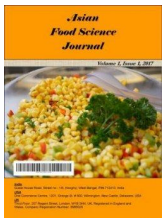

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Responses of Cucumber Fruit to Aqueous 1-Methylcyclopropene (1-MCP) Application

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Authors' contributions

This manuscript is produced from MSc thesis of author NGK under supervision of author ME. Author ME designed the study, performed the statistical analyses and wrote the initial draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: The objectives of the present study were to evaluate effects of aqueous 1-methylcyclopropene (1-MCP) on quality of cucumber fruit, and to compare with/to gaseous 1-MCP and modified atmosphere packaging (MAP) applications.
Study Design: A randomized complete block design (RCBD) was set up for the experiment.
Place and Duration of Study: Department of Horticulture, Bingol University, Turkey; between September - December 2017.
Methodology: Cucumber fruits (ErdemliF1) were either treated with aqueous or gaseous 1-MCP (1 ppm), or left untreated for MAP storage or controls. The fruits were afterwards put into PET clamshell containers except for MAP application and stored 23 ± 1°C for 10 days for simulating retail shelf-life conditions. Samples of cucumbers were then tested periodically to record changes in quality as determined by weight loss, firmness, color, gas composition (O_2, CO_2 and N_2), total soluble solids, pH, titratable acidity, chlorophyll content, and decay during the storage time.
Results: Neither aqueous nor gaseous 1-MCP application had a significant effect on weight or firmness loss. According to peel color values recording during the storage period, there were no significant differences among the treatments. Total soluble solids, pH or titratable acidity did not show a significant change or variation among treatments during the storage. Fruits stored in

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modified atmosphere packages showed higher chlorophyll a amount than fruit treated with 1-MCP.
Conclusion: The study revealed that neither aqueous 1-MCP application nor gaseous 1-MCP application is effective for retaining quality loses and consequently for extending shelf life of the cucumbers kept at 23°C.

Keywords: Postharvest quality; quality loss; modified atmosphere packing; cucumber placenta.

1. INTRODUCTION

Cucumbers (*Cucumis sativus* L.) are members of Cucurbitaceae family which includes some horticulturally important species including melons, squashes and pumpkins [1]. Cucumber fruit is classified as a "non-climacteric" fruit, and it can be borne on indeterminate, tendril-bearing vines of subtropical and tropical origin [2]. The fruit is harvested at a range of developmental stages, depending on the intended use. For fresh consumption, it should be harvested at an immature stage near full size but before its seeds is fully enlarged and hardened [3]. The time from planting until the beginning of harvest generally ranges between 55 to 60 days, depending on the cultivar and growing conditions.

Immature harvesting accompanied by its delicate and watery fruit structure makes cucumber fruit be a highly perishable. Moreover, storing cucumber fruit below 10°C may lead to chilling injuries [4]. Therefore, cucumber fruit is not suited for long-term storage [4]. At optimal temperatures of 10-12°C and RH of more than 80%, cucumbers may last up to 14 days [5]. The main deteriorative changes in cucumbers during storage and distribution are mostly attributed to yellowing, loss of moisture leading to shriveling, and physiological injuries caused mostly by chilling temperatures [6].

Today a wide array of postharvest applications is applied to fresh horticultural crops in order to extend their shelf lives and delay quality losses. An ethylene action inhibitor 1-methylcyclopropene (1-MCP) and modified atmosphere packaging (MAP) are the two important tools in use, and still a great potential to explore. 1-MCP has been reported to extend shelf lives and suppress quality losses in many horticultural crops [7]. 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 [8,9]. The efficacy of 1-MCP has been less studied on non-climacteric than on climacteric fruits, showing variable results in the delay of fruit ripening [7]. Only very few 1-MCP studies have been reported on cucumbers, in which 1-MCP was ineffective retaining postharvest quality loss and extending the shelf life [10,11].

MAP has been developed over the recent decades as a technique to retain quality losses [12]. MAP delays ripening and senescence, reduces respiration rate, ethylene production, texture loss, rate of microbial growth and spoilage, chlorophyll and other pigment degradation [13]. MAP applications are 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 [14].

The use of MAP has been increased by many folds for a variety of fruits and vegetables but not for cucumbers despite some registered benefits. Studies have reported that cucumbers can benefit from MAP applications by reducing chilling injuries at 5°C [15,16], limiting weight loss as expected [15-17], and retaining quality and extending shelf life [16-21].

