18.8±3.3^{ab}	-	15.9±2.5^{ab}	-	17.4±1.8^{abc}	13.2±1.9^{a}	13.8±1.2^{a}
13	18.4±2.3^{ab}	17.7±2.1^{abc}	19.8±2.7^{ab}	17.9±1.8^{abc}	-	15.9±3.7^{ab}	-	17.0±1.2^{abcd}	13.9±1.0^{a}	13.1±1.1^{a}
15	19.4±2.5^{a}	19.5±2.8^{a}	20.8±0.7^{a}	20.7±2.1^{a}	-	N/A	-	18.1±1.5^{a}	N/A	13.8±1.2^{a}

Values are means of three replicates ± standard errors of the means. Mean values in the same column and row with similar superscript letters are not significantly different ($p < 0.05$). NA – Not Applicable.

4.2.1.2 Pulp firmness

Pulp firmness is one of the key indicators of postharvest quality of mature green bananas given that fruits soften as they ripen during storage (Manigo and Limbaga, 2019; Morris et al., 2014). Fruits treated with 1-MCP have been found to have firmer pulp than untreated fruits according to previous studies (Manigo and Limbaga, 2019). In the present study, there were no significant differences ($P<0.05$) between pulp hardness of treated and control banana samples of the same variety (Table 4.2). Among varieties, there was no significant difference ($P<0.05$) in pulp firmness. In general, there was a general small decrease in pulp firmness (not significantly different ($p<0.05$)) across varieties in both treated and control bananas over the storage period. Saeed and Abu-Goukh, (2013) reported a progressive decline in flesh firmness during storage of banana fruits. The pulp firmness at the harvest time was not significantly different from the firmness at the end of green life. Moreover, untreated NARITA 16 on day 11 had the highest pulp texture of 5.45N. These results are in agreement with Harris et al. (2000) who reported that at a concentration of 300nl l^{-1}, ripening was delayed yet there was no observable difference between treated and untreated fruits with regards to firmness.

It can be noted that even though the statistical analysis showed no significant differences in the 1-MCP treated and control bananas in terms of pulp firmness, physical differences were observed. No numerical data was obtained from soft bananas because the texture analyser used during the experiments measured bananas within the normal range of hardness of green cooking bananas and read N/A when the banana softens.

Therefore, 1-MCP treatment delayed softening of the banana pulp especially the hybrids during storage by three to four days.

Table 4.2: Changes in pulp firmness (N) among 1-MCP treated bananas during storage

STORAGE DAYS	VARIETIES									
	MPOLOGOMA		NFUUKA		NARITA 2		NARITA 4		NARITA 16	
	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm
0	4.3±0.5^{a}	4.3±0.5^{a}	4.6±0.4^{a}	4.6±0.4^{a}	3.7±0.4^{a}	3.7±0.4^{a}	4.3±0.4^{a}	4.3±0.4^{a}	4.8±0.5^{a}	4.8±0.5^{a}
1	3.8±0.7^{ab}	4.2±0.9^{b}	4.2±0.8^{ab}	4.3±0.7^{ab}	3.6±0.8^{ab}	3.3±1.0^{ab}	3.8±0.9^{a}	4.0±0.7^{a}	4.1±1.0^{a}	4.2±0.9^{a}
3	3.8±0.3^{ab}	3.9±0.7^{ab}	4.0±0.3^{ab}	4.1±0.5^{ab}	3.4±0.6^{ab}	3.3±0.6^{ab}	3.74±0.6^{a}	4.1±0.7^{a}	4.2±0.6^{a}	4.0±0.9^{a}
5	3.9±0.4^{ab}	3.8±0.5^{ab}	3.5±0.8^{b}	4.1±0.5^{ab}	2.6±1.6^{ab}	3.2±0.9^{ab}	3.99±0.6^{a}	4.0±0.6^{a}	3.4±1.3^{a}	3.8±1.0^{a}
7	3.9±0.6^{ab}	4.2±0.3^{ab}	3.8±0.6^{ab}	4.2±0.4^{ab}	3.2±1.5^{ab}	2.3.0±1.0^{ab}	3.87±0.4^{a}	4.5±1.2^{a}	3.4±1.5^{a}	4.0±1.2^{a}
9	4.0±0.5^{ab}	4.0±0.7^{ab}	3.4±1.0^{b}	3.9±0.6^{ab}	N/A	2.9±1.2^{ab}	N/A	4.0±0.5^{a}	4.2±0.3^{a}	3.5±1.3^{a}
11	3.8±0.7^{ab}	4.5±0.6^{a}	3.7±0.8^{ab}	4.4±0.7^{ab}	-	1.2.0±1.6^{b}	-	3.7±1.5^{a}	5.5±0.4^{a}	4.2±2.1^{a}
13	3.4±0.6^{b}	4.1±0.5^{ab}	3.8±0.9^{ab}	3.9±0.8^{ab}	-	3.0±0.4^{ab}	-	4.0±0.5^{a}	4.5±1.5^{a}	4.9±0.8^{a}
15	3.8±0.4^{ab}	4.1±0.6^{ab}	3.9±0.9^{ab}	3.±0.6^{ab}	-	N/A	-	4.1±0.3^{a}	N/A	4.4±0.3^{a}

Values are means of three replicates ± standard errors of the means. Mean values in the same column and row with similar superscript letters are not significantly different ($p < 0.05$). NA – Not Applicable.

4.2.2 Chemical attributes

4.2.2.1 Dry matter content

Dry matter content of the bananas ranged from 24.29 to 34.00% (Table 4.3). In the local cultivars, dry matter content ranged from 24.39% to 30.24% and from 26.21% to 34.00% in the hybrid cultivars. The lowest dry matter values were recorded in *Mpologoma* cultivar (24.29%) while the highest were recorded in NARITA 4 (34.00%). However, there were no significant differences between the dry matter content of 1-MCP treated and the control bananas which could indicate that the 1-MCP treatment has no significant effect ($P<0.05$) on the dry matter content of cooking bananas. The results also show a general increase in dry matter content of the bananas which can probably be explained by the possible loss of moisture during storage. The results of dry matter content observed in this study are similar to those reported in literature. Dotto et al. (2019) and Annor et al. (2016) reported dry matter content of indigenous and hybrid cooking bananas from Ghana to be between 26% and 34%. High dry matter content has been linked to better eating quality of cooking bananas, freshness and a longer green life of cooking bananas (Annor et al., 2016). Dufour et al. (2009) found dry matter content to be lower in local cooking bananas (32.0%) than in hybrid cooking bananas (34.2%). This attempts to explain why the highest values were recorded in NARITA 4, a hybrid cooking variety and the lowest in *Mpologoma*, a local cooking cultivar showing that dry matter content can vary depending on the cultivar. There was no significant difference ($P<0.05$) in dry matter content between 1-MCP treated and control bananas possibly because the experiment was terminated at end of green life and dry matter could not be measured further.

