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# Combination of Essential Oil Postharvest Vaporization and Modified Atmosphere Storage to Control Postharvest Rots of Nectarine and Maintain Fruit Quality

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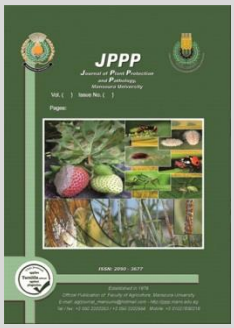


## ABSTRACT

Gray mold and *Rhizopus* rot incited by *Botrytis cinerea* and *Rhizopus stolonifer*, respectively, cause major postharvest losses in nectarine fruits cv. 'Florda' during cold storage. The effect of cinnamon and carnation oils and/or some levels of modified atmospheres, i.e. 5% $O_2$+ 5% $CO_2$ + 90% $N_2$ (MA1), 10% $O_2$ + 5% $CO_2$ + 85% $N_2$ (MA2) or 5% $O_2$ +10% $CO_2$ + 85% $N_2$ (MA3) against *B. cinerea* and *R. stolonifer* was investigated *in vitro* and *in vivo* on nectarines during cold storage. Growth of *B. cinerea* and *R. stolonifer* was completely inhibited by the application of cinnamon and carnation oils at concentrations of 50, 75 and 100 µl/L air *in vitro*. Individual treatments of nectarines with cinnamon, carnation oils and modified atmosphere MA2 were the most suppressive treatments against gray mold and Rhizopus rot on fruits stored at 0°C for 45 days during seasons 2017 and 2018. Cinnamon oil gave the highest control against fungal decay during simulated market life in both tested seasons. *In vivo* results showed also that nectarine fruits treated with the combination of either cinnamon oil or carnation oil accompanied with modified atmosphere at the level of MA2 exhibited the most suppressive treatments of decay incited by *B. cinerea* and *R. stolonifer* on nectarine fruits or simulated market life comparing with such adopted individual treatment. Combination of different modified atmospheres with cinnamon or carnation oils maintained highest fruit quality characteristics such as fruit firmness, total soluble solids, titratable acidity and reduced fruit losses.

***Keywords:*** Nectarine, gray mold, *Rhizopus rot*, essential oils, modified atmosphere

## INTRODUCTION

Nectarine (*Prunus persica*), smooth-skinned peach of the family Rosaceae is grown throughout the warmer temperate regions of both Northern and Southern hemispheres. A genetic variant of common nectarine and peach trees are virtually indistinguishable.

Several fungi cause deterioration of nectarines after harvest. Fourie and Holz (1995) followed up the infection and decay progress of nectarines and plums with *Botrytis cinerea* as a major pathogen causing grey mould. *Rhizopus stolonifer* is also considered another major pathogen of stone fruits including nectarines distinguished as transit rot, where it is usually developed in boxed fruits during transportation (Pitt and Hocking, 2009). *R. stolonifer* causes a soft rot starting in a single fruit, which transfer rapidly to all surrounding fruits. During storage, transport, marketing and shipping for export of nectarine fruits, decay caused by several mould fungi, e.g. *B. cinerea*, *R. stolonifer* as well as *Monilinia fructicola* is established causing huge losses (Förster *et al*., 2007).

Postharvest fungicides are not allowed to be adopted on stone fruits harvest including nectarine fruits in Egypt as well as Europe. Various natural compounds including flavor compounds, essential oils, acetic acid, jasmonates, chitosan and plant extracts were used as fungicide alternatives to control postharvest diseases of fruits and vegetables (Tripathi and Dubey 2004). They attributed use of certain abiotic factors particularly essential oils to play important role in plant disease resistance induction against several diseases. Plant disease management with plant essential oils has been applied as one of the eco-friendly control measures (Isman, 2000 and Koul *et al*., 2008). Essential oils including eugenol, carvacrol, thymol and menthol were effective to reduce decay, maintain quality and achieve potential improvement of post-harvest life of sweet cherry and papaya fruits and proved efficacy against *R. stolonifer* and *Colletotrichum gloeosporioides* (Serrano *et al.*, 2005, and Bosquez-Molina *et al.*, 2010). Vapors of clove, cinnamon and lemongrass oils exhibited strong inhibitory effects of *B. cinerea* causing grey mould (Sirirat *et al.* 2009). Fennel, anise, peppermint and cinnamon oils completely inhibited *B. cinerea* growth on strawberry fruits and caused an increase in the shelf life (Samane and Aminifrad 2012). However, treatment with plant essential oils proved noticeable evident as useful eco-friendly control of postharvest decay caused by some fungal species during fruit storage (Sivakumar and Bautista-Baños, 2014). Jeum *et al*. (2015) consequently used plant essential oils, volatile aromatic compounds such as glucosinolates, jasmonates and acetaldehydes as plant-based antimicrobial substances to control anthracnose on pepper fruits. The application of thyme and savory essential oil vapors significantly reduced

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the rots and decreased postharvest losses and preserving the quality of peaches and nectarines (Santoro *et al,* 2018).

