THE USE OF AQUEOUS 1-METHYLCYCLOPROPENE (1-MCP) IN PACKAGED CUCUMBERS (*Cucumis sativus* L.)

Najat Ghareeb KAREEM

Master's Thesis

Department of Horticulture

Supervisor: Prof. Dr. Muharrem ERGUN

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REPUBLIC OF TURKEY
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This master's thesis was accepted by the following committee on 08.06.2017 with the vote unity.

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PREFACE

1 would like to express my sincere gratitude to my supervisor, Prof. Dr. Muharrem Ergun for his valuable time, indispensable advice and knowledge, ceaseless encouragement, and friendly leadership throughout this study. I would also like to offer thanks to Assistant Prof. Dr. Nusret Özbay for his indispensable advice, knowledge, and helping nature throughout my study. I owe my deepest gratitude to Zahide Sislüoğlu, for all her help and guidance for the use of some laboratory equipment. She was always available for any help, and support throughout my thesis work. 1 also offer my thanks to Nazan Ergun who helped me throughout my thesis work in laboratory. I am very grateful for the help, encouragement, and support given to me by my Dear friend Omeed Mohammed Ali Qaradaqi. I express my thanks also to Mr.Arsalan G. Sulaiman for his encouragement, nice advice and recommendation about academic writing. I am sincerely grateful goes to the Ministry of Agriculture in Iraq – Erbil for the opportunity they have given me to gain knowledge in the field of postharvest technology. I would also like to thanks all my friends for their support and encouragement they have given me during my study. Special thanks goes to Dilshad Abubakir for his help .1 would like to express my gratitude and love to all my family members, my brothers and my sisters for their unwavering encouragement and support throughout my study.

Last but not the least the almighty God for letting me through all the tests of life during this journey.

Dedication

I dedicate this work to my beloved mother and my father. Thank you for your encouragement and support.

Najat Ghareeb KAREEM

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CONTENTS

LIST OF SYMBOLS

1-MCP	: 1-Methylcyclopropene
pH	: Potential of Hydrogen
CA	: Controlled atmosphere
CO_2	: Carbon dioxide
O_2	: Oxygen
N_2	: Nitrogen
N	: Newton
mm	: Mille meter
PE	: Polyethylene
h	: Hour
mg	: Milligram
kg	: Kilogram
LDPE	: Low density polyethylene
TSS	: Total soluble solids
ppm	: Part Per Million
MAP	: Modified atmosphere packaging
TA	: Titratable acidity
NaOH	: Sodium hydroxide
C_2H_4	: Ethylene
RH	: Relative humidity
a*	: Greenness to redness
b*	: Blueness to yellowness
L*	: Lightness
NA	: Normal atmosphere
°C	: Degree Celsius
min	: Minute
nm	: Nanometer

μg : microgram

μL : microliter

μM : micro molar

C4H6 : 1-Methylcyclopropene

% : Percentage

PET : Plastic packaging box

cm^3 : Cubic centimeter

micg : Microgram

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PAKETLENMİŞ HIYARLARDA SIVI 1-METİLSİKLOPROPEN (1-MCP) KULLANIMI

ÖZET

Bu çalışmanın amacı hıyar meyvelerinin hasat sonu ömrü ve kalitesi üzerine modifiye atmosfer paketleme (MAP), sıvı ve gaz 1-metilsikloprepen (1-MCP) uygulamalarının etkileri araştırılırmıştır.

Çalışma Bingöl Üniversitesi, Ziraat Fakültesi, Bahçe Bitkileri Bölümü Hasat Sonu Laboratuvarı'nda 2016 yılında gerçekleştirilmiştir. Çalışmada 'Erdemli F1' hıyar meyvesi kullanılmış olup, meyveler Mersin'deki bir sera üreticisinden temin edilmiştir. Meyveler uygulamalar öncesi çeşme suyu ile yıkanmış ve daha sonra 4 gruba ayrılmıştır: Birinci grup kontrol, ikinci grup MAP, üçüncü grup sıvı 1-MCP ve dördüncü grup gaz meyvelerini oluşturmuştur. Meyveler uygulamalar sonrası 10 gün süre ile 23 ± 1 °C'de muhafaza edilmiştir. MAP uygulaması için bir LPDE tipi paketleme materyali, 1-MCP uygulamaları için Sensy Fresh Tozu (aktif bileşen % 3,3 1-MCP; Agroberst Firması, İzmir) kullanılmıştır. Meyve örneklerinde depolama boyunca kalite değişimleri, görsel gözlemeler, ağırlık kaybı, sertlik kaybı, paket gaz içeriği (O_2, CO_2, and N_2), SEK, pH, titre edilebilir asit, klorofil içeriği ve çürüme oranı ile gözlemlenmiştir.

Sonuçlar 10 gün süre ile 23 ± 1 °C'de hıyar meyvelerinin raf ömrüne sıvı veya gaz 1-MCP uygulamasının bir katkı sağlamadığını ortaya koymuştur. Ayrıca MAP uygulamasının hıyar meyvelerinin raf ömrü üzerine olumsuz etkide bulunduğunu ortaya koymuştur.

Anahtar Kelimeler: Hıyar, 1-MCP, MAP, etilen, raf ömrü.

THE USE OF AQUEOUS 1-METHYLCYCLOPROPENE (1-MCP) IN PACKAGED CUCUMBERS (*Cucumis sativus* L.)

ABSTRACT

The objective of the present study was to investigate the effects of Modified Atmosphere Packaging (MAP) and aqueous and gaseous 1-methylcyclopropene (1-MCP) treatments on post-harvest life and quality of cucumber.

The study was conducted in the postharvest laboratory of Horticultural Department of Bingol University during 2016. 'Erdemli F1' cucumber variety obtained from a greenhouse farmer in Mersin and was used in the present study. Cucumbers were washed with tap water prior to the experiment, and distributed into four lots: the first one was for the control, the second one for MAP, the third one for aqueous 1-MCP and the fourth one for gaseous 1-MCP applications and stored at 23 ± 1 °C for 10 days. For the MAP application, a LPDE-type packaging material was used and for 1-MCP application, Sensy Fresh powder (active ingredient 3.3. % 1-MCP; Agrobest, Izmir) was used. After treatments control, aqueous 1-MCP and gaseous 1-MCP-treated fruits were placed into the PET boxes. Samples of fruits were then tested periodically to note the changes in quality as determined by visual observation, weight loss, firmness, color, gas composition (O2, CO2, and N2), SSC, PH, titratable acidity (TA), chlorophyll content, and decay during the storage time.

The overall results indicated that neither gaseous nor aqueous 1-MCP application extent shelf life of cucumbers stored at 23 ± 1 °C for 10 days. MAP application was however found to be having adverse effects on the shelf life of cucumbers.

Keywords: Cucumber, 1-MCP, MAP, ethylene, shelf life.

1. INTRODUCTION

Cucumbers (*Cucumis sativus* L.) are members of the *Cucurbitaceae* family, along with melons, squashes, and many other horticulturally important species (Biale and Young 1981). Global production of cucumber is over 75 million tones, with China being the leading producer (FAO 2014). They are grown both as a source of pickles, and to be eaten fresh. While cucumber consumption as pickles is in decrease, the use of cucumbers as a fresh fruit is increasing (Lucier and Jerardo 2007).

Cucumber fruit is classified as a "non-climacteric" fruit, and it can be borne on indeterminate, tendril-bearing vines of subtropical and tropical origin (Robinson and Decker-Walters 1997). Cucumbers are harvested at a range of developmental stages, depending on the intended use. The time from planting until the beginning of harvest generally ranges between 55 to 60 days, depending on the cultivar and growing conditions. It should be harvested at an immature stage near full size but before its seeds is fully enlarged and hardened (Bulletin 2004).

Cucumbers contain approximately 95% water, 3.6% carbohydrates, and 0.65% protein with low calories (150 $kcal.kg^{-1}$). They are a good source for the following nutrients: pantothenic acid knows as also B_5 (0.026 $mg.kg^{-1}$), vitamin C (0.28 $mg.kg^{-1}$) and magnesium (1.3) (Gebhardt et al. 2008).

As much an important fruit it is in the world, a cucumber is of a highly perishable nature; it is not suited for long-term storage, even at low temperatures. The main deteriorative changes in cucumbers during storage and distribution are mostly attributed to yellowing, loss of moisture leading to shriveling, and physiological injury caused by low temperatures (Adamicki 1985). Cucumber is mostly harvested at a physiologically immature state and the metabolic activity is extremely high. Low temperature storage below 10 °C can cause chilling injuries to cucumbers (Kader 1983). At optimal

temperatures of 10-12 °C and RH of more than 80%, a cucumber still has a very short storage life, about 10 to 14 days (Snowdon 1990).

Today several postharvest technologies applied to horticultural crops in order to extend their storage lives and delay quality losses. An ethylene action inhibitor 1-methylcyclopropene (1-MCP) and modified atmosphere packaging (MAP) are the two important technologies in use, and still a great potential to explore.

1-MCP has increased options for extending the shelf life and quality improvement of many horticultural crops (Blankenship and Dole 2003). The use of the ethylene action inhibitor 1-MCP has proven beneficial in reducing the ripening ratio especially in climacteric fruits. It is thought to bind irretrievably to ethylene receptors at very low concentrations, blocking or delaying the process of maturation and senescence normally triggered by ethylene. The influence of 1-MCP has been less studied on non-climacteric than on climacteric fruits that, showing variable results in the delay of fruit ripening (Blankenship and Dole 2003).

MAP has been developed over the recent decades as a technique to retain high quality of vegetables (Charles et al. 2008). MAP delays ripening and senescence, reduces respiration rate, ethylene production, texture loss, rate of microbial growth and spoilage, chlorophyll and other pigment degradation (Rodriguez-Aguilera and Oliveira, 2009).

The MAP technique is used with various types of products, where the mixture of gases in the package depends on the type of product, packaging materials, and storage temperature. But fruits and vegetables are respiring products where the interaction of the packaging material with the product is important. If the absorbency (for carbon dioxide and oxygen) of the packaging film is adapted to the product respiration, a balanced modified atmosphere is established in the package and the product’s shelf-life is increased (Pretel et al. 2000).

While the use of MAP for fruits and vegetables has been increased by many folds in retail stores, local markets, and by local vendors in the recent years, MAP is hardly followed for cucumber despite many benefits. Being simple, easy to use, and inexpensive, the method of MAP for cucumbers can be used by retail stores, local markets and vendors, and even by individual household.

There are very few work reports related to the technique of using 1-MCP and MAP on cucumbers to understand the effect of in-pack in details. This study tries to investigate the influence of aqueous and gaseous 1-MCP as well as treatments through MAP on postharvest life and quality of cucumbers.