This study tries to investigate the effects of aqueous 1-MCP on quality of cucumber fruit held in room temperature (at 23-25°C, 50-60% RH) simulating retail shelf-life conditions, and to compare with/to gaseous 1-MCP and MAP applications.

2. MATERIALS AND METHODS

2.1 Plant Materials

'Erdemli' F1 cucumber cultivar was used in the present experiment. Cucumbers obtained a greenhouse after 50-60 days from planting were sorted for uniformity of size and color; fruits with

physical damage or infections were left out. Prior to the experiment, cucumbers were washed with tap water to remove any dirt and surface dried in a slow air draft.

2.2 MAP Application

Approximately 100 kg fruits were used in the study; 75 fruits for each treatment. A LPDE-type packaging material (Life pack, Aypek Co. Bursa, TR) was employed for MAP application. The company was not released the thickness and water vapor transmission rate of the film.

2.3 1-MCPApplicaiton

Aqueous 1-MCP was obtained from Sensy Fresh powder (active ingredient 3.3% 1-MCP; Agrobest Grub, Kemalpasa, Izmir, TR). Required amount of the powder was dissolved in the 20-l distilled water to obtain 1 ppm (1000 µg 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 put into rigid PET clamshell container (8 x 12.5 x 20 cm^3; Petsa, K-002447, Gaziantep, TR).

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 1 m^3. Desired amount of powder dissolved in a glass vial to obtain 1 ppm (1000 µg l^{-1}) 1-MCP gas. Fruits 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. 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 PET containers.

Ethylene production rate which is one of the prognostication for 1-MCP application was not measured since cucumber fruit produces very small volume of ethylene (≤1 µl kg^{-1} h^{-1}).

2.4 Weight and Firmness Loss

Five PET containers or MAP bags from each treatment were weighed starting from day 1 for every other day to calculate the weight loss percentage. A total of five fruits from five different bags or container were randomly selected for firmness measurement. For firmness, TA-XT Plus Texture Analyzer was employed (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 depth of 0.5 mm.

2.5 Color Assessment

Lovibond (RT 300; Amesbury, DE) reflectance colorimeter was used to quantify peel (exocarp), mesocarp and placenta color. 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 placenta color values.

2.6 O_2, CO_2 and N_2 Evaluation

Five containers 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) and register as percentage.

2.7 Total Soluble Solids, pH and Titratable Acidity

Five fruits from each treatment were used for the measurements. Fruit juice was obtained with a fruit juicer (Premier, PR-603, Hong Kong). From the juice, TSS was measured using a digital reflectometer (Krüss, DE) and pH, a pH meter (Hanna, HI 2211, Woonsocket, RI, USA). For 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, JP).

2.8 Chlorophyll Extraction

Five fruits from each treatment were used for 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 (Hettich, Universal 320 R, DE). 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 Abs 663) – (2.35 x Abs 645)) 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 Abs 645) – (3.96 x Abs 663)) x ml acetone) / (w (fruit weight as mg (10) x a (path length of light 1 cm))

2.9 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.

2.10 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.

3. RESULTS AND DISCUSSION

3.1 Weight and Firmness Loss

Cucumbers lost weight during storage irrespective of the treatments (Fig. 1). 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 more water than those stored in clamshells. Neither aqueous nor gaseous 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 fruits and vegetables during storage, which reduce both market value and consumer acceptability.

Firmness of cucumber slightly decreased during storage shown in Fig. 1. 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 at the end of the storage period. Neither aqueous nor gas 1-MCP application had a significant effect on firmness, similar results were reported for cucumber by Lima et al. [10]. 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 [22] and is critical in determining the acceptability of horticultural commodities [23].

3.2 Peel Color Changes

According peel color values recording during the storage period, there were no significant differences among the treatments (Fig. 2). As storage time passed, lightness (L*) of all the treatments diminutively decreased while yellowness and greenness (a* and b*) stood still. Oxidative browning in peel causes changes in a* and b* values in cucumber [24], which was not observed in the present study.

3.3 Mesocarp and Placenta Color Changes

Lightness (L*) in mesocarp of cucumbers slightly decreased during the storage except for MAP treatment (Fig. 3). The decrease was more prominent in controls than the others after day 6. At the end of the storage, except for MAP, the mesocarp lightness in other 3 treatments was decreased. Neither greenness nor yellowness in mesocarps of any treatments were significantly changed during or after the storage period (Fig. 3).