Modified atmosphere is a promising applied approach to control postharvest diseases of fruits and vegetables. Hess-Pierce and Kader (2003) suggested storage at 7.5$^{o}$C in5 kPa $O_2$ + 15 kPa $CO_2$ as the optimum combination to maintain the original quality of 'Wonderful' pomegranates which are decayed seriously with *B. cinerea*. Karabulut and Baykal (2004) found that different postharvest diseases of peaches were effectively controlled using fungicide alternatives such as a yeast antagonistic agent, hot water and modified atmosphere packaging. Modified (MA) or controlled atmosphere (CA) have been used by several authors to extend shelf-life of fruits and vegetables, especially for those with high respiration rate as very perishable products (Pariasca *et al.*, 2001 and Sanchez-Mata *et al.*, 2003). Also, Ahmadi *et al.* (1999) exposed naturally infected and artificially inoculated nectarines with *Monilinia fructicola* to 15% $CO_2$ for short-term, 16 days at 5$^{o}$C followed by 3 days ripening at 20$^{o}$C. Brown rot incited by *M. fructicola* on nectarines was controlled by $CO_2$ storage in non-inoculated nectarines, while visual rotting of fungal sporulation was progressed rapidly in inoculated fruits. Modified atmosphere packaging (MAP) storage has been successfully applied in order to prolong the shelf-life of nectarines (Akbudak and Eris, 2004). Modified atmosphere packaging (MAP) remarkably reduced weight loss, decay incidence and maintained allover fruit quality compared to control(Samar and Nagy, 2017).

It was expected to obtain more postharvest disease control by combination of essential oil treatments and modified atmosphere storage. Sweet cherries treated with thymol oil combined with modified atmosphere packaging reduced gray mold rot of *B. cinerea* inoculated cherries (Chu *et al.* 1999). Combination between plant oils eugenol or thymol, and modified atmosphere packaging was effective to maintain postharvest quality and safety of table grapes (Valero *et al.*, 2006). Also, combination of chemical treatments and controlled atmosphere was effective to control grey mould caused by *B. cinerea* on pomegranate and prolonged its storability (Palou *et al.*, 2007). Combination of MA (8% $CO_2$, 2% $O_2$) and thyme oil significantly reduced the incidence and severity of anthracnose, grey pulp, vascular browning, weight loss, and loss of fruit firmness of avocado cvs 'Fuerte', 'Hass' and 'Ryan'(Sellamuthu *et al.* 2013).

Quality of nectarine fruits were maintained when using modified atmosphere storage. Higher fruit firmness and less softening of nectarines could be attributed to the beneficial effects of atmospheres with low $O_2$ and/or high $CO_2$ content. MAP of peaches and nectarines slowed down the respiration rate of fruits, retarded the decrease in titratable acidity values, maintained the fruit sugar and soluble solids content, flesh firmness, vitamin C and juice content, and slowed deterioration through decreasing fruit injury and delaying browning development (Santana *et al.*, 2010; and Bal, 2012).

The aim of current study was to investigate the synergistic effect of essential oils as postharvest treatment in combination with modified atmosphere during cold storage at 0$^{o}$C for up to 45 days to suppress decay of nectarines incited by *Botrytis cinerea* and *Rhizopus stolonifer*, and to maintain fruit quality.

## MATERIALS AND METHODS

**Source of the tested fungal isolates:**

*B. cinerea* and *R. stolonifer* isolates were obtained from diseased nectarine fruits collected from local market and proved their pathogenic capability on apparently healthy nectarine fruits through laboratory isolate purification and artificial inoculation on apparently healthy nectarine fruits. The most virulent isolates from both fungi were determined. Purified pathogenic isolates were kept on potato dextrose agar (PDA) under refrigeration for further studies. Activated isolates of *B. cinerea* and *R. stolonifer* were prepared on PDA grown at 20$^{o}$C for 7 days for artificial inoculation before use for *in vitro* and *in vivo* experiments.

**Source of Plant oils:**

Cinnamon (*Cinnamon zylanicum*) and carnation (*Dianthus caryophyllus*) oils were obtained from Cairo Company for oils, Cairo, Egypt.