2. LITERATURE REVIEW

2.1. Cucumber

The Cucumber (*Cucumis sativus* L.) is a widely-cultivated plant in the family *cucurbitaceae*. Cucumber has been in cultivation for at least 3000 years. Cucumber most likely originated in India (south foot of the Himalayas), from where it spread throughout tropics and subtropics but has also become important in cooler latitudes where it is grown under glass or plastic (Snowdon 1990). Or possibly Burma, where the plant is extremely adaptable both in vegetation and fruit characters. From India, the plant spread rapidly to China, and it was reportedly much treasured by the early Greeks and Romans. Cucumber is the fourth most important vegetable crop after tomato, cabbage, and onion (Tatlioglu 1993). World's cucumber production is over 75 million tones, with China being the leading producer (FAO 2014). The majority of cucumbers are eaten raw as a juicy salad vegetable, while the rest are cooked or pickled (Snowdon 1990).

Cucumber has a creeping vine that roots in the ground and grows up other supporting frames, wrapping around ribbing with thin, spiraling tendrils. The fruit is roughly cylindrical, elongated, with tapered ends, and may be as large as 60 cm long and 10 cm in diameter. Although its calorie and nutritional value is very low, it is an essential source of vitamins and minerals in the human diet (Mah 1989). In addition to its delicious taste and fairly good caloric value, it has high medicinal value for human beings. It is well known for natural diuretic and therefore it can serve as an active drug for secreting and encouraging flow of urine. Due to high content of potassium (50-80 mg/100g), cucumber can highly be beneficial for both high and low blood pressures (Kashif et al. 2008). Compared with many crops, cucumber reaches harvest stage rapidly and is mostly eaten in the unripe green form. The cucumber fruit products are used not only for fresh eating and culinary cooking, As well as for salad and pickling (Kadans 1979).

Cucumbers are generally not adapted to long term storage, and their storage life is intrinsically rather short. The freshly harvested and best picked cucumbers cannot be

expected to retain satisfactory quality for more than 10 to 14 days, even at optimum temperatures of 10 to 12°C and RH of more than 80% (Eaks and Morris, 1957; Snowdon, 1990b). Cucumber is harvested at a physiologically unripe state and is an important example of 'immature fruit vegetables' group. Due to several reasons, this group of vegetables is among the most perishable of vegetables and is therefore seldom stored for longer periods (Mohammad and Brecht 2003).

The metabolic rate of these fruit vegetables is very high, because they are unripe and are often undergoing rapid growth at the time of harvest. As a rule, generally, they have not yet entered the developmental phase during which accumulation of storage compounds would occur. Their high rates of respiration, which are associated with their high metabolic rates, coupled with the lack of storage reserves, lead to the rapid deterioration of the vegetable. Also because of their thin cuticle and epidermal layer, these vegetables are susceptible to greater water loss, and mechanical damage-disruption of cuticle results in accelerated water loss (Mohammad and Brecht 2003). Decay is also a major cause of the termination of marketable life of these fruit vegetables.

2.1.1. Harvest Maturity Indices for Cucumbers

Cucumbers are harvested at a range of developmental stages, depending on the intended use. The time from planting until the beginning of harvest generally ranges between 55 to 60 days, depending on the cultivar and growing conditions. Cucumber fruit should be harvested at an unripe stage; near full size but before the seeds are fully enlarged and become hard. The two main external indices of harvest maturity are fruit size and skin color. The main internal indices of harvest maturity are seed development, locular jelly formation, and flesh texture. The main index of harvest maturity is fruit size. The proper size depends on the use and the cultivar. Fresh market slicing cucumbers should be at least 15 cm long and firm to the touch. Skin color is another widely used index for assessing fruit maturity. The peel should be a uniform dark green color when harvested. It should also have a noticeable wax deposit on the surface. Though, some cultivars may naturally produce a lighter green fruit and environmental conditions may also affect skin color. Fruits are generally at their highest eating quality when the skin is uniformly green. The fruit should not be allowed to turn yellow which it is over-mature. Fruit that is very mature have a hard chewy skin and are bitter in flavor.

Seed development is also used to determine harvest maturity. The seeds should be uniform white in color and unripe. Large, slightly yellow, or hard seeds are a sign of over-maturity and low fruit quality. The fruit texture should be firm and hard.

Cucumbers should be harvested every other day for best yield and quality. The cucumber fruit grows rapidly to harvest size and picking the fruit as soon as they reach marketable size will maintain the vitality and productive capacity of the plant. The fruit should be handled carefully to avoid bruising and damage to the surface (Bulletin 2004).

The firmness, color and size are important quality characters which affect the market price of cucumber. Further quality indices are freedom from handling defects and decay. Cucumbers are susceptible to chilling injury at 10°C or low temperature and yellowing at 15°C or higher, therefore cucumbers must be kept at temperatures between 10°C and 15°C. Yellowing during the postharvest period is also observed if the fruits were harvested at an advanced stage of development or exposure to ethylene during storage. Furthermore, they are very susceptible to shriveling and therefore the humidity during storage, transport and marketing should be kept at 90-95% (Seagall et al. 1974).

2.1.2. Postharvest Disorders for Cucumbers

2.1.2.1. Chilling Injury

Chilling injury is a physiological disorder that occurs when Chilling sensitive fruits or vegetables are exposed to low but non-freezing temperatures (Hakim et al. 1999; Kang et al. 2002; Saltveit 2002).

Chilling injury is an accumulative process and the level of damage will depend on the temperature and the length of exposure (Cantwell and Kasmire 2002; Saltveit 2002). For chilling injury, to be evident in cucumbers the fruit must be exposed to chilling temperatures for several days (Hakim et al. 1999; Saltveit 2002) and visual symptoms may not be expressed until after the fruit is transferred to higher storage temperatures (DeEll et al. 2000). Although chilling injury in cucumbers can be depending on the cultivar (Hakim et al. 1999; Thompson 2002) and pre-harvest factors, it is generally accepted that cucumber storage below 10ºC will result in chilling injury, therefore

limiting the shelf life of the product. Symptoms of Chilling injury in cucumbers include tissue collapse, water-soaked spots, pit formation (Hakim et al. 1999), increased susceptibility to decay and the development of brown or black lesions that follow pitting (Cantwell and Kasmire 2002), reduced storage life, increased rates of ion leakage due to membrane damage (Kang et al. 2002; Saltveit 2002), as well as the appearance of dark watery spots (De Ell et al. 2000).

2.1.2.2. Yellowing

Yellowing of the peel is a common postharvest disorder of cucumbers. This may be due to some factors, including harvesting the fruit at an advanced stage of maturity, storage at ambient temperatures for several days, or exposure of the fruit to ethylene. Yellowing and decay will result from low levels of ethylene (1 to 5 ppm) exposure during distribution and storing. Cucumbers should not be stored in the same place as bananas, plantains, or other high ethylene releasing products. (Bulletin 2004)

2.1.2.3. Ethylene Injury

One very important physiological aspect of horticultural products is their response to ethylene. Given the variability that exists in cucumber germplasm it is important to determine the postharvest behavior of cultivars grown under protected culture with the aim of reducing losses due to postharvest mismanagement. Cucumbers produce little or no ethylene after harvest and there is no concomitant, rise in respiration rate allowing for the classification of cucumbers as non-climacteric (Saltveit and McFeeters 1980; Wehner et al. 2000). It is important to note that cucumbers become horticulturally or commercially mature at a physiologically immature stage, which makes ripening unnecessary from a marketing standpoint. Cucumbers react negatively to ethylene and the changes associated with ethylene exposure are considered as harmful.

2.2. Ethylene

Ethylene is a naturally produced plant hormone, primarily responsible for the ripening of climacteric fruit and several processes associated with ripening. Ethylene is a simple gaseous hydrocarbon with molecular formula C_2H_4. It can easily spread in and out of the

plant tissue from exogenous as well as endogenous sources (Watkins 2006).

The ethylene production induced during several growth stages of plant such as germination, ripening of fruits, abscission of leaves, and senescence of flowers. The action of ethylene causes considerable changes in the color, flavor, and aroma of fruits during the ripening process (Payasi et al. 2010; Bleecker 1998). The quantity of ethylene production is highly dependent on the type of plant organ or tissue (Corbineau et al. 1990). Plant cells contain ethylene binding receptors, an ethylene receptor is a protein that sits on the cell membrane and has a site for binding ethylene on the outside of the cell, which chemically reacts with ethylene and triggers ripening (Ayoub et al. 1976).

Ethylene can considerably affect the quality of harvested produce. It can be beneficial or harmful depending on the produce, its ripening stage, and its desired use (Watkins 2006; Saltveit 1999). Ethylene production is greatly affected by storage temperature of produce, the ethylene production generally reduced at low temperatures. However, a lower temperature can result in chilling injury in chilling sensitive produce like cucumber and can enhance the ethylene production. Excess ethylene gas produced during stress like situations including senescent breakdown of fruit, chilling-related disorder, ethylene–induced disorders can cause superficial scald (e.g. in apples), browning (e.g. internal flesh browning of avocados, pineapple), undesirable chemical changes (e.g. is coumarin in carrots, water-soaking of water melon) softening of tissue, and many other undesirable effects in produce crop (Watkins 2006; Devlieghere et al. 2003).

Fruits are highly perishable commodities, from the moment they are picked. They require proper ethylene management in postharvest handling to maximize freshness, quality, and shelf life from the field to the table. To decelerate the ripening process of fresh produce, we need to prevent or slow down the action of ethylene gas. Therefore, there will be slow ripening due to less available ethylene (Ponce et al. 2009; Watkins et al. 2000).

In cucumber plants, ethylene plays a part in determining sex expression, however its effects on fruit tissue are considered harmful because they reduce consumer acceptance of the product by negatively affecting appearance, firmness and other attributes, such as color, that define the quality of cucumbers. Cucumbers are highly sensitive to external

ethylene (Kader 2002) and its exposure results in accelerated color loss, higher susceptibility to decay and unfavorable tissue softening (Saltveit 1998).

2.2.1. Mechanism of Ripening by Ethylene

Ethylene receptors are embedded in the cells of fruits. The ethylene molecules in the air bind to the receptor sites and act like a “key” to unlock them. The receptor sites, then transmits a chemical signal to the fruits’ cells to perform a series of chemical reactions (Choi and Huber 2008; Blankenship 2001). These chemical reactions result in the ripening of the fruits by changing the color, flavor, aroma, and composition of fruit (water content, starch content, sugar content etc.).

2.2.2. Climacteric and Non-Climacteric Fruit

Fruits and vegetables are classified into two groups as being either climacteric or non-climacteric, depending on their respiratory pattern and capacity of producing ethylene after harvest (Giovannoni 2001).

Non-climacteric fruit ripen only while still attached to the parent plant. Their eating quality deteriorates if they are harvested before they are fully ripe because their sugar and acid contents do not increase further. Their respiration rate gradually declines during growth and after harvesting. Maturation and ripening are a gradual process. Examples of non-climacteric fruit contain cherries, cucumbers, grapes, lemons and pineapples (Sirivatanapa 2006).