Similar to lightness in mesocarp, lightness in placenta declined during the period of the storage except for MAP treatment. After 4th day of the storage period, the decrease of lightness in control, A-1-MCP or G-1-MCP were more severe, leading a statistical difference. Color values of a* and b* in placenta of any treatments showed no statistical changes over time and consequently no variation among treatments were recorded during or after storage (Fig. 3).

Contrary to our results, Nilson [11] reported a degreening of peel in cucumber treated with gaseous 1-MCP (1 ppm) after 9 d exposure to ethylene at 20°C. Ethylene accelerates the degradation of chlorophyll, resulting in undesirable yellowing [25]. On our experiment, cucumbers placed in MAP retained their brightness when compared to others. This might

be due to limited oxidative browning through restricting O_2 level in the package.

3.4 Gas Composition in Head Space

Evolution of headspace gas concentration during the storage of cucumbers is shown in Fig. 4. During the storage, almost no notable changes in O_2, CO_2 or N_2 concentration ratio for any treatments were observed. Cucumbers in MAP registered lower O_2 and N_2 value while higher CO_2 concentration ratios than cucumbers in clamshells. In the present experiment, the film of MAP allowed limited amount of gas exchange unlike clamshells, which was the causes for lower N_2 and O_2 concentrations and higher CO_2 concentrations in cucumbers stored in MAP.

3.5 Total Soluble Solids, pH and Titratable Acidity Evaluation

TSS contents did not show a significant change or variation among treatments during the storage as shown in Fig. 5. As seen in Fig. 5, pH contents very slightly decreased after 2nd day of the storage but the decrease was so minute to be significant while no variations recorded among treatments. there were no significant variations among treatments. TA content of cucumbers increased in all the treatments during the storage as seen in Fig. 5, however, no significant variations were observed among treatments. The increase in TA cloud be result of organic acids which might be used in respiration.

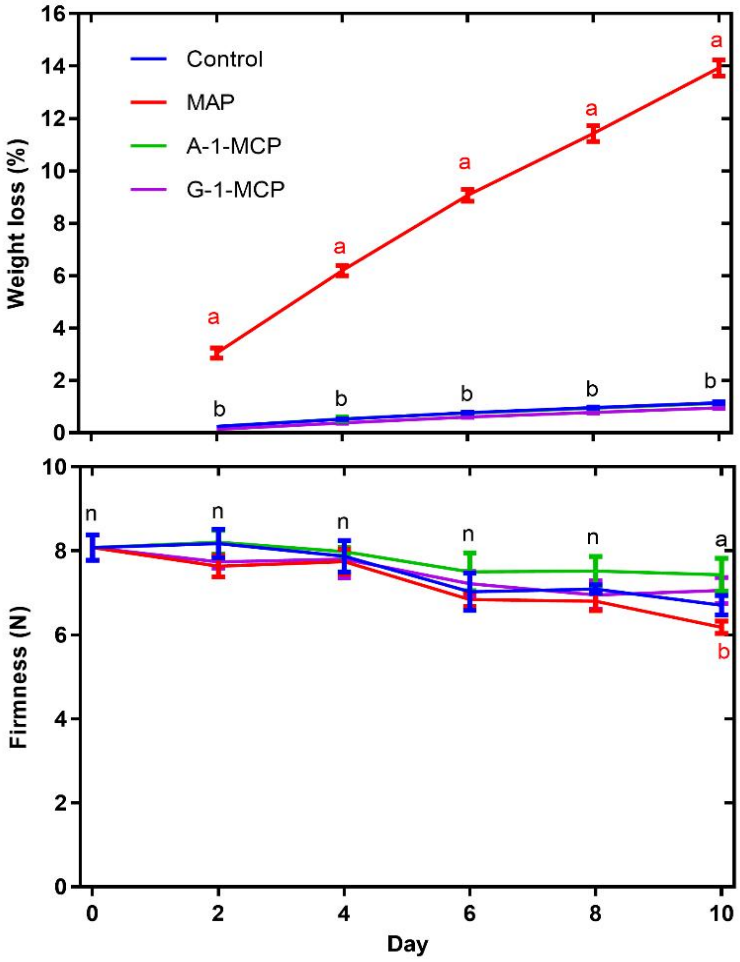

Fig. 1. Changes in weight loss (%) and firmness of cucumbers stored at 23 ± 1°C

Control: no treatment; MAP: Modified atmosphere packaging; A-1-MCP: aqueous 1-MCP treatment; G-1-MCP: gaseous 1-MCP treatment. Vertical bars represent standard errors of means. Means followed by the same letters on the same day are not significantly different by DUNCAN test P < 0.05. n: nonsignificant