In summary, 1- MCP treatment had no effect on the dry matter of the indigenous and hybrid bananas.

Table 4.3: Changes in dry matter (%) among 1-MCP treated bananas during storage

DAY	VARIETIES									
	MPOLOGOMA		NFUUKA		NARITA 2		NARITA 4		NARITA 16	
	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm
0	24.3±2.3^{a}	24.3±2.3^{a}	25.4±2.1^{a}	25.4±2.1^{a}	27.2±2.9^{a}	27.2±2.9^{a}	30.8±2.0^{ab}	30.8±2.0^{ab}	27.3±2.1^{b}	27.3±2.1^{b}
1	26.3±2.0^{a}	24.3±1.7^{a}	26.1±2.1^{a}	26.2±1.7^{a}	28.0±2.7^{a}	27.0±2.8^{a}	29.8±4.5^{b}	31.1±1.6^{ab}	29.4±1.7^{ab}	28.9±1.3^{ab}
3	25.3±2.4^{a}	25.1±2.4^{a}	26.9±3.7^{a}	27.3±1.5^{a}	28.3±3.6^{a}	27.5±3.1^{a}	32.6±1.9^{ab}	32.3±1.6^{ab}	29.6±2.1^{ab}	30.3±1.8^{ab}
5	25.3±2.3^{a}	25.5±2.2^{a}	26.2±2.6^{a}	26.3±2.2^{a}	27.8±2.8^{a}	28.1±2.6^{a}	31.9±1.7^{ab}	32.1±2.3^{ab}	28.4±2.9^{ab}	28.9±1.8^{ab}
7	25.8±1.9^{a}	25.3±1.5^{a}	26.6±2.8^{a}	26.4±2.3^{a}	26.2±4.3^{a}	27.2±3.4^{a}	34.0±0.5^{a}	31.8±1.9^{ab}	29.9±1.3^{ab}	30.64±2.3^{ab}
9	24.9±2.9^{a}	23.8±2.0^{a}	26.6±1.6^{a}	25.9±1.7^{a}	-	29.2±1.8^{a}	-	32.1±1.7^{ab}	32.6±0.4^{a}	29.1±2.2^{ab}
11	26.6±0.7^{a}	27.1±1.5^{a}	27.1±1.3^{a}	26.8±3.0^{a}	-	27.1±3.1^{a}	-	31.2±2.5^{ab}	30.6±0.0^{ab}	30.2±2.3^{ab}
13	26.1±1.6^{a}	26.5±1.7^{a}	26.9±2.0^{a}	26.0±1.5^{a}	-	26.9±2.9^{a}	-	30.8±1.6^{ab}	31.3±0.0^{ab}	31.9±1.3^{ab}
15	26.8±1.4^{a}	25.6±2.2^{a}	30.2±0.2^{a}	27.1±2.5^{a}	-	-	-	33.9±1.6^{a}	-	32.6±0.5^{a}

Values are means of three replicates ± standard errors of the means. Mean values in the same column and row with similar superscript letters are not significantly different ($p < 0.05$).

4.2.2.2 Titratable acidity

Changes in Titratable acidity (TA) of banana fruit during storage is presented in Table 4.4. The attribute generally varied according to variety and treatment and was between 0.07% and 0.12% (Table 4.4). The highest TSS values were obtained in NARITA 16 followed by NARITA 2. However, there was no significant difference ($P<0.05$) in the TA of 1-MCP treated bananas and the controls for all banana varieties.

Various studies show titratable acidity to often increase at the start of ripening due to breaking down of components like aldehydes and ketones into acids, and decrease at later stages due to conversion of starch to sugars where organic acids are utilised (González-agüero et al., 2016). Probably, the differences were not obtained because the experiments were stopped at the end of green life of the bananas meaning that results for ripened bananas were not recorded. The TA values, however, were quite similar to those obtained by Rahman et al., (2014) in the first 15 days of storage. Notable variations in the TA of indigenous and hybrid varieties were present. Notably, titratable acidity has been revealed to vary within banana cultivars (Sakyi-Dawson et al., 2008).

In summary, 1-MCP had no effect on the TA of the indigenous and hybrid bananas during the green life storage period.

Table 4.4: Changes in titratable acidity (%) among 1-MCP treated bananas during storage

STORAGE DAYS	VARIETIES									
	MPOLOGOMA		NFUUKA		NARITA 2		NARITA 4		NARITA 16	
	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm
0	0.10^{a}	0.09^{a}	0.10^{a}	0.09^{a}	0.09^{b}	0.09^{b}	0.09^{ab}	0.09^{ab}	0.12^{b}	0.12^{b}
1	0.09^{a}	0.09^{a}	0.10^{a}	0.10^{a}	0.11^{b}	0.11^{b}	0.11^{a}	0.10^{ab}	0.11^{b}	0.08^{b}
3	0.10^{a}	0.10^{a}	0.09^{a}	0.08^{a}	0.11^{b}	0.08^{b}	0.08^{ab}	0.08^{ab}	0.11^{b}	0.11^{b}
5	0.09^{a}	0.09^{a}	0.11^{a}	0.09^{a}	0.13^{b}	0.11^{b}	0.07^{b}	0.07^{b}	0.12^{b}	0.10^{b}
7	0.11^{a}	0.11^{a}	0.08^{a}	0.08^{a}	0.11^{b}	0.10^{b}	0.08^{ab}	0.08^{ab}	0.11^{b}	0.09^{b}
9	0.12^{a}	0.12^{a}	0.10^{a}	0.09^{a}	-	0.09^{b}	-	0.09^{ab}	0.10^{b}	0.11^{b}
11	0.08^{a}	0.08^{a}	0.07^{a}	0.07^{a}	-	0.10^{b}	-	0.09^{ab}	0.16^{b}	0.07^{b}
13	0.10^{a}	0.10^{a}	0.07^{a}	0.08^{a}	-	0.12^{b}	-	0.08^{ab}	0.13^{b}	0.11^{b}
15	0.09^{a}	0.09^{a}	0.08^{a}	0.10^{a}	-		-	0.11^{a}	-	0.10^{b}

Values are means of three replicates ± standard errors of the means. Mean values in the same column and row with the same superscript letters are not significantly different ($p < 0.05$).