**Effect of some plant oils or controlled atmosphere on growth of *B. cinerea* and *R. stolonifer in vitro:***

Equal volume of sterilized PDA medium was poured into Petri dishes and let for solidification under aseptic conditions. PDA medium was inoculated with 5-mm disc of 7-day-old cultures of pathogenic *B. cinerea* and *R. stolonifer* fungi. Three inoculated Petri dishes for each treatment were placed with lids removed inside a sterilized 10-liter glass jar fitted with rubber stopper with inlet and out let openings in aseptic conditions. Three glass jars were used as three replicates for such plant oil or controlled atmosphere (CA) treatment.

**a. Adopting essential oils vapor treatments *in vitro*:**

Cinnamon and carnation oils vapors were tested at concentrations of 25, 50, 75 and 100 µl oil/l liter volume of jar space containing inoculated PDA medium with such fungi. Different concentrations of plant oils were vaporized utilizing vaporizing breathing pump (Emed) (Model: A1000230 v- 50 Hz 90va Manufacturer: Elettroplastica spa via delay commercio1 travagliato (BS) Italy). Evolved vapors were approached into test jars inlet opening through pipe lines. The machine produced a capacity volume of 4000 µL oil vapor/hr.

**b. Adopting modified atmosphere treatments *in vitro*:**

Efficacy of three modified atmospheres was tested to inhibit *B. cinerea* and *R. stolonifer in vitro*. Tested modified atmospheres were as follows:

1) 5% $O_2$, 5% $CO_2$ and 90% $N_2$,
2) 10% $O_2$, 5% $CO_2$ and 85%$N_2$, and
3) 5% $O_2$, 10% $CO_2$ and 85% $N_2$.

Gas flow meter was used to determine the volume of flowing gas to obtain defined required concentrations of each gas, $O_2$, $CO_2$, and $N_2$. Quantek instruments oxygen/carbon dioxide analyzer (Model 902D Dual Trak) was used to measure and assure concentration of such prepared modified atmosphere treatment. Petri-dishes were infested with either of the two fungal pathogens and placed in a glass jar containing normal air served as a control (El-Boghdady, 1999). The diameter of developed colonies were measured when fungal mycelium covered

one plate in the control treatment and the percentage of reduction in the colony diameter was calculated using the formula suggested by Sirirat *et al.* (2009) as follows:

$$\% \text{ Fungus growth reduction} = \frac{\Delta do - \Delta d}{\Delta do} x100$$

**Where, $\Delta d_0$ and $\Delta d$ are the average diameter of the fugal colonies in the control and treatment sets, respectively.**

**Nectarine fruit source:**

Nectarine (*Prunus persica var. nectarine*, cv. Florda) fruits were harvested at maturity stage 87 described as fruit ripe for picking in the last week of April 2017 and 2018 based on skin color and flesh firmness from a commercial orchard in Behaira governorate, Egypt as categorized by Meier (2001). The fruits were transported on the same day to the laboratory. The fruits were selected for apparently healthy, uniform size, color and absence of mechanical damage. Nectarine fruits were divided into three groups. The first group of fruits contained nectarines left without sterilization was used for natural infection experimentation. The other two groups of fruits were inoculated with *B. cinerea* or *R. stolonifer* and were used for control of artificially infected fruits experimentation.

**Inoculums preparation:**

Inoculum of pathogenic isolates of *B. cinerea* and *R. stolonifer* was prepared by dislodging spores from the surface of 7-day-old cultures in Petri dishes by flooding with sterile distilled water and gentle rubbing with a sterile glass rod. The suspension was filtered through sterilized three layers of muslin cloth to remove mycelial fragments. The concentration of fungal spores was counted by hemocytometer and adjusted to 105 spores/mL with sterile distilled water (Arrebol *et. al.*, 2010).

**Inoculation of nectarine fruit with *B. cinerea and R. stolonifer*:**

The two groups of nectarine fruits were surface sterilized with 70% ethyl alcohol and wounded by puncturing the peel of each fruit on the equator with a template of 4 sterilized steel rods (2-mm deep x 0.5 mm diameter) in a square of 5 mm side length. First group of the punctured nectarine fruit was inoculated with *B. cinerea* and the other group was inoculated with *R. stolonifer*. The inoculation was carried out by spraying the surface of fruits with fresh prepared fungal spore suspension. Inoculated fruits were allowed to air dry and kept at room temperature for 24 hours, before postharvest treatments were applied, then treated with two plant oils.