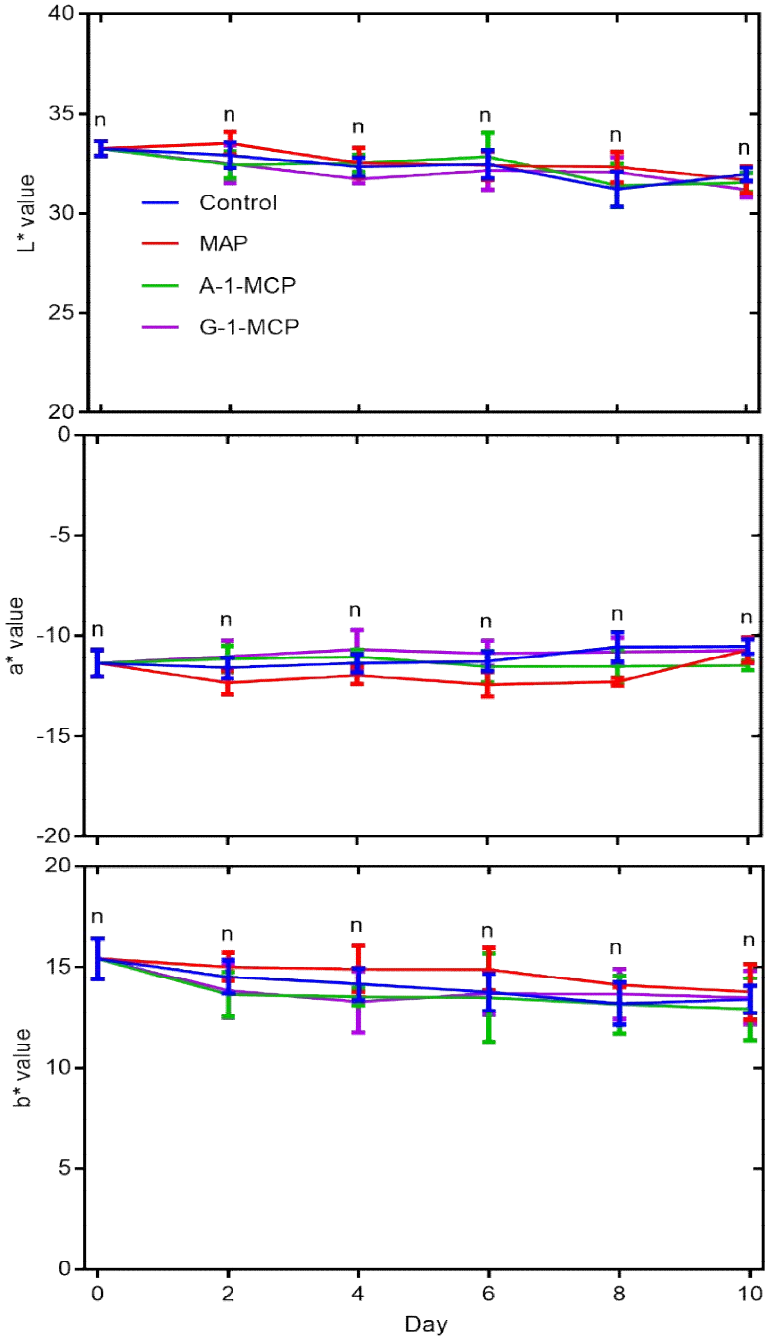

Fig. 2. Changes in peel color (L*, a* b*) of cucumbers stored at 23 ± 1°C
Treatment abbreviations and Fig. legends are the same as in Fig. 1

3.6 Chlorophyll Content

Fig. 6 shows changes in chlorophyll a and b contents of cucumbers. Cucumbers of control and MAP treatments had higher chlorophyll a values than cucumbers of 1-MCP treatments. Starting from day 6, 1-MCP seemed to suppress the increase in chlorophyll a contents. At the end of storage, the highest chlorophyll a content was recorded in control (1.81 mg 100 g^{-1}) while the lowest in aqueous-1-MCP treated ones (1.43 mg 100 g^{-1}). The chlorophyll b contents of