4.2.2.3 Total Soluble Solids (TSS)

Total soluble solid content increased gradually in both treated and non- treated fruits over the 15-day storage period (Table 4.5). However, the increase was significantly higher in control than in 1-MCP treated bananas. Across all varieties, the highest TSS values were recorded in controls between the 7th and 15th days of storage. Overall, the highest TSS (5.14%) was recorded in the control of NARITA 16 at the 7th day followed by the same (4.66%) at the 11th day and NARITA 2 control (3.94%) at the 5th day of storage. These results show that accumulation of sugar was delayed by 1-MCP treatment.

Significant differences ($P<0.05$) observed in the TSS content of the control and 1-MCP treated bananas were observed mainly at the end of green life of the control bananas. For example, NARITA 2 on day 7; *Mpologoma* on day 15; *Nfuuka* on day 3, 11 and 13. The results of this study corresponded with the findings of Rahman et al., (2014), and Xu et al. (2014), who reported a delay in the accumulation of TSS in bananas due to 1-MCP treatment. The same has been reported about other climacteric fruits like tomatoes (Xu et al., 2016). These results imply that treatment of bananas with 1-MCP delayed the accumulation of sugars (TSS) which can be explained by reduced respiration and ethylene production (Hu et al., 2016). Taking together, accumulation of TA and TSS after 1-MCP treatment may suggest a putative change on flavor properties of cooked *Matooke* mainly based on the TSS component (Khandaker et al., 2018).

In summary, 1-MCP treatment slowed down increase in TSS content of indigenous and hybrid bananas.

Table 4.5: Changes in TSS (%) content among 1-MCP treated bananas during storage

STORAGE DAYS	VARIETIES									
	MPOLOGOMA		NFUUKA		NARITA 2		NARITA 4		NARITA 16	
	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm
0	0.20^{gh}	0.20^{gh}	0.18^{e}	0.18^{e}	0.28^{d}	0.28^{d}	0.32^{e}	0.32^{e}	1.26^{cd}	1.26^{cd}
1	1.36^{defgh}	0.08^{h}	0.54^{e}	0.18^{e}	0.62^{d}	0.28^{d}	0.44^{e}	0.72^{de}	1.68^{bcd}	1.18^{cd}
3	1.10^{cdefg}	0.40^{fgh}	0.68^{cd}	0.60^{e}	1.34^{cd}	0.84^{d}	1.40^{abcde}	0.86^{bcde}	2.00^{bcd}	3.42^{cd}
5	1.40^{bcde}	0.50^{efgh}	0.88^{cd}	1.00^{de}	3.94^{a}	1.44^{cd}	1.84^{abcd}	0.76^{cde}	3.40^{abcd}	0.90^{d}
7	2.14^{b}	1.22^{bcdef}	1.76^{cd}	1.62^{cd}	3.74^{ab}	1.82^{cd}	1.86^{abc}	1.76^{abcd}	5.14^{a}	2.10^{abcd}
9	2.10^{b}	2.14^{b}	2.96^{ab}	1.68^{cd}	-	2.96^{abc}	-	1.90^{ab}	2.44^{abcd}	2.74^{abcd}
11	2.06^{b}	1.60^{bc}	2.82^{ab}	0.72^{cd}	-	3.32^{abc}	-	1.76^{abcd}	4.66^{ab}	2.72^{abcd}
13	2.06^{b}	1.54^{bcd}	3.42^{a}	1.88^{c}	-	1.94^{bcd}	-	1.64^{abcd}	4.22^{abc}	0.92^{d}
15	3.22^{a}	0.32^{bcde}	2.12^{bc}	1.96^{c}	-	-	-	2.30^{a}		3.12^{abcd}

Values are means of three replicates ± standard errors of the means. Mean values in the same column and row with similar superscript letters are not significantly different ($p < 0.05$).

4.2.2.4 Principal component analysis of gas production and consumption textural and chemical attributes

Principal component analysis (Figure 4.4) revealed that the first two principal components explained 53.66% of the total variability with F1 and F2 explaining 36.48% and 17.18% respectively. Variations in O_2, CO_2, C_2H_4 and TSS are mostly explained in F1 while in F2, peel texture was the most discriminated variable. The *Matooke* samples were distributed into four quadrants based on their similarities (Chawla et al., 2014). The biplots of the PCA revealed the characteristic attributes describing banana samples the most. Mpologoma and Nfuuka were mainly located in upper left quadrant close to the peel texture implying that they had high values of the parameter, while the NARITAs were more in the lower right and left quadrants close to dry matter and pulp texture. However, most of the sample variables were close to the centre meaning they played a negligible roll in the variations observed. Samples N16-7c, and N4-7c exhibited high TSS, CO_2, C_2H_4 (positive correlation) as O_2 was being used up (negative correlation). Treated samples from NARITA 4 and 16 were characterised by titratable acidity towards the end of the storage period that is day nine to 15. The control samples of all varieties understudy at the end of their green life were characterised by TSS, carbon dioxide production and ethylene production at the end of their green life. These findings indicate that Ethylene production, respiration and total soluble solids are important variables in explaining the effect of 1-methylcyclopropene on mature green Ugandan indigenous and hybrid cooking bananas. The ethylene production, respiration rate and total soluble solids were related significantly showing that they are important parameters in explaining the effect of 1-methylcyclopropene on mature green Ugandan indigenous and hybrid bananas. The close proximity between TSS, Ethylene, and CO_2 showed these three parameters to increase concurrently during the storage period, with increased O_2 consumption. The results are in agreement with Narayanapurapu., 2012 who reported that the breakdown of complex carbohydrates into soluble solids is due to the respiration and ripening of fruits. During respiration, the complex carbohydrates are metabolised into simple sugars leading to an increase in TSS content accompanied with O_2 utilisation and release of CO_2 (Narayanapurapu., 2012).