Climacteric fruit can be harvested when ripen but before the onset of ripening. These fruits may undergo either natural or artificial ripening. The onset of ripening is accompanied by a rapid rise in respiration rate, generally referred to as the respiratory climacteric. After the climacteric, the respiration rate slows down as the fruit ripens and develops good eating quality. Examples of climacteric fruit contain apples, bananas, melons, papaya and tomatoes (Sirivatanapa 2006). Ethylene is required to complete the ripening process in climacteric fruit but not in non-climacteric fruit (Lelièvre et al. 1997; Phillips et al. 2004).

2.3. 1-Methylcyclopropene (1-MCP)

1-MCP is a colorless gas with a molecular weight of 54, a formula of C_4H_6, with a double bond between carbon number one and two, and a methyl group on number one carbon (Blankenship and Dole 2003; Watkins 2006a). Commercially, 1-MCP can be complexed with γ-cyclodextrin to produce a stable compound, and then 1-MCP is released as a gas when the 1-MCP complex is dissolved in water. Synthetic regulator 1-MCP has been shown to bind to the ethylene receptors and prevent the physiological action of ethylene (Sisler et al. 1996; Sisler and Serek 1997).

The ethylene receptors are negative regulators of ethylene production and perception. That is, when the ethylene receptors are not restricted to ethylene, these receptors actively prevent ethylene response or ethylene signal transduction pathways. On the other hand, when the receptors are bound to ethylene, it allows ethylene signal transduction pathway for additional physiological responses, like fruit ripening, or senescence (Hua and Meyerowitz 1998; Alonso and Stepanova 2004). 1-MCP is more actively bound to ethylene receptors than ethylene because the affinity of 1-MCP for the ethylene receptors is much greater than that of ethylene (Blankenship and Dole 2003).

The use of cyclopropanes to prevent ethylene action was patented by (Sisler and Blankenship 1996). A commercial breakthrough in 1-MCP application technology resulted from the formulation of 1-MCP as a stable powder in which it is complexed with γ-cyclodextrin, so that 1-MCP is easily released as a gas when the powder is dissolved in water. 1-MCP was approved by the Environmental Protection Agency (EPA) in 1999 for use on ornamentals, and was marketed as EthylBloc® by Floralife, Inc. (Walterboro, SC). AgroFresh, Inc., a subsidiary of Rohm and Haas (Springhouse, PA), subsequently developed 1-MCP under the trade name SmartFres® and have global use rights for edible horticultural products. 1-MCP has a non-toxic mode of action, negligible residue and is active at very low concentrations (E.P.A. 2002).

1-MCP is being considered as an emerging tool with satisfactory results in terms of prolonging shelf life and quality improvement in several fruits (Blankenship and Dole 2003) by preventing the increase of respiration ratio and ethylene production (Ku and Wills 1999; Fan and Mattheis 2000b). 1-MCP is registered for use on a wide variety of

fruits and vegetables including apple, avocado, banana, broccoli, cucumber, date, kiwi fruit, mango, melon, nectarine, papaya, peach, pear, pepper, persimmon, pineapple, plantain, plum, squash and tomato. The particular products that are registered within each country differ according to the importance of the crop in that country.

1-MCP has been useful to protect fruit and vegetables from exogenous and self-produced ethylene, increasing their shelf life and providing more flexibility during storage, distribution, and retail (Watkins and Miller 2005; Watkins 2008). Depending on the variety being treated, 1-MCP may have a variety of effects on respiration, ethylene production, volatile production, chlorophyll deterioration and other color changes, protein and membrane changes, softening, disorders, and diseases (Watkins 2006). Several studies have shown the usefulness of 1-MCP in maintaining quality and postponing ripening of climacteric fruits, but the number of studies evaluating the effects of 1-MCP in non-climacteric commodities is more limited (Bower et al. 2003).

Important factors regarding the effectiveness of 1-MCP treatment are: 1) its concentration, time and temperature dependency; 2) the concentration required to prevent ripening varies with the types of fruit and the stage of ripening at the time of treatment; and 3) although common opinion accepts that 1-MCP binding to the ethylene receptor is irreversible (Blankenship and Dole 2003).

2.3.1. Mechanism of Blocking Ethylene Receptor Sites

1-MCP reacts with the ethylene receptor and inhibits the action of ethylene. When 1-MCP molecules reside on ethylene receptor sites, it binds the receptors sites and does not let the receptor to “unlock” like the ethylene molecule does. As a result, no signal can be sent for a chemical reaction, which defers further ripening. Ethylene and receptor site formation are an ongoing process, and 1-MCP does not bind the receptor site permanently Therefore, eventually new receptor sites can be formed and ethylene can regain its sensitivity for them, the once available 1-MCP molecule has been used up to block available receptor sites (Blankenship 2001).

2.3.2. 1-MCP Effects in Some Non-Climacteric Horticultural Crops

Jiang et al. (2001) showed that Strawberry (*Fragaria x ananassa* Duch.) cv. Everest fruit were treated with 1-MCP at different concentrations from 0 to 1000 nl/l for 2 h at 20°C. They were then kept individually in closed but vented containers for 3 days in the dark at 20°C and 95-100% RH. 1-MCP treatment tended to preserve strawberry fruit firmness and color.

Huang et al. (2003) showed that pepper fruit treated with 250 n/l 1-MCP delayed color loss and fruit softening and extended the storage life of pepper fruits by prohibiting ethylene biosynthesis.

Nilsson (2005) reported little benefit from fumigation with 1-MCP on the shelf-life of European seedless cucumbers (*Cucumis sativus* L.) unless exogenous ethylene is present. 1-MCP has been shown to be ineffective in extending the shelf-life of cucumber fruit.

Ilic et al. (2011) found that 1-MCP treatment of non-climacteric green pepper (*C. annuum* L.) cv. 'Selika' (original red cultivar) and cv. 'H1530' (ever-green). After 18 days' storage at 7°C and 3 days at 20°C, 1-MCP had a marked effect on delaying ripening as shown by inhibiting color change, limiting weight loss, softening, decay development, and sustaining quality of non-climacteric green pepper fruit.

Massolo et al. (2011) reported that 1-MCP treatments of non-climacteric eggplant (*Solanum melongena* L.) cv. 'Lucia' was treated with 1-MCP (1 µl/l, 12 h at 20°C), stored at 10°C for 21 days and subsequently kept at 20°C for 2 days. Results showed 1-MCP delayed senescence, prevented browning, and maintained lower weight loss and therefore prolonged the postharvest life of eggplant fruit.

Cao et al. (2012) investigated that a postharvest application of 1-MCP of green bell pepper (*Capsicum annuum* cv. 'Sujiao' 13; ever-green cultivar) were treated with 0.5, 1.0 or 1.5 µl/l 1-MCP and then stored for 10 d at 20°C. The results showed that the application of 1-MCP was significantly delayed senescence and maintained overall quality, therefore prolonging the shelf-life of green bell pepper fruit.

Tan et al. (2012) evaluated the effect of a postharvest treatment on the Peppers (*Capsicum annuum* 'Kulai'). The fruits were treated in advance by modified atmosphere packaging (MAP) with or without treatment with 1-MCP before cold storage at 10°C.

Results showed that treatment with MAP or MAP+1-MCP can be substantially delayed the chilling injury development at low temperatures and extended the shelf life of a pepper by up to 25 days while retaining the nutritional quality of the pepper.

Sabir (2012) investigated the effects of 1-MCP and MAP treatments alone or in combination on postharvest life and quality of broccoli (*Brassica tolerance* var. *italica*) heads during cold storage at 0°C and 95% RH. 1-MCP and MAP application better achieved in keeping the quality and extending postharvest life of broccoli florets during 28 day-storage.

2.4. Modified Atmosphere Packaging (MAP)

MAP has been developed over the past decades as a technique to sustain high quality of vegetables (Charles et al. 2008) by delaying ripening and senescence, limiting respiration rate, ethylene production, texture loss, rate of microbial growth and spoilage, chlorophyll and other pigment degradation (Rodriguez-Aguilera and Oliveira 2009). In MAP technique, the air surrounding the crops in the package is made to another composition. Thus the initial fresh condition of the product may be extended. MAP is used with different types of products, where the mixture of gases in the package relies on the sort of product, packaging materials and storage temperature. However, fruits and vegetables are respiring products where the interaction of the packaging material with the product is essential. If the permeability (for O_2 and CO_2) of the packaging film is adapted to the product respiration, an equilibrium modified atmosphere will establish in the package and the postharvest life of the product will increase.

The effectiveness of modified atmosphere packaging depends on many factors: freshness and level of product processing, its properties, including the character of metabolism and microbiological quality, appropriate composition of a gas mixture, barrier potential of packaging material and its reliance on the temperature and intensity of product respiration (Hertog et al. 1998; Fonseca et al. 2002). For instance, different products have different amounts of internal air space (potatoes 1-2%, tomatoes 15-20%, apples 25-30%).

2.4.1. Previous MAP Related Researches with Cucumbers

Wang and Qi (1997a) reported that cucumbers packaged in perforated or sealed 31.75 μm low-density polyethylene (LDPE) bags and stored at 5ºC and maintained 90-95% relative humidity (RH) at 5ºC. Packaging with LDPE in operation has been able to significantly reduce chilling injury. In packaged products, the CO_2 concentration rose to 3%, while the O_2 concentration decreased to 16%. Also, LPDE packaging has been able to limit weight loss to a large extent. As a result of the study, it was found that the level of putrescent was increased in the fruits packed with LPDE, which is considered to be the effect of reducing the chilling injury. It is not known if the CO_2 accumulated in the film package would adversely affect the sensitivity of cucumbers to chilling injury.

Wang and Qi (1997b) indicated that controlled atmospheres (CA) maintained the quality of cucumbers better than conventional refrigerated storage at 5°C. Elevated levels of CO_2 (3 %) and decreased concentrations of O_2 (1 and 15%) also increased the tolerance of cucumbers to chilling exposure. The respiration rates (measured as CO_2 production) of cucumber fruit during storage at 5°C were noticeably constrained under CA conditions. CA storage was found to be beneficial in reducing chilling injury and maintaining cucumber quality. They found that chilling injury and the occurrence of decay were also reduced by the elevated CO_2 levels and low O_2, concentrations. The general quality of cucumbers was better maintained when the fruit were stored in CA storage.

Sudhakar Rao et al. (2000) investigated the influence of MAP and shrink wrapping on shelf life of cucumber and reported that shrink wrapping with Polyethylene (PE) film can extend the shelf life of cucumber up to 24 days at 10°C.

Krattak et al. (2005) applied a gamma ray to extend the shelf life of minimally processed cabbage and cucumber, packaged them at 5ºC for two weeks. The application of high gamma radiation has significantly reduced the loss of hardness in fruiting. Besides, high gamma rays have been instrumental in producing sensory higher values. With the application of high gamma rays, the development of microorganisms has remained very poor.