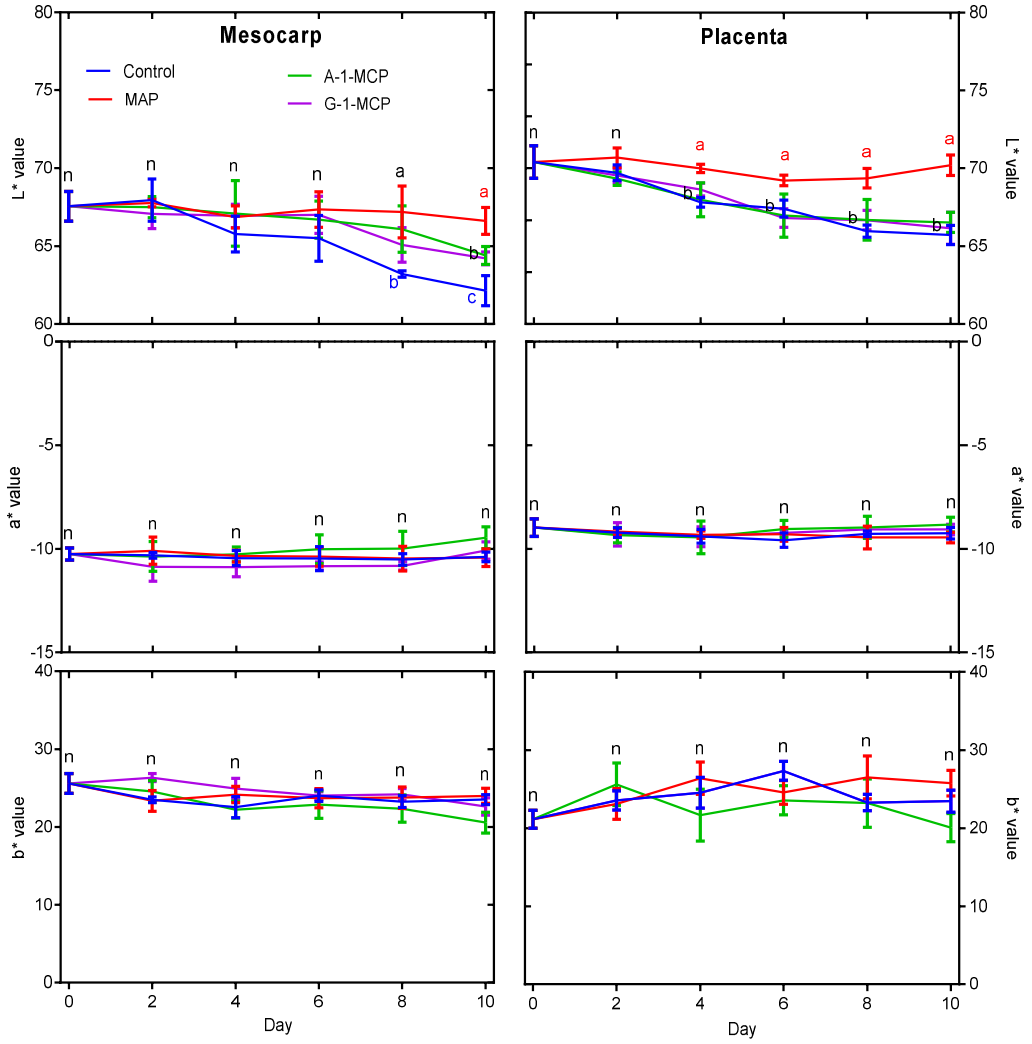

Fig. 3. Changes in mesocarp and placenta color (L*, a* b*) of cucumbers stored at 23 ± 1°C
Treatment abbreviations and Fig. legends are the same as in Fig. 1

cucumbers showed very minute changes during the storage (Fig. 6). At the end of the storage period, the chlorophyll b content was the highest (1.80 mg 100 g^{-1}) for control, followed by G-1-MCP (1.54 mg 100 g^{-1}) and A-1-MCP (1.43 mg 100 g^{-1}); the lowest value (1.21 mg 100 g^{-1}) was registered by cucumbers saved in MAP. The decrease in chlorophylls during storage is expected due to chlorophyll degradation as a result of chlorophyll enzyme activity possibly leading fruit to senescence [26]. In our experiment cucumber stored in MAP registered higher chlorophyll a values, which is consistent a previously published study by Dhall et al. [12].