**Effect of plant oils on controlling nectarine fruit rots caused by *B. cinerea and R. stolonifer:***

Nectarine fruit groups of naturally infected and artificially inoculated were vaporized separately with the plant oil treatment, while fruits of control treatment were vapored by normal air. Fruits of each replicate were placed in 10 L glass jar. Plant oil vapor was introduced into the jars through the inlet opening of the rubber jar cover**.** Plant oils concentration of 100µl/l package volume space was vaporized utilizing breathing pump described before.

Both naturally infected and artificially inoculated fruits were subjected to such oil vapor treatment. Oil treated fruits and control ones were packed in polypropylene punnets with 28 holes (0.8 mm- diameter each). Each punnet contained 6 fruits.Three punnets were used as replicates for each treatment.

**Modified Atmosphere treatment:**

Naturally infected or artificially inoculated fruits with *B. cinerea* or *R. stolonifer* were packed in punnets. Each punnet contained 6 fruits and placed in non-perforated low-density polyethylene bags (30 µm-thickness). Each bag contained one punnet. The polyethylene bags containing nectarine fruits were subjected to gas-flushing by prepared gas mixture enough to change the internal atmosphere to desired concentrations of modified atmospheres, i.e. (5% $O_2$ + 5% $CO_2$+ 90% $N_2$),(10% $0_2$ + 5% $CO_2$ + 85% $N_2$) and (5% $0_2$ + 10% $CO_2$ + 85% $N_2$) comparing with the control as normal air containing 21% $0_2$ + 0.03% $CO_2$ +78.97 % $N_2$. Gas mixture concentrations were measured and adjusted using $O_2$/$CO_2$ gas analyzer (Dualtrak model 902D).

**Combination of oil treatments with modified atmosphere:**

Fruits were treated with defined oil vapor treatment, then stored under air or tested modified atmosphere.

**Summation of postharvest Treatments of nectarine fruits with plant oils and Modified Atmosphere as follows:**

1) Cinnamon oil (100 µl/L)
2) Carnation oil(100 µl/L)
3) 5% $O_2$ + 5% $CO_2$ + 90% $N_2$
4) 10% O2 + 5% $CO_2$ + 85% $N_2$
5) 5% O2 + 10% $CO_2$ + 85% $N_2$
6) Cinnamon oil(100 µl/L) + 5% $O_2$ + 5% $CO_2$ + 90% $N_2$
7) Cinnamon oil (100 µl/L)+ 10% $O_2$ + 5% $CO_2$ + 85% $N_2$
8) Cinnamon oil (100 µl/L)+ 5% $O_2$ +10% $CO_2$ + 85% $N_2$
9) Carnation oil (100 µl/L)+ 5% $O_2$ + 5% $CO_2$ + 90% $N_2$
10) Carnation oil (100 µl/L)+ 10% $O_2$ + 5% $CO_2$ + 85% $N_2$
11) Carnation oil (100 µl/L)+ 5% $O_2$ + 10% $CO_2$ + 85% $N_2$
12) Control, artificially inoculated nectarine fruits with *B. cinerea* or *R. stolonifer* or without infection and untreated

Treatments from number 1 to number 12 were adopted on naturally infected nectarines as well as on artificially inoculated ones with *B. cinerea* or *R. stolonifer*. Cinnamon and carnation oils were adopted on nectarine fruits at the concentration of 100 µl oil/L space volume.

**Disease incidence assessment*:***

Disease incidence (%) was determined according to Zeng *et al*. (2006). Nectarine fruit was counted decayed when the visible rot zone on fruit surface around the wounded puncture was more than 0.5 mm-wide. Efficiency of the tested treatments to control the postharvest diseases was calculated as follows:

**% Disease incidence (DI) = no. of diseased fruits*100/total no. of treatment fruit**

**% Efficiency (E) = mean DI of the control - mean DI of treatment*100/ mean DI of the control**

**Determination of physical and chemical properties:**

Fruit samples of such treatment were subjected to quality evaluation tests during cold storage as follows:

**Fruit firmness, total soluble solids (TSS) % and titratable acidity (TA) %**

Fruit firmness was measured on the two opposite sides of nectarine fruit samples by using a hand Magness Taylor pressure tester (lb/in2). Total soluble solids (TSS) were measured using Digital refractometer, PR32 (0-32%)

Meiji Techno CO., Tokyo, Japan. Titratable acidity (TA) was determined by titrating 5-ml juice with 0.1 N sodium hydroxide using phenolphthalein as indicator and expressed as malic acid % (A.O.A.C., 2000).

**Shelf life:**

At the end of storage at 0°C and 90% RH for 45 days, fruits from such treatment of oil and/or modified atmosphere of naturally infected fruits were held in ambient room conditions at 25°C and 75 % relative humidity (RH) for 5 days simulating handling and market conditions. Decay development and quality of fruit were determined after the shelf life test period.