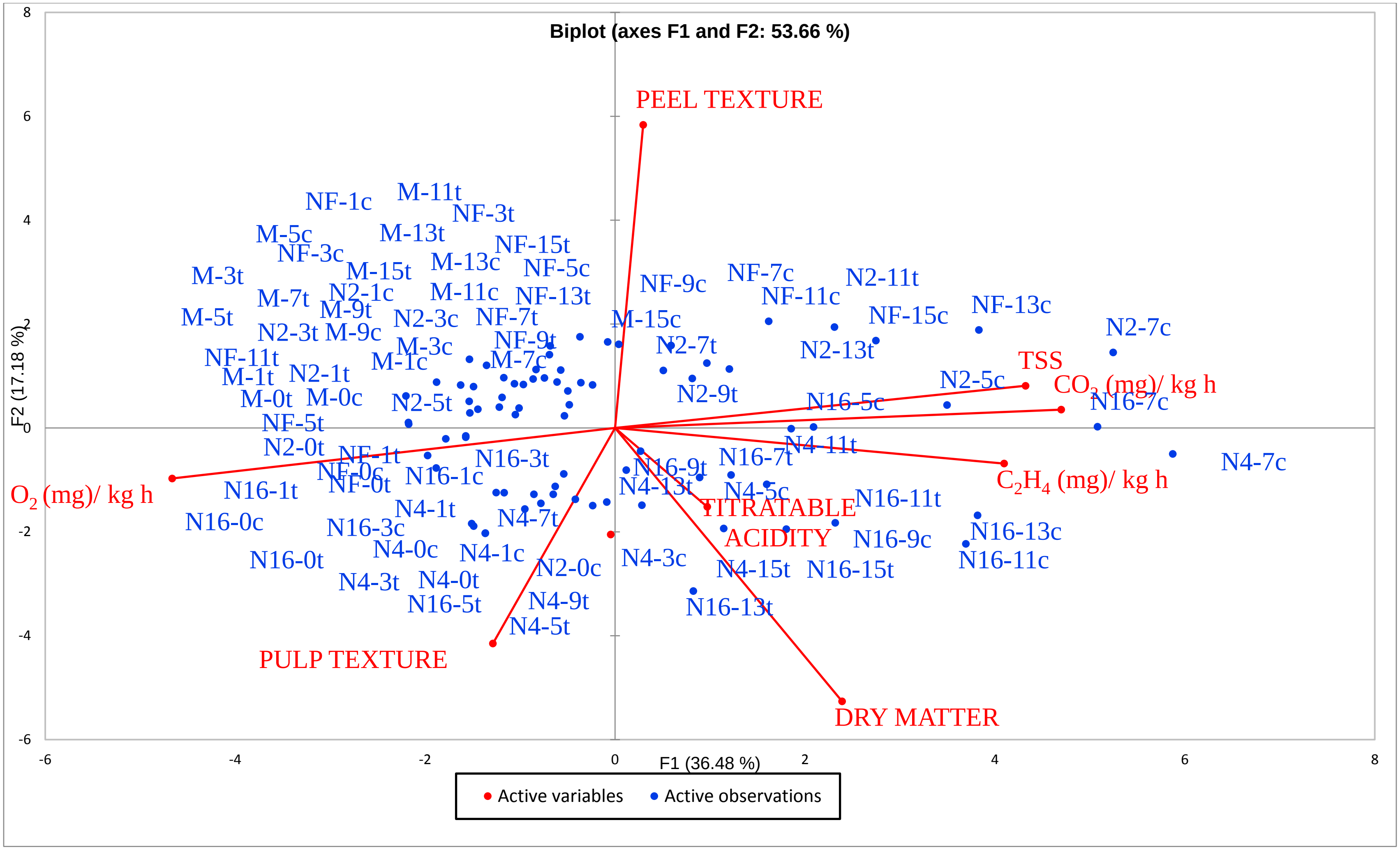

Figure 4.4: Principal component analysis results for physicochemical attributes.

*Biplots of variables and observations of the first two principal components. *F1: the first principal component, *F2: the second principal component. Sample code: *M=Mpologoma, *NF= Nfuuka, *N2= NARITA 2, *N16= NARITA 16, *N4 = NARITA 4; Days: *0 = day 0; *1 = day 1; *3 = day 3; *5 = day 5; *7 = day 7; *9 = day 9; *11 = day 11; *13 = day 13; *15 = day 15; *c = control; *t = treated

4.2.3 Sensory attributes

4.2.3.1 Sensory Evaluation Scores

1-MCP treatment has been found to maintain the sensory profiles of some climacteric fruits such as pears (Escribano et al., 2016), and improve sensory quality in terms of flavor (Boquete et al., 2004). In this study, no significant differences ($p<0.05$) in sensory properties were observed between 1-MCP treated and non- treated bananas (Table 4.6). However, in some cases significant differences ($P<0.05$) were observed between indigenous and hybrid banana varieties. For example, colour related characteristics including 'yellowness', and 'homogeneity', differed significantly ($p<0.05$) between indigenous and hybrid varieties, the former having higher yellow colour and uniformity scores (8 - 9) than the latter (5 - 7). In this case, the sensory scores were influenced by variety rather than treatment. A similar pattern was observed in the smoothness scores. The rest of the sensory characteristics including sweetness did not differ significantly among the different varieties under study. Escribano et al. (2016) reported that the sensory profiles of 1-MCP treated pears were more stable than the sensory profiles of ethylene treated fruit because panellists gave high scores to 1-MCP treated fruit for desirable traits like sweetness, juiciness, fruity taste and pear aroma.

In summary, 1-MCP treatment had no effect on the sensory properties of the indigenous and hybrid bananas.