3.7 Decayed Fruit Ratio

Fig. 7 shows the development of fungal decay in cucumbers at the end of the storage, expressed as the percentage of visibly infected samples out of the total amount of stored samples. Cucumbers treated with aqueous 1-MCP showed higher decayed fruit ratio compared to control, MAP or gaseous 1-MCP applications. The high fungal growth ratio seen in aqueous-treated cucumbers may be attributed to preparation of the treatment in which the cucumbers immersed in 1-MCP diluted water, which might have caused a microbial contamination.

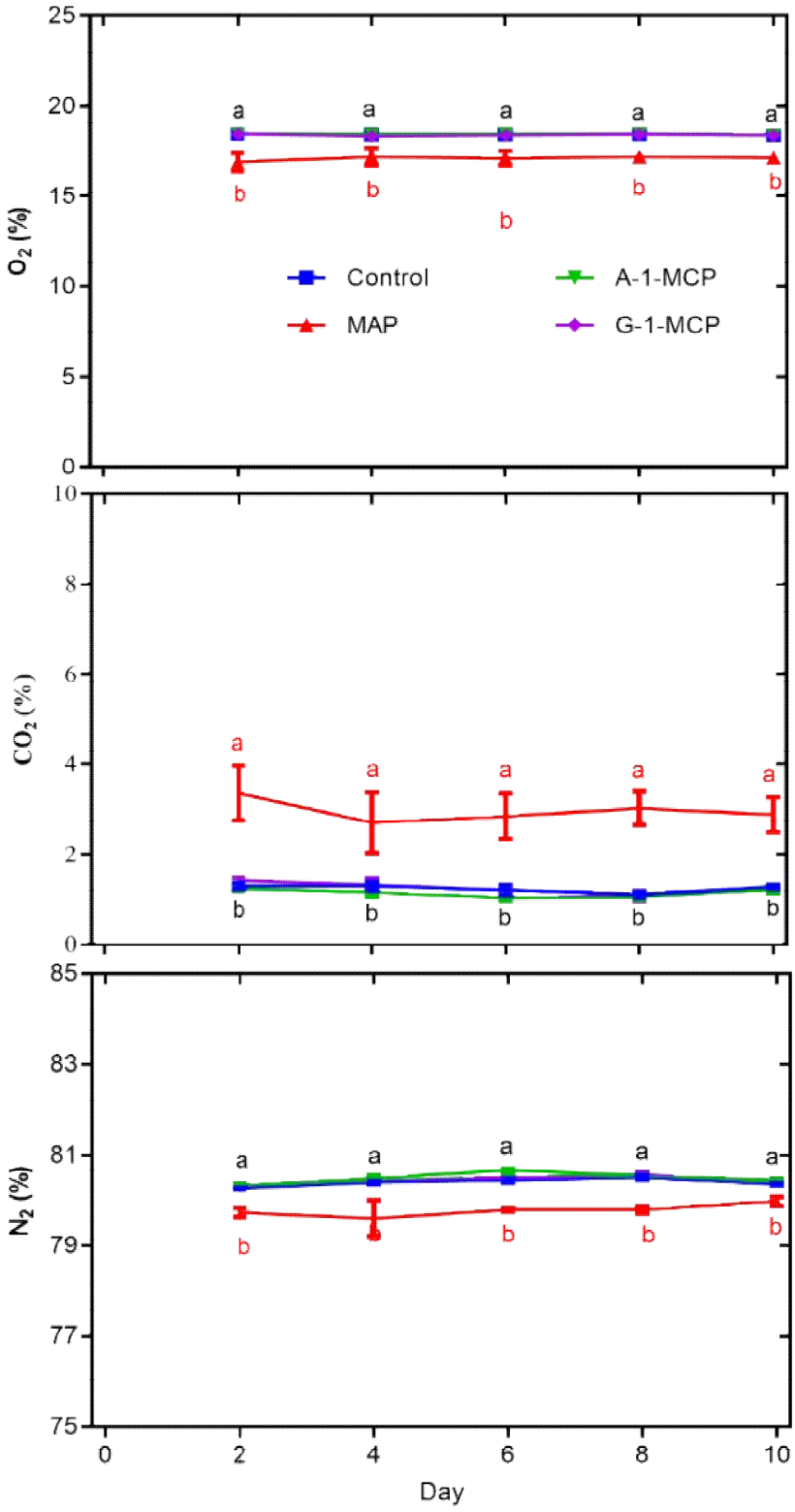

Fig. 4. Changes in headspace gas composition of packages stored with cucumbers at 23 ± 1°C