**Experimental design and statistical analysis:**

Complete randomized design was followed up to adopt both laboratory and cold storage experiments. The results of the parameters (linear growth, disease incidence and efficiency as well as quality evaluation of treatments were analyzed using CoStat version 6.400- CoHort Software. Data were analyzed with the Analysis of variance (ANOVA) procedure. Significant differences were determined according to the least significant difference (LSD) test at the 5% probability for experiments in both investigated seasons (Snedecor and Cochran, 1980). Means of tested treatments were compared by LSD values at 5% probability.

## RESULTS AND DISCUSSION

**Effect of some plant oils and modified atmosphere on linear growth of *B. cinerea* and *R. stolonifer*:**

Linear growth of *B. cinerea* and *R. stolonifer* as affected by plant oils and modified atmosphere incubation is introduced in Table (1). All tested concentrations of cinnamon and carnation oils significantly inhibited *B. cinerea* and *R. stolonifer* growth *in vitro*. When oils were tested at 25 µl/L space size, they significantly inhibited the fungal growth comparing with the control, while no mycelium growth of both pathogenic fungi was detected at oil concentrations of 50, 75 and 100 µl oil/L space size during incubation at 20°C for 7 days. Similarly, Plotto *et al*. (2003) reported that *B. cinerea* and *R. stolonifer* growth was inhibited by certain tested essential oils particularly thyme oil that exhibited 100% inhbition of *B. cinerea, R. stolonifer*, as well as *Alternaria alternata*. Also, Sirirat *et al.* (2009) reported that vapors of clove, cinnamon and lemongrass oils exhibited high inhibitory effects on grey mold incited by *B. cinerea* which is in concomitant with the current results of cinnamon oil effect. The growth of *B. cinerea* and *Pythium aphanidermatum* was completely inhibited by cinnamon and carnation oils at concentrations of 0.25% as obtained by Abdel-Mageed *et al*. (2014). Also, cinnamon oil completely inhibited the mycelial growth and spore germination of *Colletotrichum acutatum* at the concentrations of 0.200 µL/mL and 0.175 µL/mL (v/v) (He *et al*, 2018), and it significantly reduced the mycelial growth and conidial germination of *Villosiclava virens* (Zheng *et al*, 2019). Meanwhile, the highest linear growth of *B. cinerea* and *R. stolonifer* was observed in the control (un-treated fungal cultures with any plant oil or modified atmosphere).

On the other hand, modified atmospheres at tested concentrations of $CO_2$, $O_2$ and $N_2$ significantly decreased growth of *B. cinerea* and *R. stolonifer in vitro*. Modified atmosphere contained gas mixture of 10% $O_2$, 5% $CO_2$ and 85 %$N_2$ was the most effective atmosphere to reduce *B. cinerea* and *R. stolonifer* growth comparing with other tested levels of modified atmosphere, followed by modified atmosphere of 5% $O_2$, 5% $CO_2$, 90% $N_2$ mixture. Modified atmosphere of 5% $O_2$, 10% $CO_2$, and 85% $N_2$ was the least effective gas mixture to suppress growth of both fungi on PDA medium. Cia *et al*. (2003) found that the atmospheres of (3% $O_2$ + 8%, 10% or 12% $CO_2$) and (5% $O_2$ + 10 or 12% $CO_2$) significantly inhibited the mycelial growth of *R. stolonifer* on PDA medium. On the other hand, Reyes (1990) used lower $O_2$ concentration down to 1.5% + high $CO_2$ to 7.5% to suppress growth and sporulation of *B. cinerea* and *Mucor mucedo* on aubergine-extract agar medium maintained at 13°C for 4 or 14 days. On contrary, Bertolini *et al*. (2009) reported that mycelial growth of *B. cinerea* on potato dextrose agar decreased linearly with increasing tested $CO_2$ concentrations from 5, 10, 15 to 20% $CO_2$. However, these findings are not confirmed by our obtained results.