Table 4.6 a: Scores of sensory characteristics of the steamed matooke product

	Yellow	Homogeneity of colour	Firmness	Moisture	Smoothness	Hardness	Moldability	Stickiness	Sweetness	Astringency	Sourness	Matooke aroma
M-0c	8.24^{abcdef}	8.30^{abcdefg}	2.15^{bcdefg}	6.77^{abcdefgh}	8.18^{abcde}	2.00^{efgh}	8.18^{abcdefg}	4.25^{abc}	0.79^{cd}	0.65^{a}	0.65^{a}	7.76^{abcdefg}
M-1c	9.44^{a}	9.38^{a}	1.49^{fg}	7.84^{abc}	9.03^{a}	1.70^{fgh}	8.87^{abcdef}	5.55^{ab}	1.42^{bcd}	0.36^{a}	0.61^{a}	8.94^{a}
M-1t	8.87^{ab}	8.72^{abcdef}	1.35^{g}	7.84^{abc}	8.93^{ab}	1.49^{gh}	8.72^{abcdef}	4.91^{abc}	2.15^{abcd}	0.43^{a}	0.79^{a}	8.29^{abcde}
M-4c	8.72^{abc}	9.09^{abc}	1.78^{defg}	7.47^{abcdef}	8.59^{ab}	1.92^{efgh}	9.16^{a}	5.00^{abc}	2.73^{abc}	0.09^{a}	0.28^{a}	8.36^{abcde}
M-4t	9.23^{a}	8.94^{abcd}	1.64^{fg}	7.24^{abcdef}	8.81^{ab}	1.70^{fgh}	9.23^{a}	3.53^{abc}	1.79^{abcd}	0.36^{a}	0.21^{a}	8.58^{abc}
M-8c	8.67^{abc}	8.68^{abcdef}	1.74^{defg}	7.73^{abcd}	8.86^{ab}	1.82^{fgh}	8.89^{abcdef}	5.63^{ab}	1.70^{abcd}	0.50^{a}	0.45^{a}	8.50^{abcd}
M-8t	9.34^{a}	9.27^{ab}	1.49^{fg}	8.37^{a}	8.78^{ab}	1.40^{h}	8.98^{abc}	5.33^{abc}	2.08^{abcd}	0.25^{a}	0.36^{a}	8.42^{abcde}
M-11t	9.10^{a}	8.86^{abcd}	1.52^{fg}	7.66^{abcde}	8.67^{ab}	1.63^{fgh}	8.95^{abcd}	5.02^{abc}	2.13^{abcd}	0.06^{a}	0.17^{a}	8.71^{ab}
M-13t	9.08^{a}	8.74^{abcde}	1.79^{cdefg}	7.97^{ab}	8.69^{ab}	1.92^{efgh}	8.94^{abcd}	3.69^{abc}	2.28^{abcd}	0.20^{a}	0.33^{a}	8.67^{abc}
N2-0c	6.40^{ijk}	7.30^{efghij}	2.25^{abcdefg}	6.58^{abcdefghi}	7.13^{abcdefg}	2.42^{cdefgh}	7.76^{abcdefg}	4.64^{abc}	0.52^{d}	1.01^{a}	0.50^{a}	6.82^{efg}
N2-1c	7.25^{bcdefghij}	7.18^{fghij}	2.43^{abcdefg}	5.99^{bcdefghi}	6.49^{cdefg}	3.00^{abcdefgh}	7.78^{abcdefg}	4.11^{abc}	1.35^{cd}	0.72^{a}	0.72^{a}	7.85^{abcdefg}
N2-1t	6.80^{fghijk}	6.87^{ghij}	2.09^{cdefg}	7.00^{abcdefg}	7.20^{abcdefg}	2.20^{defgh}	7.49^{bcdefg}	5.56^{ab}	0.84^{cd}	0.50^{a}	0.65^{a}	7.33^{abcdefg}
N2-4c	6.72^{fghijk}	6.70^{hij}	2.65^{abcdefg}	6.49^{abcdefghi}	6.56^{cdefg}	2.77^{bcdefgh}	7.78^{abcdefg}	5.16^{abc}	1.47^{bcd}	0.31^{a}	0.23^{a}	6.80^{efg}
N2-4t	6.50^{ghijk}	6.80^{ghij}	2.57^{abcdefg}	6.02^{bcdefghi}	6.17^{fg}	3.53^{abcdefg}	6.88^{g}	4.91^{abc}	1.39^{cd}	0.61^{a}	0.36^{a}	6.64^{fg}
N2-8c	6.276^{ijk}	6.29^{j}	2.29^{abcdefg}	6.67^{abcdefgh}	6.40^{defg}	2.86^{abcdefgh}	8.14^{abcdefg}	4.41^{abc}	0.99^{cd}	0.18^{a}	0.57^{a}	6.85^{efg}
N2-8t	6.94^{defghij}	7.47^{defghij}	1.74^{defg}	6.87^{abcdefgh}	7.07^{bcdefg}	2.16^{efgh}	8.34^{abcdefg}	6.36^{a}	1.67^{abcd}	0.63^{a}	0.59^{a}	6.91^{defg}
N2-11t	5.27^{k}	6.44^{ij}	2.86^{abcdefg}	4.77^{hi}	5.52^{g}	3.58^{abcdef}	7.27^{efg}	3.77^{abc}	1.42^{bcd}	0.18^{a}	-0.01^{a}	6.56^{g}