Treatment abbreviations and Fig. legends are the same as in Fig. 1

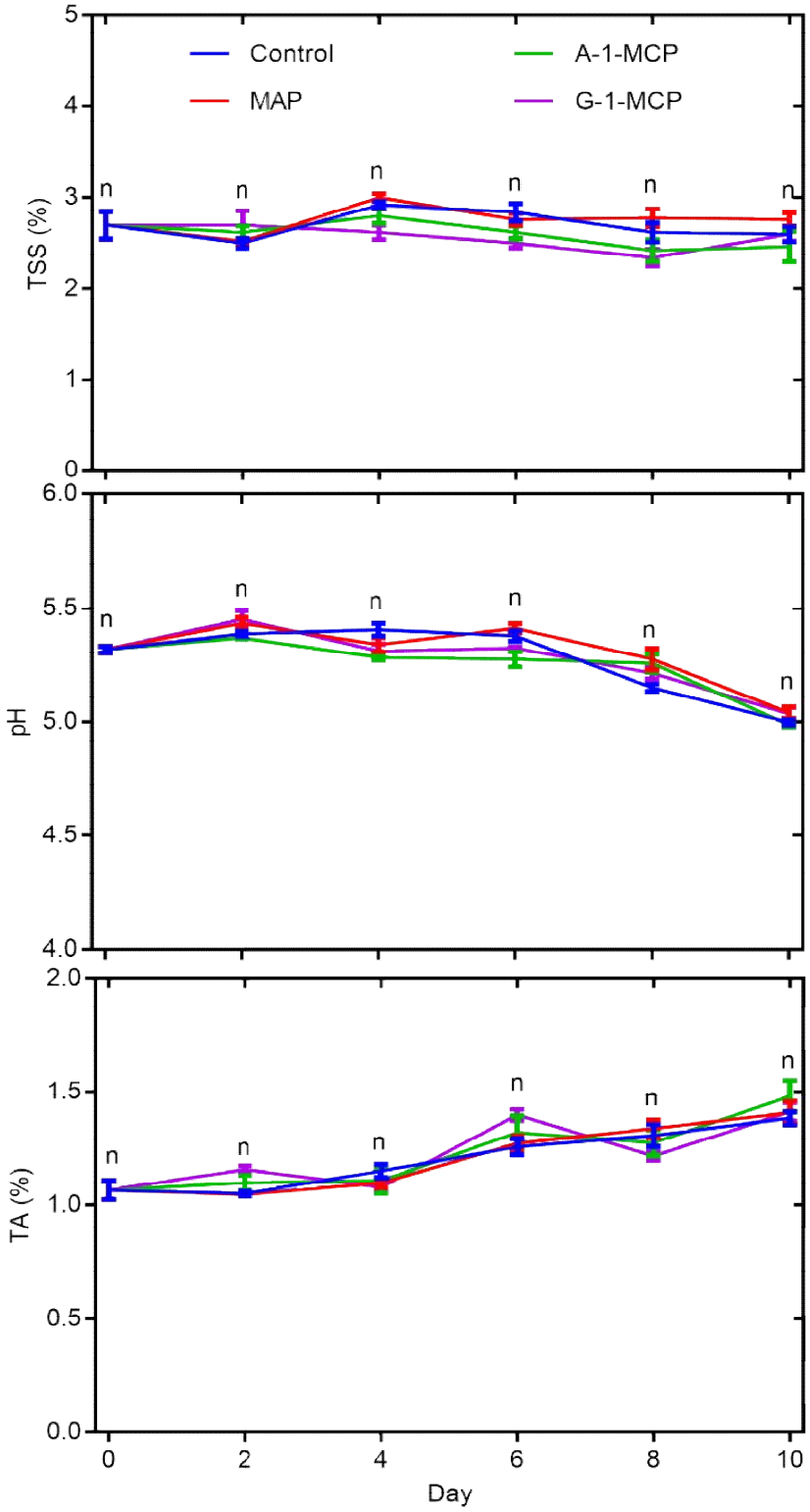

Fig. 5. Changes in total soluble solids, pH and treatable acidity contents cucumbers at 23 ± 1°C