Ozer et al. (2006) examined the influence of different CA with combinations for fresh

pickling cucumbers (cv. ‘Troy’) for 30 days at 7°C and 90-95% RH. It was found that storage of cucumbers to be processed to pickle could be possible for less than 10 days at 7°C temperature and 90-95 RH under normal atmosphere. However, the period of storing the product could be prolonged up to 30 days with reasonable quality losses under the same storage conditions, on the condition that the suitable atmosphere combinations are adhered to (particularly 10% CO_2+3% O_2 or 20% CO_2+3% O_2).

Akbudak et al. (2007) carried out with the Fresh pickling cucumbers cv. ‘Octobus’ could be stored less than 10 days under normal atmosphere conditions consisting of 7°C temperature and 90-95% RH. However, the storage periods could be prolonged up to 30 days with acceptable quality losses under the same storage conditions, provided that the suitable atmosphere combinations are used (especially 10% CO_2 +3% O_2 or 20% CO_2 +3% O_2). It was found that storage of cucumbers to be processed to pickle could be possible for less than 10 days at 7ºC temperature and 90–95 RH under normal atmosphere (NA).

Dhall et al. (2012) tried to determine the shelf life of 'Padmini' cucumber variety in a 90-95% RH environment at 12ºC, separately shrink wrapping with Cryovak D955 stretch film. Individual shrink wrapped has prevented water loss from the cucumber significantly, and it has been able to provide a more severe protection of the cucumber. cucumber wrapped in stretch film were able to maintain their qualities for a long time (9 days) at the highest level, but from the 15th day onwards they began to show signs of reeling and decay. As a result of the work, shrink wrap packaging reduced the weight loss, retained the freshness, color and firmness of cucumber without any decay. The storage life of shrink wrapped cucumber can be prolonged up to 15 days at 12±1°C, 90-95% RH and 5 days at ambient conditions (29-33°C, 65-70% RH).

Manjunatha and Anurag (2014) indicated weight loss, firmness, color, chilling injury and sensory properties of Cucumbers (*Cucumis sativus* L.) under cold room (4±1 °C and 90±2 % RH) and ambient condition (23-26°C and 63-66 % RH) in perforated MAP containers for 12 days. The firmness of cucumbers showed a decrease in all applications treatments. Weight loss was observed in samples stored at least 4ºC. On the contrary, color change occurred at least in the samples stored at 4ºC. The results demonstrated that cucumber can be kept under MAP with 2 perforations at (4±1°C and 90±2 % RH) and

ambient condition (23-26 °C and 63–66 % RH) for 12 and 6 days.

3. MATERIAL AND METHOD

3.1. Plant Material

Cucumbers (*Cucumis sativus* L. cv. 'Erdemli F1') were obtained from a greenhouse farmer in Mersin (Figure 3.1). The fruits were sorted for uniformity of size and color; fruits with physical damage or infections were not used. Prior to the experiment, the fruits were washed with tap water to remove any dirt and surface dried in a slow air draft.

Figure 3.1. Cucumber fruits used for the experiment

3.2. 1-MCP and MAP Treatments

The cucumbers were randomly distributed into four lots The first one was for the control, the second one for MAP, the third one for aqueous 1-MCP and the fourth one for gaseous 1-MCP applications. Approximately 100 kg fruits were used in the study; 75 fruits were employed for each treatment.

For the control fruits, 2-l rigid PET boxes (8 x 12.5 x 20 cm^3; Petsa, K-002447, Gaziantep, TR) were used. Before packaging, a 5 mm-hole was made in the upper side of the boxes in order to permit exchange gas and water vapor.

For the MAP application, a LPDE-type packaging material (LIFEPACK) was obtained from Aypek Ltd. Co. (Bursa, TR). The company were not released the thickness and water vapor transmission rate of the film. In the present experiment, one MAP bag were cut into 6 same sized bags. Loose ends of the bags were hot-sealed by a hot sealer and only one side of the bag was left unsealed. Three fruits were placed into the bags and the loose end was loosely enclosed by a rubber band.

Figure 3.2. Gaseous 1-MCP application

Aqueous 1-MCP was obtained from Sensy Fresh powder (active ingredient 3.3. % 1-MCP; Agrobest, Izmir). Required amount of the powder was dissolved in the 20-l distilled water to obtain 1000 $micg.l^{-1}$ concentration. The solution was stirred with a plastic spatula for 1 min and waited for 9 more min. Fruits were immersed into the solution in a 50-l plastic cap and waited for 30 min. The fruits were then dried with a paper towel and placed into the PET boxes.

Gaseous 1-MCP was prepared from the same powder used for the aqueous 1-MCP

application. According the company instruction 0.042 g powder releases 625 ppb in a m^3. Desired amount of powder dissolved in a glass vial to obtain 1 ppm (1000 $\mu g.l^{-1}$) 1-MCP gas. Fruits or roots were placed in a 50-l plastic cap along with the vial containing the solution, then the lid sealed with a duct tape and waited for 12 h (Figure 3.2). The lid was opened the vial was replaced containing fresh solution and treated 12 more h. A total 24 h gaseous 1-MCP application was applied to fruits. The fruits were then placed into the PET boxes.

3.3. Weight Loss

Five boxes or bags from each treatment were weighed starting from day zero for every other day to calculate the weight loss percentage.

Figure 3.3. Firmness assessment

3.4. Firmness loss

A total of five fruits from five different bags or container were randomly selected for firmness, color, TSS, pH and TA measurement. For firmness, TA-XT Plus Texture Analyzer was used (Stable Micro System Ltd., Surrey, UK). A probe with 2-mm diameter was inserted into fruit at the equatorial area at a speed of 0.83 $mm.s^{-1}$ with a depth of 10

mm, then the reading was recorded as N (newton) at the dept of 0.2 or 0.5 mm (Figure 3.3).

3.5. Color Measurement

Lovibond (RT 300; Amesbury, Germany) reflectance colorimeter was used to quantify peel, mesocarp (cortex) and endocarp color (Figure 4). The values L*, a* and b* were recorded from the fruits. At the equatorial area, peel color was read, then fruits were sliced to read mesocarp and endocarp values.

Figure 3.4. Color assessment

3.6. TSS, pH and TA Measurement

A total of 5 fruits were used the measurements. Fruit juice was obtained with a fruit juicer (Premier, PR-603, Hong Kong). From the juice, total soluble solids (TSS) was measured using a digital reflectometer (Krüss, Germany) and pH, a pH meter (Hanna, HI 2211, Woonsocket, RI, USA). For titratable acidity (TA) (%) 6 g juice was titrated with 0.1 M NaOH until the pH reaching 8.2 with using automatic titrator (Automatic Potentiometric Titrator, AT-510; KEM Kyoto Elect., Tokyo, Japan; Figure 3.5).

3.7. O_2, CO_2 and N_2 Measurement in Packages

Five boxes or bags from each treatment were used to obtain gas composition. The measurement was done by a gas analyzer (Systech Inst., Gaspace Advance, GS3/L; Johnsburg, IL, USA; Figure 3.6).

Figure 3.5. Automatic potentiometric titrator

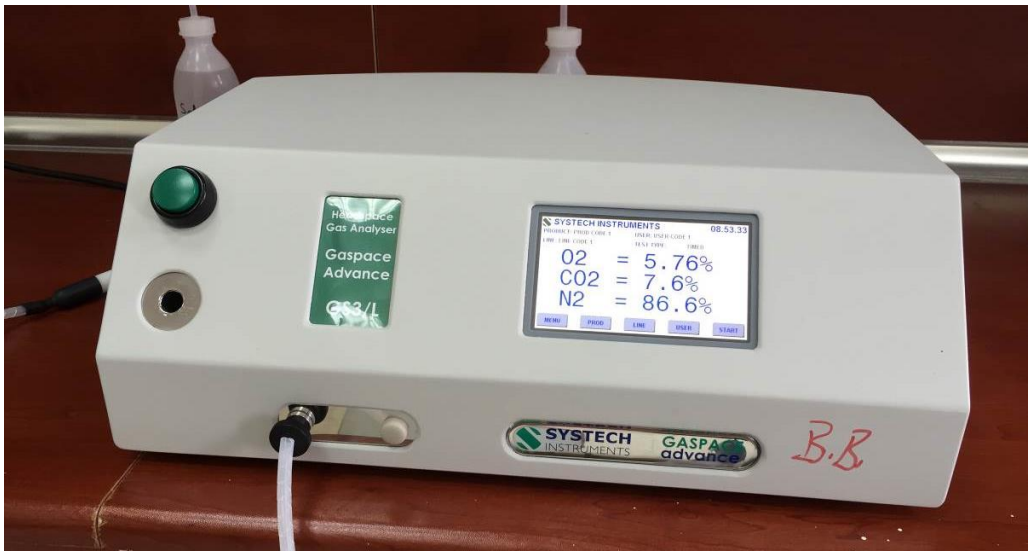

Figure 3.6. Gas analyzer

3.8. Chlorophyll Extraction

Five fruits from each treatment were used to chlorophyll extraction. After mixing 1 ml fruit juice with 9 ml acetone, the solution was vortexed, then kept at the dark at 4 °C for at least 4 h. The sample was later centrifuged at a speed of 2,000 rpm for 10 min. The supernatant was separated form and read at a spectrophotometry at 663 nm for chlorophyll a and at 645 for chlorophyll b.

The calculation was:

Chlorophyll a ($mg.100^{-1}$ g fruit weight) = (((11.75 x Abs663) – (2.35 x Abs645)) x ml acetone) / (w (fruit weight as mg (10) x a (path length of light 1 cm))

Chlorophyll b ($mg.100^{-1}$ g fruit weight) = (((18.61 x Abs645) – (3.96 x Abs663)) x ml acetone) / (w (fruit weight as mg (10) x a (path length of light 1 cm))

3.9. Decayed Fruit Ratio

During the experiment, total decayed fruits were counted and ratio was calculated over total fruit counted at the beginning of the experiment.

3.10. Treatment Design and Data Analyzing

There were 4 treatments with 5 replications, and each replication seeded with 3 sub replications when needed. A randomized complete block design (RCBD) was set up for the experiment. Weight loss, firmness, color, TSS, pH, TA, package gas composition was measured bi-daily; chlorophylls extraction was done at day 0, 5 and 10.

Data analysis was done by an analysis of variance, with mean separation of Duncan at 0.05 level, using SAS statistical software (Version 8.1, SAS Inst., Cary, NC, USA). Data are presented as the mean ± standard error of the mean.

4. RESULTS AND DISCUSSION

4.1. Weight Loss

Table 4.1. Changes in weight loss (%) of cucumbers stored 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
2	0.24 b	3.04 a	0.24 b	0.13 b
4	0.52 b	6.19 a	0.53 b	0.37 b
6	0.77 b	9.07 a	0.76 b	0.60 b
8	0.96 b	11.43 a	0.94 b	0.78 b
10	1.14 b	13.93 a	1.13 b	0.95 b

Control: no treatment; MAP: modified atmosphere packaging; A-1-MCP: aqueous 1-MCP treatment; G-1-MCP gaseous treatment. Means in the same row with same letters were not significantly different at $P \leq 0.05$.