**Table 1. Efficacy of some plant oils and modified atmosphere on linear growth of *B. cinerea* and *R. stolonifer* grown on PDA medium at 20°C for 7 days.**

| Treatment | Concentration | *B. Cinerea* | | *R. stolonifer* | |
|---|---|---|---|---|---|
| | | Growth (mm) | Efficacy (%) | Growth (mm) | Efficacy (%) |
| Cinnamon oil | 25 µl/ L space size | 10.0 | 88.9 | 12.7 | 85.9 |
| | 50 µl/ L space size | 0.0 | 100.0 | 0.0 | 100.0 |
| | 75 µl/ L space size | 0.0 | 100.0 | 0.0 | 100.0 |
| | 100 µl/ L space size | 0.0 | 100.0 | 0.0 | 100.0 |
| Carnation oil | 25 µl/ L space size | 21.7 | 75.9 | 33.7 | 62.6 |
| | 50 µl/ L space size | 0.0 | 100.0 | 0.0 | 100.0 |
| | 75 µl/ L ai space size | 0.0 | 100.0 | 0.0 | 100.0 |
| | 100 µl/ L space size | 0.0 | 100.0 | 0.0 | 100.0 |
| Modified atmosphere | 5% O2 + 5% CO2 + 90% N2 | 22.7 | 74.8 | 42.3 | 53.0 |
| | 10% O2 + 5% CO2 + 85% N2` | 18.7 | 79.3 | 25.7 | 71.5 |
| | 5% O2 + 10% CO2 + 85% N2 | 29.3 | 67.4 | 57.7 | 35.9 |
| Control | Normal air | 90.0 | 0.0 | 90.0 | 0.0 |
| LSD at 5% | | 2.47 | | 2.69 | |

**Effect of plant oils and/or modified atmosphere to control gray mold and Rhizopus rot of nectarine fruits during cold storage at 0°C for 45 days:**

Vaporization of nectarine fruits with either cinnamon or carnation oils at concentration of 100 µl/ L space size reduced greatly the disease incidence of artificially inoculated fruits with *B. cinerea* and *R. stolonifer* stored at 0°C for 45 days as shown in Table (2). Vaporization of nectarine fruits with cinnamon oil after harvest was the best effective treatment, where it completely prevented the disease incidence of the two tested mold pathogens on artificially infected nectarines as well as decay development in naturally infected fruits during the cold storage at 0°C for 45 days in season 2017. Similarly, carnation oil completely inhibited the infection on fruits inoculated with *R. stolonifer* and decay development on naturally infected nectarines during the cold storage for 45 days in same season. Second season, 2018, treated nectarine fruits with carnation oil gave higher control of *B. cinerea* and *R. stolonifer* infection on artificially inoculated nectarines than cinnamon oil, where its efficacy reached 97.3% and 100% for both fungi, comparing with efficacy of cinnamon oil as 95.8% and 84.3%, respectively. This approach of disease control using plant oils was also adopted by Sukatta *et al.* (2008) who showed that mixing of clove and cinnamon oils at appropriate ratios resulted in enhancing their efficacy against *A. alternata*, *Phomopsis viticola* and *R. stolonifer* causing postharvest decay of grapes. On the other hand, effectiveness of essential oil application to control the postharvest decay increased when a combination of eucalyptus and cinnamon essential oils vapour was applied on strawberry and tomato fruit (Tzortzakis, 2007 a and 2007 b). Andrew *et al* (2013) used oregano and lemon oils as very effective in controlling disease severity of infected fruit by *B. cinera* in tomatoes, strawberries and cucumbers. The occurrence of gray mold rot of *B. cinerea* and other unknown fungi was significantly reduced by fumigation with 30 µg/mL thymol in several table grape cultivars (Shin *et al.*, 2014). Also, usage of essential oils as bergamot, lemongrass, Savory and thyme oils significantly reduced postharvest decay of nectarine and peach fruits during storage at 0°C for 28 days (Abd El wahab, 2015 and Santoro *et al*, 2018). So, it was found previously positive effectiveness of essential oils to control postharvest diseases supporting our results to control postharvest decay of nectarines with major fungi.