Table 4.6 b: Scores of sensory characteristics of the steamed matooke product

	Yellow	Homogeneity of colour	Firmness	Moisture	Smoothness	Hardness	Moldability	Stickiness	Sweetness	Astringency	Sourness	Matooke aroma
N4-0c	6.46^{hijk}	$7.52^{defghij}$	4.134^{ab}	$5.77^{cdefghi}$	6.39^{efg}	4.50^{ab}	$7.58^{abcdefg}$	2.22^{c}	0.58^{d}	0.34^{a}	0.46^{a}	$7.29^{abcdefg}$
N4-1c	$7.28^{bcdefghij}$	$7.78^{bcdefghij}$	3.73^{abcd}	5.70^{defghi}	6.40^{defg}	4.87^{a}	7.34^{cdefg}	3.17^{abc}	0.84^{cd}	0.07^{a}	0.65^{a}	7.21^{bcdefg}
N4-1t	$7.21^{cdefghij}$	$7.57^{cdefghij}$	$3.08^{abcdefg}$	$5.917^{bcdefghi}$	7.06^{bcdefg}	3.95^{abcde}	$7.92^{abcdefg}$	4.18^{abc}	1.13^{cd}	0.29^{a}	0.61^{a}	$7.71^{abcdefg}$
N4-4	5.91^{jk}	6.77^{ghij}	3.66^{abcde}	4.92^{ghi}	5.49^{g}	4.31^{abc}	7.25^{fg}	4.33^{abc}	2.52^{abcd}	0.14^{a}	0.07^{a}	7.03^{cdefg}
N4-4t	$6.85^{efghijk}$	$7.49^{defghij}$	3.80^{abc}	4.55^{i}	6.16^{fg}	4.57^{ab}	7.31^{defg}	3.23^{abc}	1.28^{cd}	0.21^{a}	0.01^{a}	$7.35^{abcdefg}$
N4-8t	6.49^{ghijk}	$7.64^{cdefghij}$	4.19^{a}	5.45^{fghi}	6.25^{fg}	4.23^{abcd}	7.48^{bcdefg}	2.07^{c}	3.46^{ab}	0.29^{a}	0.21^{a}	$7.35^{abcdefg}$
N4-11t	6.52^{ghijk}	$7.52^{defghij}$	3.47^{abcdef}	$5.75^{cdefghi}$	6.20^{fg}	3.90^{abcde}	$7.57^{abcdefg}$	3.40^{abc}	2.49^{abcd}	0.17^{a}	0.11^{a}	$7.63^{abcdefg}$
NF-0c	$7.88^{abcdefghi}$	$8.18^{abcdefgh}$	3.41^{abcdef}	5.61^{efghi}	7.71^{abcdef}	$2.50^{bcdefgh}$	$8.18^{abcdefg}$	2.89^{bc}	0.63^{d}	0.47^{a}	0.65^{a}	8.24^{abcdef}
NF-1c	8.29^{abcdef}	8.58^{abcdef}	2.14^{bcdefg}	7.55^{abcdef}	$8.5s3^{ab}$	$2.57^{bcdefgh}$	8.87^{abcdef}	4.09^{abc}	0.99^{cd}	0.21^{a}	0.43^{a}	8.50^{abcd}
NF-1t	8.65^{abc}	8.81^{abcde}	1.71^{efg}	7.55^{abcdef}	8.59^{ab}	2.14^{efgh}	8.87^{abcdef}	4.55^{abc}	1.13^{cd}	0.41^{a}	0.69^{a}	8.65^{abc}
NF-4c	$8.07^{abcdefgh}$	$8.29^{abcdefg}$	$2.50^{abcdefg}$	$6.77^{abcdefgh}$	7.94^{abcdef}	$3.00^{abcdefgh}$	$8.21^{abcdefg}$	4.65^{abc}	2.22^{abcd}	0.50^{a}	0.21^{a}	8.36^{abcde}
NF-4t	8.43^{abcde}	8.51^{abcdef}	$2.31^{abcdefg}$	5.61^{efghi}	8.08^{abcdef}	$3.44^{abcdefgh}$	$8.16^{abcdefg}$	4.09^{abc}	1.64^{bcd}	0.29^{a}	0.01^{a}	8.22^{abcdef}
NF-8c	8.67^{abc}	8.76^{abcde}	1.58^{fg}	7.64^{abcde}	8.69^{ab}	1.74^{fgh}	8.93^{abcde}	6.38^{a}	2.43^{abcd}	0.36^{a}	0.25^{a}	8.59^{abc}
NF-8t	$8.116^{abcdefg}$	$7.97^{abcdefghi}$	1.69^{efg}	$6.76^{abcdefgh}$	8.36^{abc}	2.17^{defgh}	$8.36^{abcdefg}$	2.23^{bc}	2.41^{abcd}	0.29^{a}	0.24^{a}	8.39^{abcde}
NF-11c	8.20^{abcdef}	$8.10^{abcdefgh}$	1.90^{cdefg}	7.33^{abcdef}	8.53^{ab}	2.30^{cdefgh}	8.81^{abcdef}	4.44^{abc}	3.70^{a}	0.20^{a}	0.20^{a}	$8.10^{abcdefg}$
NF-11t	8.57^{abcd}	8.51^{abcdef}	1.74^{defg}	7.27^{abcdef}	8.33^{abcd}	2.18^{defgh}	9.08^{ab}	3.71^{abc}	2.71^{abc}	0.27^{a}	0.19^{a}	8.44^{abcde}
NF-13t	8.51^{abcd}	$8.25^{abcdefg}$	1.81^{cdefg}	7.76^{abcd}	8.52^{ab}	1.80^{fgh}	8.82^{abcdef}	4.12^{abc}	1.85^{abcd}	0.12^{a}	0.19^{a}	8.50^{abcd}

*****Values are means of three replicates. Values in columns and rows with similar superscript letters are not significantly different ($p < 0.05$). Scale: 0.00 = Absence of a characteristic; 10.00 = Extreme perception of a characteristic. Sample code: *M = Mpologoma; *NF = Nfuuka; *N2 = NARITA 2; *N4 = NARITA 4; *0 = day 0; *1 = day 1; *4 = day 4; *8 = day 8; *11 = day 11; *13 = day 13; *c = control; *t = treated

4.2.3.2 Principal Component Analysis of Sensory Attributes

There were six main components offered by PCA (Figure 4.5). With F1 and F2 accounting for 83.73% and 11.70%, respectively, of the variance, the first two PCs accounted for 95.42% of the overall variance. Moldability, smoothness, moisture, and yellow color aided in explaining the variation in F1. Due to their proximity, the attributes were shown to be correlated. The indigenous banana types appeared to be more linked with characteristics including smoothness, homogeneity of color, moldability, stickiness, sweetness, and yellow color. However, hardness, sourness, and astringency seem to be associated with hybrid varieties. Regarding descriptive sensory evaluation, the PCA still shows no obvious association between the treated and untreated banana samples.