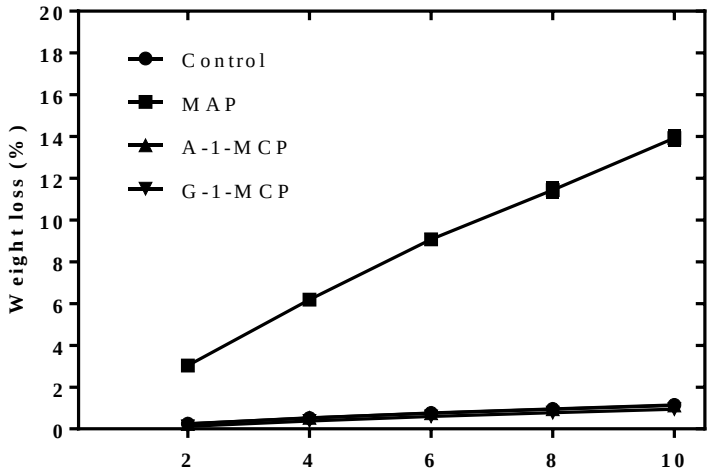

Figure 4.1. Changes in weight loss (%) of cucumbers stored at 23 ± 1 °C
Control: no treatment; MAP: modified atmosphere packaging; A-1-MCP: aqueous 1-MCP treatment; G-1-MCP gaseous treatment. Vertical bars represent standard errors of means.

Cucumbers lost weight during storage irrespective of the treatments (Table 4.1 and Figure 4.1). Weight loss percentage of control reached 1.14 %, of MAP did 13.93 %, of A-1-MCP did 1.13 and of G-1-MCP did 0.95 % at the end of the storage. Control, A-1-MCP

and G-1-MCP did not show a significant difference when compared to each other, however, the weight loss was significantly higher in MAP.

MAP was designed to allow a limited gas exchange including water vapor unlike clamshells. Therefore, cucumbers stored in MAP lost water than those stored in clamshells. Neither aqueous nor gas 1-MCP application had a significant effect on weight loss. Water loss is a critical factor in shortening the storage life and increasing deterioration of many fruit during storage, which reduce both market value and consumer acceptability.

4.2. Firmness

Table 4.2. Changes in firmness of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	8.08 a	8.08 a	8.08 a	8.08 a
2	8.16 a	7.64 ab	8.21 a	7.74 a
4	7.88 a	7.24 a	7.99 a	7.81 a
6	7.03 a	6.84 a	7.50 a	7.22 a
8	7.10 a	6.80 a	7.52 a	6.95 a
10	6.71 a	6.18 b	7.13 a	7.06 ab

Table legends are the same in Table 1.

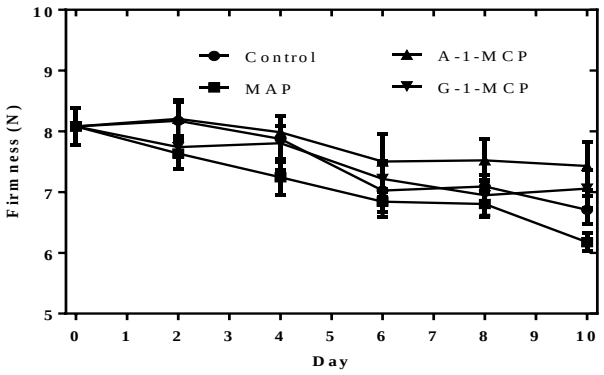

Figure 4.2. Changes in firmness of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

Firmness of cucumber decreased during storage shown in Table 4.2 and Figure 4.2. Firmness of control reached 6.71 N, of MAP did 6.18 N, of A-1-MCP did 7.13 N and of

G-1-MCP did 7.06 N at the end of the storage. Control, A-1-MCP and G-1-MCP did not show a significant difference when compared to each other. However, the loss of firmness was significantly higher in MAP.

Cucumbers stored in MAP lost firmness than the other treatments. Neither aqueous nor gas 1-MCP application had a significant effect on firmness. Respectively aqueous 1-MCP treated sample shows promising result to maintain firmness better than control, MAP, and gas 1-MCP, similar results were reported for cucumber (Lima et al. 2005) and watermelon (Mao et al. 2004) fruit treated with gaseous 1-MCP .

The post-harvest change in texture primarily results from enzymatic degradation of the components responsible for structural rigidity of the fruit. Firmness is one of the components of texture which is a complex sensory attribute that also includes crispiness and juiciness (Konopacka and Plocharski 2004) and is critical in determining the acceptability of horticultural commodities (Gross et al. 2004). The maintenance of higher firmness as a result of 1-MCP treatment may be due to its ability to prevent water loss during storage and to inhibit/delay ethylene production (Jiang et al. 2001; Dong et al. 2002). 1-MCP has been reported to delay softening in avocado, custard apple, mango and papaya (Hofman et al. 2001) as well.

4.3. Peel Color

Table 4.3. Changes in peel color (L*) of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	33.27 a	33.27 a	33.27 a	33.27 a
2	32.94 a	33.53 a	32.45 a	32.49 a
4	32.35 a	32.56 a	32.53 a	31.74 a
6	32.48 a	32.41 a	32.88 a	32.16 a
8	31.22 a	32.33 a	31.42 a	32.08 a
10	31.97 a	31.69 a	31.53 a	31.19 a

Table legends are the same in Table 1.

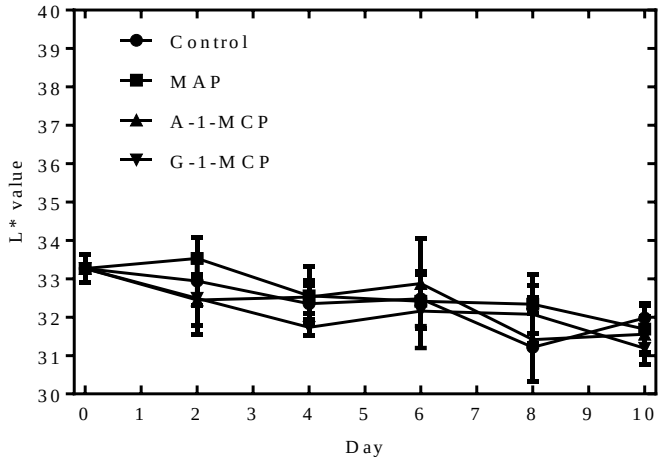

Figure 4.3. Changes in peel color (L*) of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

According L* values, there was no significant difference among MAP, A-1-MCP and G-1-MCP treated cucumbers (Table 4.3 and Figure 4.3). L* value in peel color of all samples decreased throughout time, however the controls (darker fruit) show higher (31.97) values than the other samples by the end of storage.

Table 4.4. Changes in peel color (a*) of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	-11.34 a	-11.34 a	-11.34 a	-11.34 a
2	-11.58 a	-12.33 ab	-11.13 a	-11.02 a
4	-11.35 a	-11.95 ab	-11.03 a	-10.66 a
6	-11.26 a	-12.41 ab	-11.53 a	-10.87 a
8	-10.55 a	-12.28 ab	-11.52 a	-10.79 a
10	-10.52 a	-10.69 a	-11.46 a	-10.71 a

Table legends are the same in Table 1.

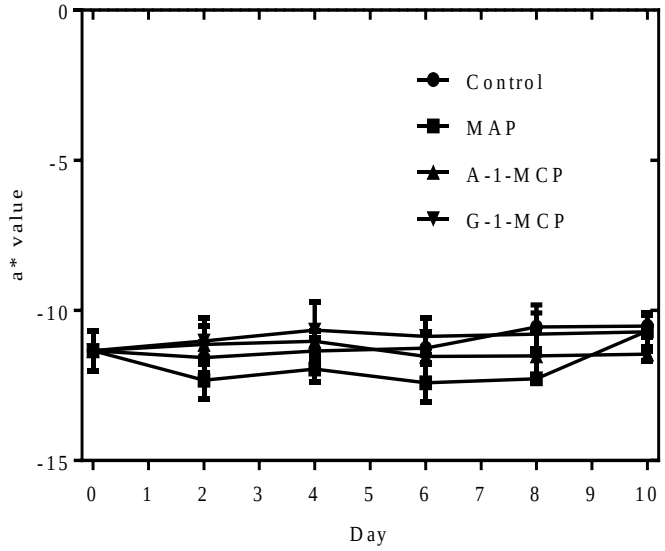

Figure 4.4. Changes in peel color (a*) of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

As shown in Table 4.4 and Figure 4.4, a* value in peel color was more negative in A-1-MCP showing a more predominant greenness of cucumbers. Statistical analysis showed no significant differences between a* value in all the treated or non-treated samples

Table 4.5. Changes in peel color (b*) of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	15.43 a	15.42 a	15.42 a	15.42 a
2	14.53 a	15.02 a	13.64 a	13.84 a
4	14.17 a	14.91 a	13.54 a	13.28 a
6	13.76 a	14.90 a	13.49 a	13.69 a
8	13.20 a	14.12 a	13.16 a	13.67 a
10	13.40 a	13.78 a	12.93 a	13.49 a

Table legends are the same in Table 1.

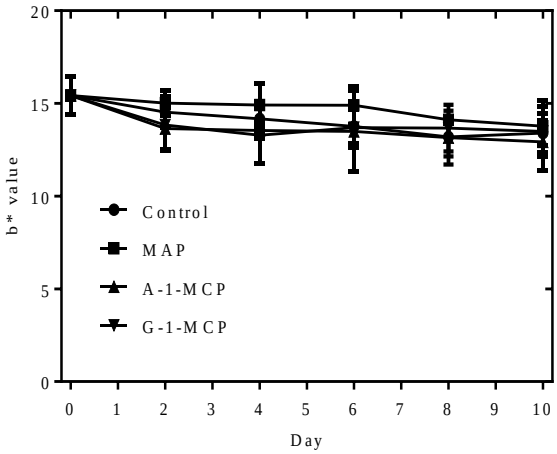

Figure 4.5. Changes in peel color (b*) of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

Table 4.5 and Figure 4.5 shows a slight decrease in b* value in peel of the samples. Similar to L* or a* values, no significant variations of b* values were recorded among treatments.

Changes in a* and b*values are good indicators of absence of oxidative browning of cucumber (Rocha and Moraes 2000).

4.4. Mesocarp Color

Table 4.6. Changes in mesocarp color (L*) of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	67.55 a	67.55 a	67.55 a	67.55 a
2	67.94 a	67.75 a	67.50 a	67.08 a
4	65.77 a	66.87 a	67.09 a	66.94 a
6	65.50 ab	66.34 a	66.70 a	67.00 a
8	63.21 c	67.19 a	66.09 b	65.08 b
10	62.14 c	66.11 a	64.40 b	64.22 b

Table legends are the same in Table 1.