The three tested levels of modified atmosphere (5% $O_2$ : 5% $CO_2$ : 90% $N_2$ and 10% $O_2$ : 5% $CO_2$ : 85% $N_2$ and 5% $O_2$ : 10% $CO_2$ : 95% $N_2$) to control gray mold and Rhizopus rot of nectarine fruits achieved remarkable control during cold storage at 0°C for 45 days in both experimentation seasons as presented in Table (2). Modified atmosphere containing 10% $O_2$ : 5% $CO_2$ : 85% $N_2$ was the most effective modified atmosphere treatment, where it completely inhibited disease incidence incited *B. cinerea* and *R. stolonifer* on artificially inoculated nectarine fruits in season 2017 and on naturally infected fruits in season 2018. Also, inoculated nectarine fruits with *B. cinerea* and *R. stolonifer* then stored under modified atmosphere containing 5% $O_2$ : 5% $CO_2$ : 90% $N_2$ had significant lower gray mold rot and Rhizopus rot incidence than those found on inoculated nectarines stored in normal air (control) during seasons 2017 and 2018. Meanwhile, the level of modified atmosphere containing 5% $O_2$ : 10% $CO_2$ : 85% N was less effective modified atmosphere to reduce infection of nectarine fruits with *R. stolonifer* during first season, and so on *R. stolonifer* in the second season, referring to collaboration effect of both $O_2$ and $CO_2$ concentration regardless increasing $CO_2$ level. On contrary, Almenar *et al* (2006) mentioned that using of controlled atmosphere containing 11% $CO_2$ and 10% $O_2$ caused inhibition of the development of *B. cinerea* on strawberry fruit during storage. Bertolini *et al.* (2009) found that increasing $CO_2$ concentration to 10% and 15% $CO_2$ was concomitant with decreased heads lesion area caused by *B. cinerea* in artificially inoculated red chicory for up to 60 days long storage. In naturally infected heads, effect of 5% and 10% $CO_2$ was remarkable even after 150 days of storage as it prevented growth of *B. cinerea* in each single head. So, it could be expected different effectiveness of $CO_2$ concentration according to the potential of fungal infection particularly *B. cinerea* as demonstrated by artificial inoculation versus natural infection investigation. Also, keeping Kurdistan strawberries at 4°C under modified atmosphere containing 5-10% $O_2$ and 5-10% $CO_2$ gave a good control against *B. cinerea* on fruits for 3 week (Jouki and Khazaei, 2012). Modified atmosphere storage containing 5% $O_2$ + 10% $CO_2$ was highly effective to control the growth of molds after 15 days storage of sweet cherry fruits (Serradilla *et al.*, 2013). All of these investigations emphasized the effectiveness of $CO_2$ against *B. cinerea* growth on different fruits at concentrations mostly up to 10%. Also, Almenar *et al* (2006) mentioned that using of controlled atmosphere containing 11% $CO_2$ and 10% $O_2$ caused inhibition of the development of *B. cinerea* on strawberry fruit during storage. In this respect, modified atmosphere packaging (MAP) strongly reduced the disease incidince of peach, Its effect may be attributed to a reduction of respiratory activity, delay in ripening and softening, and a reduced incidence of various physiological disorders and pathogenic infection (Samar and Nagy, 2017).

Combination of plant oil treatments and modified atmosphere storage approach showed significant effect against infection of nectarine fruits with *B. cinerea*, *R. stolonifer* on artificially inoculated and naturally infected fruits. Combination of carnation oil and the level of MA containing 10% $O_2$ + 5 $CO_2$ + 85% $N_2$ was the most effective treatment where it completely inhibited the infection of nectarine fruits with *B. cinerea* and *R. stolonifer* during cold storage for 45 days in the two seasons. Similar results of this combination were obtained on naturally infected nectarines in the first season as well as occupying most effective treatment of non-inoculated nectarines in the second season.

Also, nectarine fruits treated with cinnamon oil combined with modified atmosphere containing10% $O_2$ + 5% $CO_2$ + 85% $N_2$ or 5% $O_2$ + 10% $CO_2$ + 85% $N_2$ completely inhibited the infection of nectarine fruits infected with *R. stolonifer* and natural infection fruits during the cold storage for 45 days in season 2017. While, Nectarine fruits treated with carnation oil combined with the levels of modified atmosphere containing 5% $O_2$ + 5% CO2 + 85% $N_2$ or 5% $O_2$ + 10% $CO_2$ + 85% $N_2$ as post-harvest

treatments completely inhibited the disease incidence of *R. stolonifer* and natural infection on nectarine fruits during season 2017 and infection of Nectarine fruits with *R. stolonifer* in season 2018. On the other hand, high percentage of incidence of gray mold and rhizopus rot occurred in control treatments either artificially inoculated nectarine with fungi or not without oil and modified atmosphere treatments. Similarly, combinations of MAP and application of eugenol or thymol were reported to reduce incidences of microbial spoilage in sweet cherry (Serrano *et al*., 2005). Also, the combination of modified atmosphere (8% $CO_2$ + 2% $O_2$) and thyme oil significantly reduced the incidence and severity of anthracnose and grey pulp of avocado (Sellamuthu *et al* 2013). Meanwhile, Carnation or cinnamon oils combined with modified atmosphere packaging reduced decay percentage in snap bean pods infected with *B. cinerea* and *Pythium aphandermatum* during cold storage (Abdel-Mageed *et al*. 2014). Also, Almenar *et al* (2006) mentioned that using of controlled atmosphere containing 11% $CO_2$ and 10% $O_2$ caused inhibition of the development of *B. cinerea* on strawberry fruit during storage.