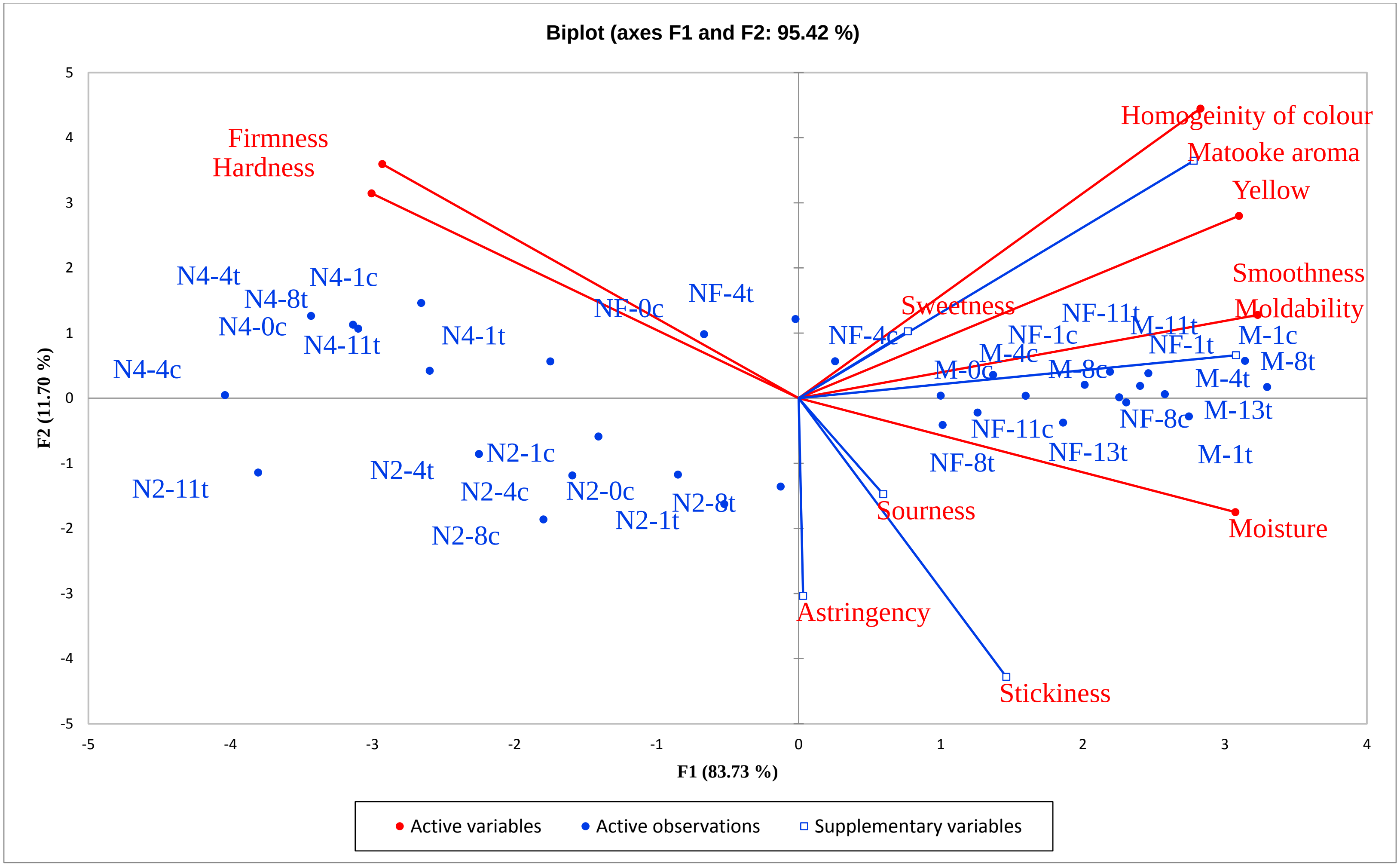

Figure 4.5: Principal component analysis results for sensory characterisation by descriptive analysis.

*Biplots of variables and observations of the first two principal components. *F1: the first principal component; *F2: the second principal component. *M = Mpologoma; *NF = Nfuuka; *N2 = NARITA 2; *N4 = NARITA 4; *0 = day 0; *1 = day 1; *4 = day 4; *8 = day 8; *11 = day 11; *13 = day 13; *c = control; *t = treated

4.3 Effect of 1-MCP treatment on green life

Green life study results are shown in Table 4.7. According to the results across the rows, 1-MCP treatment significantly ($p<0.05$) delayed ripening of the banana fingers which were kept at ambient temperature. The duration of the green life was varietal dependent. In general, indigenous bananas exhibited a longer green life than the hybrids regardless of whether they were treated or not. The action of 1-MCP was more pronounced in the treated *Mpologoma* which stayed green for 18 days and was significantly longer ($P<0.05$) than its control (which lasted for 13 days). This was followed closely by *Nfuuka* that had a green life of 16 days with treatment and 10 days without. Treated hybrid varieties lasted for a significantly shorter period of between 12 to 13 days. The corresponding controls took between 5 and 7 days to ripen at ambient condition with average of 6 days.

Table 4.7: The average green life expressed in days of control and 1-MCP treated bananas

VARIETY	CONTROL	1-MCP
Mpologoma	13.86 ± 2.10^{a}	18.86 ± 2.10^{b}
Nfuuka	10.71 ± 2.49^{a}	16.86 ± 1.81^{b}
NARITA 4	6.14 ± 3.00^{a}	13.57 ± 2.06^{b}
NARITA 2	5.86 ± 2.10^{a}	12.14 ± 2.36^{b}
NARITA 16	7.29 ± 3.45^{a}	12.14 ± 2.36^{b}

Values are means of three replicates ± standard errors of the means. Mean values in the same row with different superscript letters are significantly different ($p < 0.05$).

These results agree with Nalunga et al. (2015) who reported that cooking bananas ripen within 4 to 5 days. They also correspond with Mudiyanselage et al., (2021) and Rahman et al., (2014) who reported that 1-MCP treatment delays the ripening process of green bananas. Delayed ripening due to 1-MCP might have happened because 1-MCP competes more favorably for the ethylene receptor sites where it remains locked thereby preventing the binding of ethylene and hence obstructing the chemical reaction (Merisko and Liversidge, 2011). Therefore, 1-MCP treatment is able to regulate the stay-green disorder of banana peels thereby maintaining the green colour (Zhu et al., 2020). In other climacteric fruits such as pears, 1-MCP has been found to delay postharvest ripening hence improving the storage potential (Villalobos-acuna et al., 2011). According to Mudiyanselage et al. (2021), the outcome of 1-MCP treatment varies with type of commodity which explains why the different varieties responded differently to the treatment.

In summary, 1-MCP treatment delayed ripening of indigenous and hybrid bananas hence increasing their postharvest green life

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

1-MCP reduced the rate of ethylene production in the treated bananas. It also decreased respiration rates in both indigenous and hybrid cooking bananas.

1-MCP delayed softening of the banana pulp and peel during storage by three to four days. It also slowed down the increase in TSS of indigenous and hybrid bananas. 1-MCP had no effect on the sensory properties of the indigenous and hybrid cooking bananas during green life storage.

1-MCP delayed ripening of indigenous and hybrid bananas hence increasing their postharvest green life.

In conclusion, 1-MCP could be used to delay the physiological activities thus extending the postharvest green life of Ugandan indigenous and hybrid cooking bananas.

5.2 Recommendations

1. According to this study, the action of 1-MCP varied with cultivar. Therefore, there's need to conduct a study among the various Ugandan indigenous and hybrid cooking banana cultivars to ascertain the most responsive.

2. A study should be carried out with varied concentrations of 1-MCP to determine if there are other concentrations that can extend the green life beyond the one that has been determined in this study.