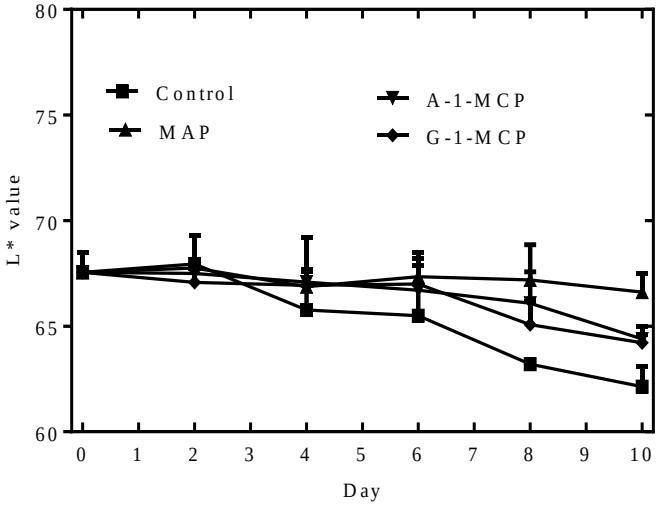

Figure 4.6. Changes in mesocarp color (L*) of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

Lightness (L*) of mesocarp color of cucumber slightly decreases during the storage (Table 4.6 and Figure 4.6). The decrease was more prominent in control, A-1-MCP and G-1-MCP after day 6. At the end of the storage, a statistical difference was observed among the treatments with values of MAP (66.11), A-1-MCP (64.40), G-1-MCP (64.22) and control (62.14).

Table 4.7. Changes in mesocarp color (a*) of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	-10.25 a	-10.25 a	-10.25 a	-10.25 a
2	-10.31 a	-10.08 a	-10.36 a	-10.87 a
4	-10.44 a	-10.35 a	-10.26 a	-10.89 a
6	-10.47 a	-10.38 a	-10.02 a	-10.83 a
8	-10.51 a	-10.47 a	-9.98 a	-10.82 a
10	-10.38 a	-10.42 a	-9.46 a	-10.08 a

Table legends are the same in Table 1.

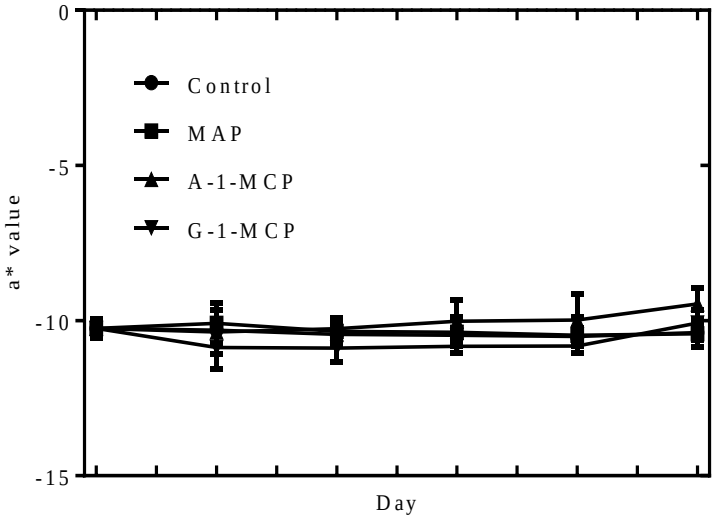

Figure 4.7. Changes in mesocarp color (a*) of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

Table 4.7 and Figure 4.7 illustrates a slight increase in mesocarp color (a*) of cucumbers during the storage period with having no significant difference among the treatments.

Table 4.8. Changes in mesocarp color (b*) of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	25.59 a	25.59 a	25.59 a	25.59 a
2	23.50 a	23.36 a	24.57 a	26.34 a
4	22.56 a	24.16 a	22.22 a	24.92 a
6	24.02 a	23.69 a	22.87 a	24.02 a
8	23.27 a	23.76 a	22.36 a	24.18 a
10	23.52 a	24.00 a	20.56 ab	22.65 a

Table legends are the same in Table 1.

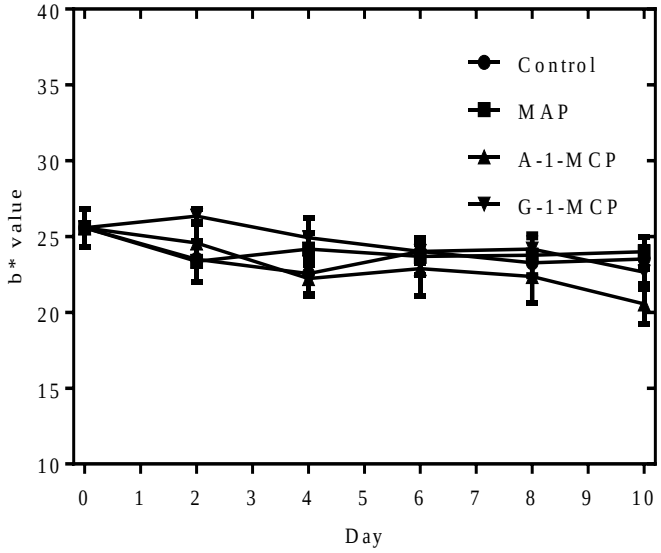

Figure 4.8. Changes in mesocarp color (b*) of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

A slight decline was noted in the mesocarp color (b*) of cucumbers during the storage, with having no variations among the treatments (Table 4.8 and Figure 4.8).

4.5. Endocarp Color

Table 4.9. Changes in endocarp color (L*) of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	65.61 a	65.61 a	65.61 a	65.61 a
2	64.55 a	66.02 a	64.01 a	64.30 a
4	61.72 b	64.97 a	61.97 b	62.94 b
6	61.11 b	63.83 a	60.44 b	60.21 b
8	58.94 b	64.04 a	60.04 b	59.99 b
10	58.57 b	65.28 a	59.79 b	59.20 b

Table legends are the same in Table 1.

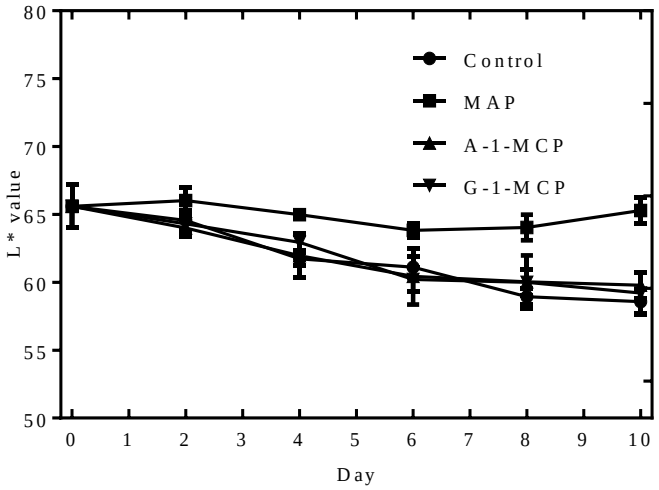

Figure 4.9. Changes in endocarp color (L*) of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

A slight reduction was observed in the brightness (L*) in endocarp color during storage of cucumbers shown in Table 4.9 and Figure 4.9. The reduction in MAP however was very slight, resulting in a significant difference compared to other treatments. MAP lost more water compared to the other treatments and this lost may cause brighter peel in cucumber.

Table 4.10. Changes in endocarp color (a*) of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	-8.97 a	-8.97 a	-8.97 a	-8.97 a
2	-9.21 a	-9.18 a	-9.34 a	-9.30 a
4	-9.40 a	-9.32 a	-9.44 a	-9.41 a
6	-9.58 a	-9.30 a	-9.04 a	-9.24 a
8	-9.27 a	-9.45 a	-8.96 a	-9.07 a
10	-9.24 a	-9.46 a	-8.83 a	-9.07 a

Table legends are the same in Table 1.

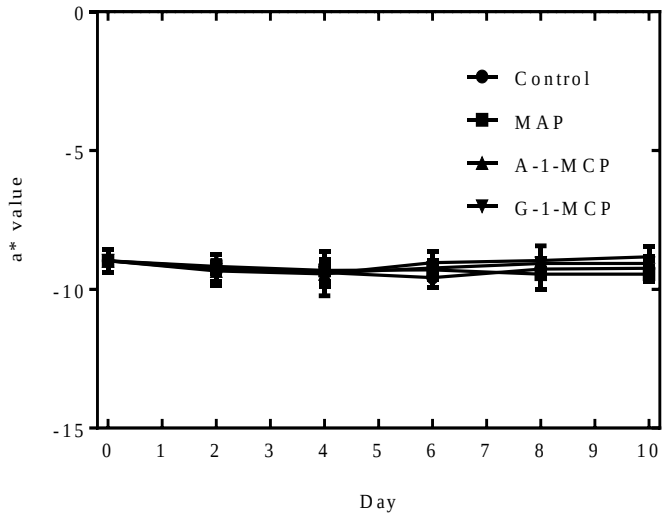

Figure 4.10. Changes in endocarp color (a*) of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

As shown in Table 4.10 and Figure 4.10, almost no changes and variations of endocarp a* values were recorded among treatments.

Table 4.11. Changes in endocarp color (b*) of cucumbers stored at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	20.56 a	20.56 a	20.56 a	20.56 a
2	21.78 a	21.55 a	22.80 a	21.78 a
4	22.27 a	23.19 a	20.84 a	22.27 a
6	23.67 a	22.29 a	21.78 a	23.67 a
8	21.64 a	23.25 a	21.61 a	21.64 a
10	21.73 a	22.89 a	20.03 a	21.73 a

Table legends are the same in Table 1.

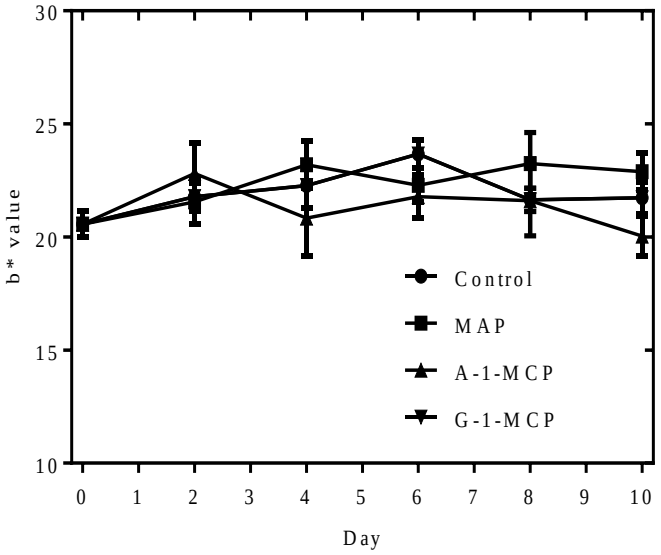

Figure 4.11. Changes in endocarp color (b*) of cucumbers stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

Table 4.11 and Figure 4.11 indicates the increase in the yellowness (b*) values in endocarp color of cucumbers at the end of storage. No significant difference however was found among treatments. Villaita et al. (2004) did not find differences in the external color of cucumbers stored under different ethylene concentrations after 3-day storage. Nilson (2005) reported degreening of peel in cucumber treated with gaseous 1-MCP (1 ppm) after 9 days exposure to ethylene at 20 °C. In green tissue, ethylene accelerates the degradation of chlorophyll, resulting in undesirable yellowing (Kays and Paull 2004).