Treatment abbreviations and Fig. legends are the same as in Fig. 1

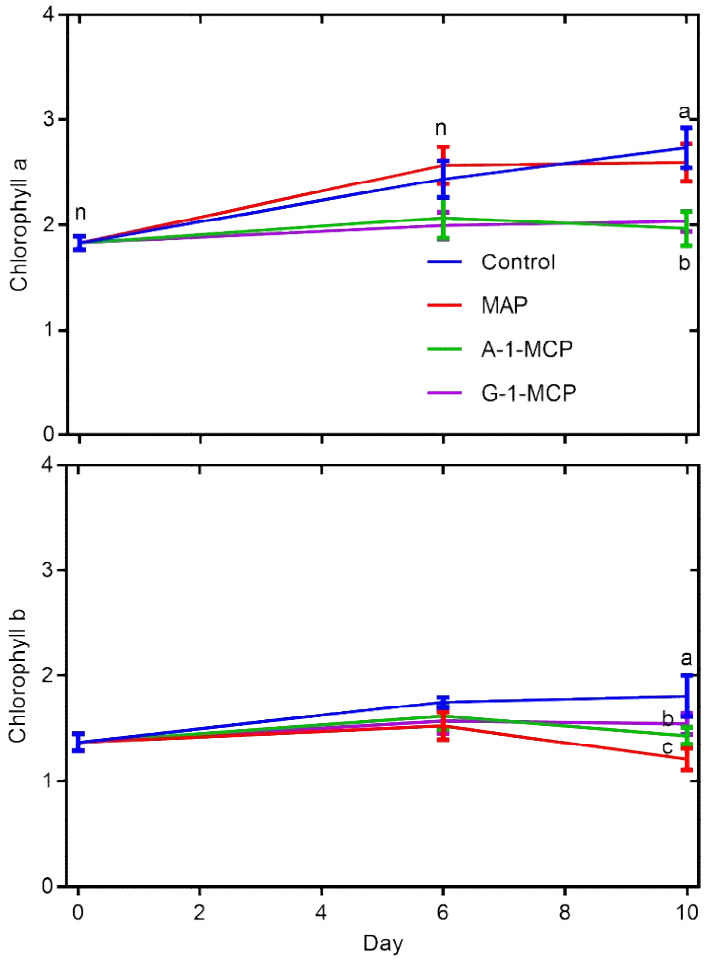

Fig. 6. Changes in chlorophyll a and b contents of cucumbers at 23 ± 1°C
Treatment abbreviations and Fig. legends are the same as in Fig. 1

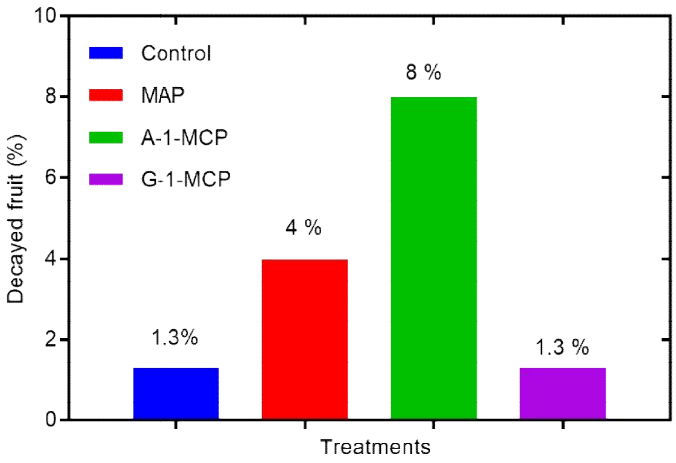

Fig. 7. Decayed fruit ratio of cucumbers at the end of storage period stored at 23 ± 1°C
Treatment abbreviations and Fig. legends are the same as in Fig. 1

4. CONCLUSION

The results indicate that neither gaseous nor aqueous 1-MCP application extend shelf life cucumbers stored at 23 ± 1°C for 10 days assessed by quality losses possibly due to cucumber's fruit non-climacteric behavior. What is more, MAP application was found to be having adverse effects on the quality of cucumbers judge by the extensive moisture and texture losses. In order to rule out the use 1-MCP on cucumber fruits, more researches are needed including 1-MCP effects on fungi proliferation and on chlorophyll degradation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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