APPENDIX

ANNEX 1: Changes in CO_2 production among 1-MCP treated bananas during storage

STORAGE DAYS	VARIETIES MPOLOGOMA		NFUUKA		NARITA 2		NARITA 4		NARITA 16	
	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm
0	60.23^{bc}	60.23^{bc}	87.43^{d}	87.43^{d}	75.46^{c}	75.46^{c}	65.513^{c}	65.51^{c}	67.29^{c}	67.29^{c}
1	69.32^{bc}	49.18^{c}	89.09^{d}	64.11^{d}	92.47^{c}	58.56^{c}	174.11^{bc}	54.65^{c}	97.71^{bc}	76.16^{bc}
3	112.09^{abc}	58.63^{bc}	116.83^{d}	87.41^{d}	128.85^{c}	115.51^{c}	203.69^{bc}	70.41^{c}	114.88^{bc}	96.98^{bc}
5	130.49^{abc}	75.13^{abc}	198.67^{cd}	105.77^{d}	475.63^{b}	110.98^{c}	365.52^{b}	96.46^{c}	407.45^{abc}	93.40^{bc}
7	159.49^{a}	119.54^{abc}	431.64^{ab}	175.84^{cd}	823.05^{a}	233.48^{bc}	939.04^{a}	166.68^{bc}	749.59^{a}	199.55^{bc}
9	96.03^{abc}	78.74^{abc}	223.93^{bcd}	147.93^{d}	-	292.59^{bc}	-	156.59^{c}	444.06^{ab}	245.37^{bc}
11	95.97^{abc}	76.33^{abc}	374.58^{abc}	123.21^{d}	-	346.25^{bc}	-	185.98^{bc}	415.30^{abc}	315.73^{bc}
13	88.38^{abc}	55.38^{bc}	204.29^{cd}	92.47^{d}	-	207.13^{bc}	-	157.80^{c}	363.35^{bc}	242.72^{bc}
15	145.40^{ab}	70.90^{bc}	539.09^{a}	134.81^{d}	-	-	-	159.05^{c}		195.91^{bc}

Values are means of three replicates ± standard errors of the means. Mean values in the same column and row with similar superscript letters are not significantly different ($p < 0.05$).

ANNEX 2: Changes in O_2 consumption among 1-MCP treated bananas during storage

STORAGE DAYS	VARIETIES									
	MPOLOGOMA		NFUUKA		NARITA 2		NARITA 4		NARITA 16	
	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm
0	-58.37^{a}	-58.37^{a}	-66.20^{a}	-66.20^{a}	-76.552^{a}	-76.55^{a}	-75.85^{a}	-75.85^{a}	-69.26^{a}	-69.26^{a}
1	-65.36^{a}	-51.73^{a}	-88.99^{a}	-63.48^{a}	-95.174^{a}	-72.79^{a}	-170.47^{a}	-63.42^{a}	-90.19^{a}	-77.33^{a}
3	-94.26^{a}	-54.95^{a}	-108.15^{a}	-83.21^{a}	-116.968^{a}	-83.77^{a}	-166.70^{a}	-70.29^{a}	-108.93^{abc}	-91.63^{a}
5	-110.45^{a}	-74.15^{a}	-185.19^{ab}	-106.15^{a}	-425.845^{b}	-114.79^{a}	-278.84^{ab}	-91.31^{a}	-381.02^{cd}	-103.59^{ab}
7	-136.03^{a}	-123.40^{a}	-378.31^{b}	-182.85^{ab}	-686.027^{c}	-238.77^{ab}	-755.90^{b}	-159.84^{a}	-564.10^{d}	-212.41^{abc}
9	-85.84^{a}	-85.68^{a}	-187.29^{ab}	-152.97^{ab}	-	-262.30^{ab}	-	-152.05^{a}	-288.55^{abc}	-225.86^{abc}
11	-91.87^{a}	-75.38^{a}	-315.03^{ab}	-118.77^{a}	-	-324.21^{ab}	-	-672.86^{b}	-376.52^{bcd}	-308.96^{abcd}
13	-62.82^{a}	-248.01^{a}	-703.79^{c}	-63.30^{a}	-	-198.13^{ab}	-	-123.97^{a}	-266.28^{abc}	-216.55^{abc}
15	-132.01^{a}	-61.05^{a}	-502.74^{bc}	-117.03^{a}	-	-	-	-130.24^{a}		-163.05^{abc}

Values are means of three replicates ± standard errors of the means. Mean values in the same column and row with similar superscript letters are not significantly different ($p < 0.05$).

ANNEX 3: Changes in ethylene production among 1-MCP treated bananas during storage

STORAGE DAYS	VARIETIES MPOLOGOMA		NFUUKA		NARITA 2		NARITA 4		NARITA 16	
	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm	0 ppm	5 ppm
0	18.80^{a}	18.80^{a}	39.50^{de}	39.50^{de}	36.724^{c}	36.724^{c}	51.06^{c}	51.06^{c}	20.19^{d}	20.19^{d}
1	20.01^{a}	28.39^{a}	37.55^{de}	26.92^{de}	-30.055^{c}	47.823^{c}	108.35^{c}	3.85^{c}	54.71^{d}	42.59^{d}
3	47.10^{a}	20.93^{a}	34.22^{de}	30.23^{de}	61.795^{c}	49.580^{c}	173.23^{c}	35.72^{c}	48.49^{d}	39.80^{d}
5	152.83^{a}	47.73^{a}	96.48^{de}	27.70^{de}	259.315^{bc}	58.646^{c}	282.75^{bc}	43.18^{c}	248.08^{d}	23.27^{d}
7	286.02^{a}	219.39^{a}	245.98^{cde}	177.53^{cde}	1373.056^{a}	208.403^{c}	1512.64^{a}	93.91^{c}	916.18^{bc}	146.10^{d}
9	53.51^{a}	67.35^{a}	140.45^{de}	-40.89^{e}	-	433.951^{bc}	-	181.82^{c}	332.59^{cd}	401.79^{cd}
11	75.96^{a}	171.15^{a}	611.23^{bc}	336.00^{bcde}	-	705.470^{abc}	-	208.54^{c}	1810.43^{ab}	546.80^{cd}
13	92.91^{a}	120.30^{a}	1593.78^{a}	465.51^{bcd}	-	956.533^{ab}	-	478.88^{bc}	2374.02^{a}	560.76^{cd}
15	81.72^{a}	39.66^{a}	700.11^{b}	138.90^{de}	-	-	-	1026.03^{ab}		1937.30^{a}

Values are means of three replicates ± standard errors of the means. Mean values in the same column and row with similar superscript letters are not significantly different ($p < 0.05$).

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