4.6. Gas Composition

Table 4.12. Changes in O_2 gas composition of packages stored with cucumbers at 23 ± 1 °C.

Day	Control	MAP	A-1-MCP	G-1-MCP
2	18.44 a	16.90 b	18.44 a	18.42 a
4	18.38 a	17.18 b	18.38 a	18.30 a
6	18.40 a	17.10 b	18.40 a	18.36 a
8	18.42 a	17.18 b	18.42 a	18.40 a
10	18.36 a	17.14 b	18.36 a	18.36 a

Table legends are the same in Table 1.

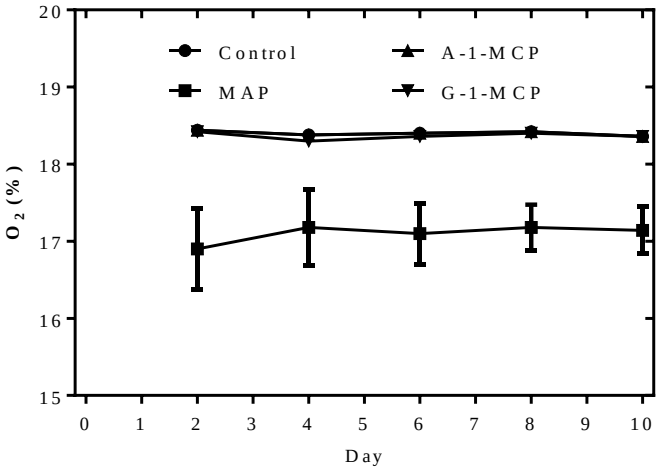

Figure 4.12. Changes in O_2 gas composition of packages stored with cucumbers at 23 ± 1 °C
Figure legends are the same in Figure 1.

Evolution of O_2 concentration during the storage of cucumbers is shown in Table 4.12 and Figure 4.12. During the storage, almost no changes were observed but MAP showed lower concentrations throughout the storage period than the others did.

Table 4.13. Changes in CO_2 gas composition of packages stored with cucumbers at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
2	1.30 b	3.36 a	1.24 b	1.42 b
4	1.30 b	2.70 a	1.14 b	1.32 b
6	1.20 b	2.84 a	1.02 b	1.20 b
8	1.10 b	3.02 a	1.04 b	1.06 b
10	1.28 b	2.88 a	1.20 b	1.26 b

Table legends are the same in Table 1.

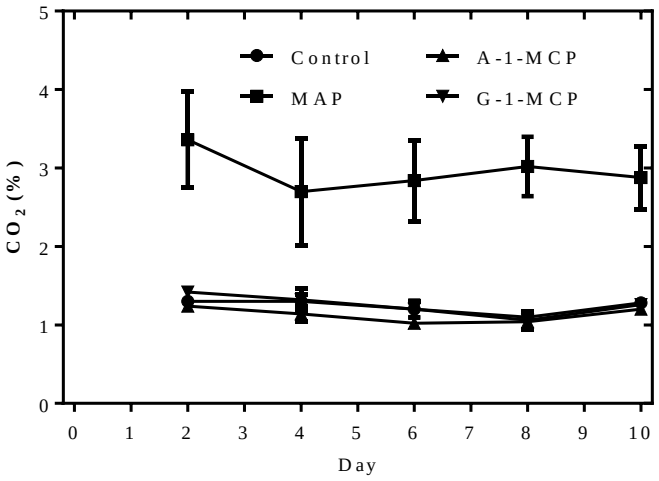

Figure 4.13. Changes in CO_2 gas composition of packages stored with cucumbers at 23 ± 1 °C
Figure legends are the same in Figure 1.

Evolution of CO_2 during the storage of cucumbers is shown in Table 4.13 and Figure 4.13. During the storage, almost no changes were observed but MAP showed lower concentrations throughout the storage period than the others did.

Table 4.14. Changes in N_2 gas composition of packages stored with cucumbers at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
2	80.26 a	79.74 b	80.32 a	80.32 a
4	80.40 a	79.60 b	80.48 a	80.42 a
6	80.44 a	79.80 b	80.66 a	80.50 a
8	80.50 a	79.80 b	80.54 a	80.56 a
10	80.36 a	79.98 b	80.44 a	80.42 a

Table legends are the same in Table 1.

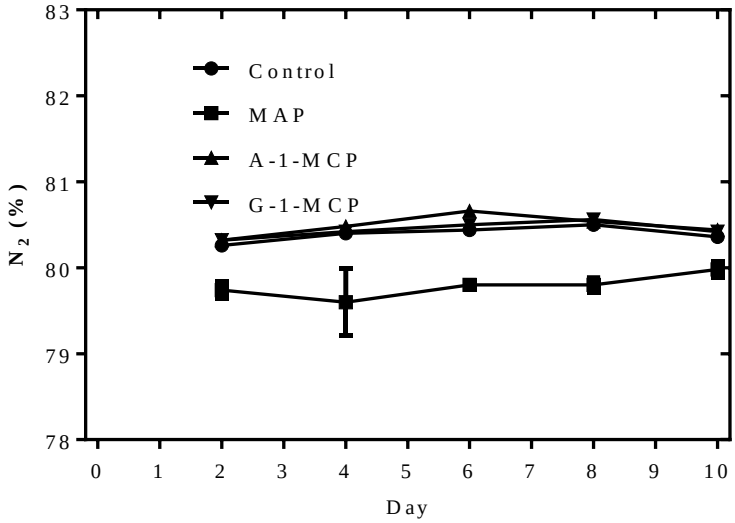

Figure 4.14. Changes in N_2 gas composition of packages stored with cucumbers at 23 ± 1 °C
Figure legends are the same in Figure 1.

Evolution of N_2 during the storage of cucumbers in Table 4.14 and Figure 4.14. During the storage, almost no changes were observed but MAP showed higher concentrations throughout the storage period than the others did.

The film used for MAP allows some degree of gas exchange unlike clamshells, which was the causes higher N_2 and O_2 concentrations and lower CO_2 concentrations in MAP.

4.7. SSC Content

Table 4.15. Changes in SSC content of cucumbers at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	2.70 a	2.70 a	2.70 a	2.70 a
2	2.50 a	2.52 a	2.62 a	2.70 a
4	2.92 a	3.00 a	2.80 a	2.62 ab
6	2.84 a	2.76 a	2.62 a	2.50 ab
8	2.62 a	2.78 a	2.52 ab	2.54 ab
10	2.60 a	2.76 a	2.46 ab	2.60 ab

Table legends are the same in Table 1.

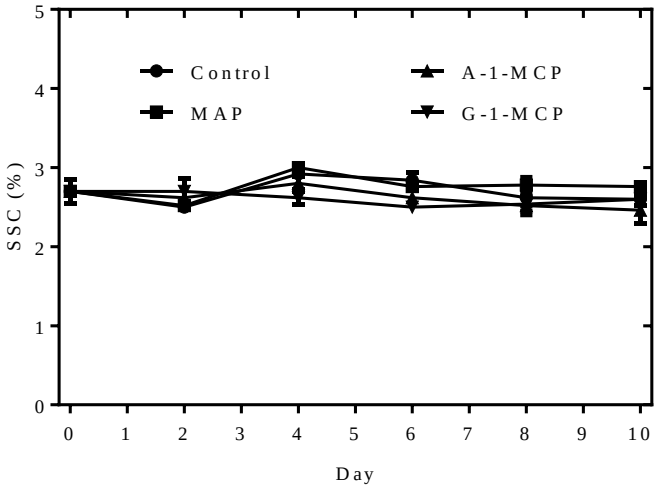

Figure 4.15. Changes in SSC content of cucumbers at 23 ± 1 °C
Figure legends are the same in Figure 1.

SSC contents did not show a significant change or variation among treatments during the storage as shown in Table 4.15 and Figure 4.15. SSC content of cucumbers was 2.70% at the beginning of storage; and at 10 days, MAP was 2.76%, followed by G-1-MCP (2.60%), control (2.60%) and A-1-MCP (2.46%).

4.8. PH Content

Table 4.16. Changes in pH content of cucumbers at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	5.32 a	5.32 a	5.32 a	5.32 a
2	5.39 a	5.43 a	5.37 a	5.45 a
4	5.41 a	5.34 a	5.28 a	5.31 a
6	5.38 a	5.41 a	5.27 ab	5.32 a
8	5.15 ab	5.28 a	5.26 a	5.21 a
10	5.00 a	5.04 a	4.99 a	5.03 a

Table legends are the same in Table 1.

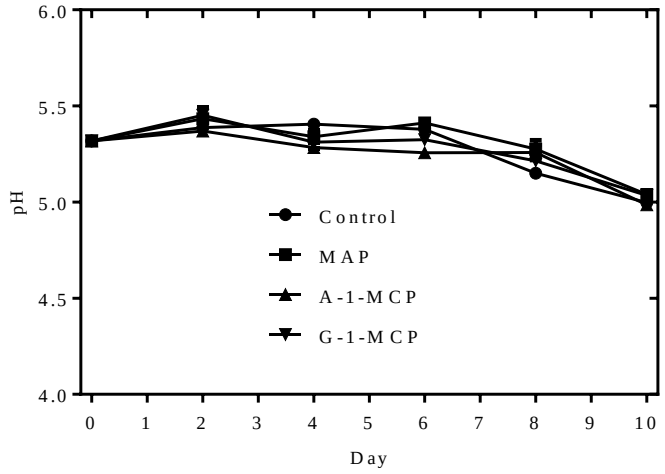

Figure 4.16. Changes in pH content of cucumbers at 23 ± 1 ℃
Figure legends are the same in Figure 1.

As seen in Table 4.16. In addition, Figure 4.16, pH contents decreased after 2nd of the storage, reaching values of MAP 5.4, of A-1-MCP 4.99 and of G-1-MCP 5.3 at the end of storage. There were no significant variations among treatments.

4.9. TA Content

Table 4.17. Changes in TA content of cucumbers at 23 ± 1 ℃

Day	Control	MAP	A-1-MCP	G-1-MCP
0	1.07 a	1.07 a	1.07 a	1.07 a
2	1.05 a	1.05 a	1.10 a	1.16 a
4	1.15 a	1.10 a	1.11 a	1.08 a
6	1.26 ab	1.27 ab	1.32 a	1.40 a
8	1.31 a	1.34 a	1.27 a	1.22 ab
10	1.38 a	1.41 a	1.48 a	1.41 a

Table legends are the same in Table 1.

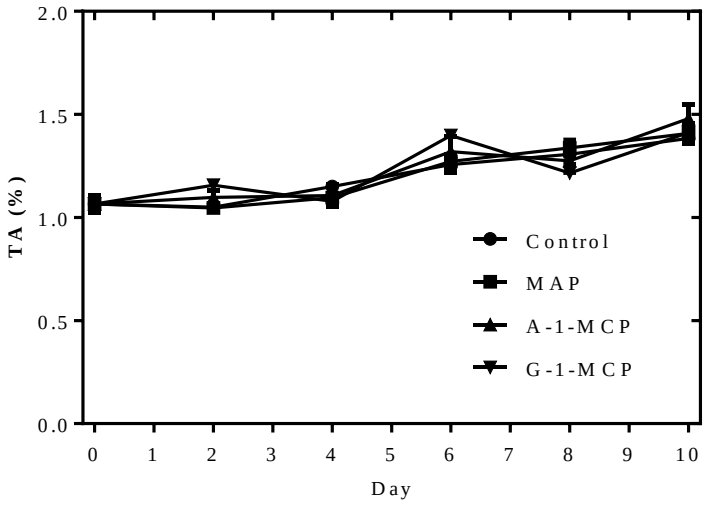

Figure 4.17. Changes in TA content of cucumbers at 23 ± 1 °C
Figure legends are the same in Figure 1.

Titratable acidity (TA) content of cucumbers increased in all the treatments during the storage as seen in Table 4.17 and Figure 4.17. However, no significant variations were observed among treatments.

4.10. Chlorophyll Content

Table 4.18. Changes in chlorophyll a content of cucumbers at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	1.38 a	1.37 a	1.37 a	1.38 a
6	1.75 a	1.75 a	1.61 ab	1.57 ab
10	1.81 a	1.80 a	1.43 b	1.54 b

Table legends are the same in Table 1.

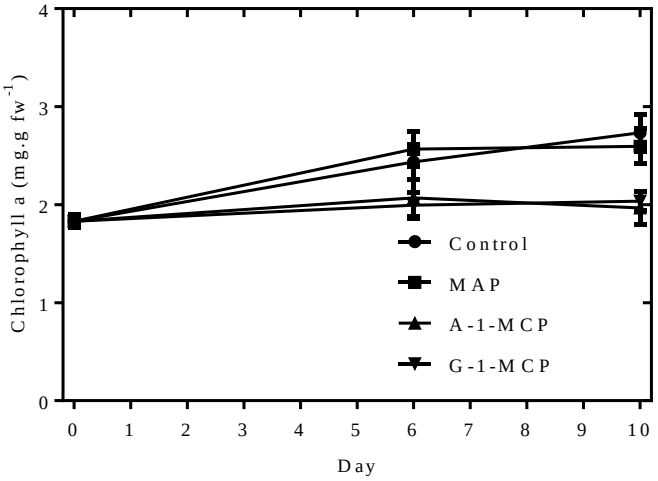

Figure 4.18. Changes in chlorophyll a content of cucumbers at 23 ± 1 °C
Figure legends are the same in Figure 1.

Table 4.18 and Figure 4.18 show changes in chlorophyll a contents of cucumbers that increased in all the treatments during the storage. After day 6, 1-MCP seemed to suppress the increase in chlorophyll contents. At the end of storage, the highest chlorophyll a content was determined in Control (1.81 mg 100 g^{-1}) while least amount was detected in A-1-MCP (1.43 mg 100 g^{-1}).

Table 4.19. Changes in chlorophyll b content of cucumbers at 23 ± 1 °C

Day	Control	MAP	A-1-MCP	G-1-MCP
0	1.37 a	1.37	1.37 a	1.37 a
6	1.75 a	1.52 ab	1.61 ab	1.57 ab
10	1.80 a	1.21 b	1.43 ab	1.54 ab

Table legends are the same in Table 1.

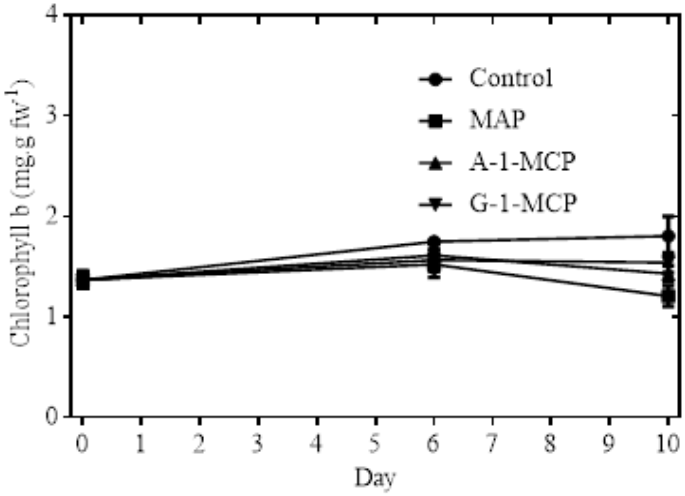

Figure 4.19. Changes in chlorophyll b content of cucumbers at 23 ± 1 °C
Figure legends are the same in Figure 1.

The chlorophyll b contents of cucumbers showed very slight changes during the storage (Table 4.19 and Figure 4.19) while resulting no variations among treatments. At the end of the storage period, the chlorophyll b content was 1.80 for control, 1.54 for G-1-MCP and 1.43 mg 100 g^{-1} A-1-MCP

The decrease in chlorophyll during storage is expected due to chlorophyll degradation as a result of chlorophylls enzyme activity leading to senescence (Gong and Mattheis 2003). The maintenance of green color in modified atmosphere packaged cucumber during storage was reported by Dhall et al. (2012).

4.11. Decayed Fruit

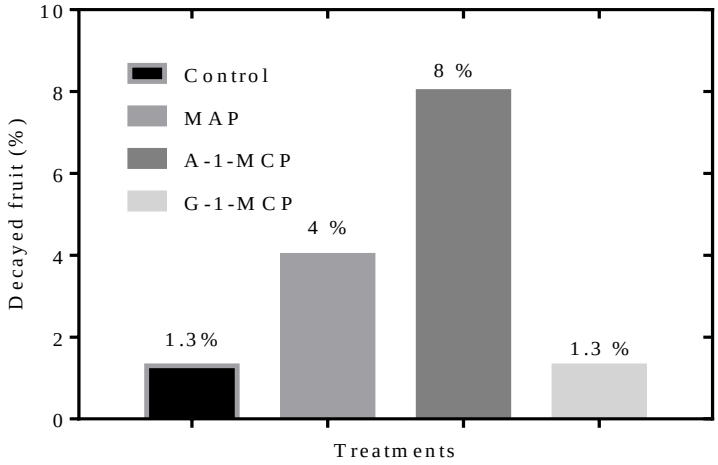

Figure 4.20. Decayed fruit ratio of cucumbers at the end of storage period stored at 23 ± 1 °C
Figure legends are the same in Figure 1.

Figure 4.20 shows the development of fungal decay of cucumbers at the end of the storage, expressed as the percentage of visibly infected samples out of the total amount of stored samples. Fruit treated with aqueous 1-MCP and stored in MAP showed higher decayed fruit ratio compared to control or gaseous 1-MCP applications. Keeping cucumber fruits for a limited time in water for the aqueous 1-MCP treatments may enhance decay development.

5. CONCLUSIONS

Cucumbers (Cucumis sativus L.) are members of the Cucurbitaceae family, along with melons, squashes, and many other horticulturally important species. Cucumber as a good source of antioxidants is one of the most popular and widely grown vegetable crops not only in the word but also in Turkey.

However, it has a short shelf life due to firmness loss, discoloration, water loss and fungal rots. The postharvest applications targeting for those losses would be a successful tool to extend the very short life of the vegetables. In this study, the shelf life and quality values of the cucumbers were observed with the MAP (LDPE type), aqueous 1-MCP and gaseous 1-MCP applications.

In order to find out the amount of weight loss, the containers containing cucumbers were weighed at 2 days intervals and values were obtained. According to the findings, weight loss was significantly higher in MAP than the others. This is because of MAP was designed to allow a limited gas exchange including water vapor unlike clamshells, which is the main reason for the very high weight loss.

In order to observe the firmness values, the hardness of cucumbers was measured randomly taken from 2 days. According to the results obtained, irrespective of the treatments, cucumbers showed a softening during storage. The reason for these changes in stiffness is that respiration and some biochemical continue to increase during storage.

In order to observe the Color Measurement, the values L*, a* and b* were recorded from the fruits taken every 2 days. At the equatorial area, peel color was read, then fruits were sliced to read mesocarp and endocarp values. In peel, mesocarp, and endocarp color of the samples. No significant variations of L*, a*, and b* values were recorded among treatments. However the L*value in endocarp color recorded a very slight reduction that resulting in a significant difference compared to other treatments and cause brighter peel

in cucumber. O_2, CO_2, N_2, changes were measured in Boxes containing cucumber every 2 days. It was seen that no changes were observed but MAP in O_2 showed lower concentrations throughout the storage period than the others did. O_2 increased and N_2 values change depending on the increase of CO_2 in the obtained data. The reason for these changes is increased respiration during storage and the (LDPE) that used for MAP allows some degree of gas exchange unlike clamshells, which were the causes higher N_2 and O_2 concentrations and lower CO_2 concentrations in MAP.

SSC content values were measured using juice from cucumbers taken every 2 days. According to the results obtained, the values of SSC content did not show a significant change or variation among treatments during the storage. SSC content values showed a slight decrease and were not affected by the 1-MCP applications, but there was a little increase in MAP. The reason for this difference is due to the water loss in cucumber.

In order to observe the pH and TA values, measurements were made using the juices of the cucumbers taken from the packages with intervals of 2 days. The values attained show small changes and with no significant variations among the treatments in the pH with TA at end of storage.

In order to find out the amount of chlorophyll a, b contents, using juice from cucumbers taken in first, mid and last day of the experiment. The values obtained show slight changes and with no significant variations among the treatments in chlorophyll a, b contents at end of storage.

For determining the decayed fruit ratio, total decayed fruits were counted with intervals of 2 days. According to the results obtained, it was seen that Fruit treated with aqueous 1-MCP and stored in MAP showed higher decayed fruit ratio compared to control or gaseous 1-MCP applications.

The overall results indicated that neither gaseous nor aqueous 1-MCP application extent shelf life of cucumbers stored at 23 ± 1 °C for 10 days. MAP application was however found to be having adverse effects on the shelf life of cucumbers.

However, in order to determine the feasibility of using 1-MCP and MAP on a commercial

scale, extensive post-harvest research is necessary. Also future investigations are needed to explore the potential of 1-MCP in controlling post-harvest decay of cucumbers.

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BIOGRAPHICAL SKETCH

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