**Table 2. Comparative effectiveness of plant oils at 100 µl/L space size and/or modified atmosphere on disease incidence in naturally infected nectarines as well as inoculated fruits with *B. cinerea* or *R. stolonifer* during cold storage at $0^0$C for 45 days**

| Treatments | Disease incidence (%) 2017 season | | | | | | Disease incidence (%) 2018 season | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Artificially inoculated | | | | Natural infection | | Artificially inoculated | | | | Natural infection | |
| | *B. cinerea* | | *R. stolonifer* | | | | *B. cinerea* | | *R. stolonifer* | | | |
| | D.I.% | E % | D.I.% | E % | D.I.% | E % | D.I.% | E % | D.I.% | E % | D.I.% | E % |
| Cinnamon oil | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 2.0 | 95.8 | 1.3 | 84.3 | 0.7 | 91.3 |
| carnation oil | 2.3 | 93.3 | 0.0 | 100.0 | 0.0 | 100.0 | 1.3 | 97.3 | 0.0 | 100.0 | 0.7 | 91.3 |
| MA 1 | 3.0 | 91.4 | 0.7 | 90.4 | 2.3 | 80.6 | 6.0 | 87.3 | 1.7 | 79.5 | 1.7 | 78.8 |
| MA 2 | 0.0 | 100.0 | 0.0 | 100.0 | 1.0 | 91.7 | 2.3 | 95.1 | 1.3 | 84.3 | 0.0 | 100.0 |
| MA 3 | 3.3 | 90.4 | 1.0 | 85.7 | 3.0 | 75.0 | 5.7 | 88.0 | 2.7 | 67.5 | 1.0 | 87.5 |
| Cinnamon oil + MA1 | 1.7 | 95.2 | 0.0 | 100.0 | 2.0 | 83.3 | 5.0 | 89.4 | 0.3 | 96.8 | 1.3 | 83.8 |
| Cinnamon oil + MA2 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 3.0 | 93.7 | 0.7 | 91.6 | 1.0 | 87.5 |
| Cinnamon oil + MA3 | 2.0 | 95.2 | 0.0 | 100.0 | 0.0 | 100.0 | 5.7 | 88.0 | 1.3 | 84.3 | 1.0 | 87.5 |
| Carnation oil + MA1 | 3.0 | 91.4 | 0.0 | 100.0 | 0.0 | 100.0 | 2.0 | 95.8 | 0.0 | 100.0 | 1.7 | 78.8 |
| Carnation oil + MA2 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 0.7 | 91.3 |
| Carnation oil + MA3 | 2.7 | 92.3 | 0.0 | 100.0 | 0.0 | 100.0 | 1.7 | 96.0 | 0.0 | 100.0 | 1.3 | 83.8 |
| Control | 34.7 | | 7.0 | | 12.0 | | 47.3 | | 8.3 | | 8.0 | |
| LSD at 5% | 1.03 | | 1.51 | | 0.97 | | 1.93 | | 1.44 | | 2.14 | |

**D.I. = Disease incidence** **E. = Efficiency** **MA = Modified atmosphere**
**MA 1 = 5% $O_2$ +5% $CO_2$ +90%$N_2$** **MA 2 = 10% $O_2$ +5% $CO_2$ +85%$N_2$** **MA 3 = 5% $O_2$ + 10% $CO_2$+85%$N_2$**
**Control, artificially inoculated nectarine fruits with *B. cinerea* or *R. stolonifer* or without infection and untreated**

**Effect of plant oils and /or modified atmosphere on controlling gray mold and Rhizopus rot of nectarine fruits during market life at 25°C for 5 days following cold storage at 0°C for 45 days:**

The efficacy of individual treatments, either plant oils or modified atmospheres and combination between them were evaluated to reduce disease incidence on nectarine fruits artificially infected with *B. cinerea*, *R. stolonifer* or under natural infection conditions after 5 days at 25°C as market life. Results in table (3) indicated that all tested treatments generally reduced the decay development on nectarine fruits caused by *B. cinerea* and *R. stolonifer* after 5 days of market life, comparing with the control as naturally infected or artificially inoculated nectarines kept without adopting investigated control measures. Cinnamon oil showed higher effectiveness than carnation on artificially inoculated nectarines, while the opposite was true on naturally infected ones during season 2017. Second season, cinnamon oil was more effective than carnation oil for either naturally infected or artificially inoculated nectarines with *B. cinerea* and *R. stolonifer*. The modified atmosphere containing 10% $O_2$ + 5% $CO_2$ + 85% $N_2$ was the most effective modified atmosphere treatment to control decay development on nectarines at different fungal inoculation conditions during both investigation seasons. Plant oils generally were more effective than all tested levels of modified atmosphere in reducing the infection caused by *B. cinerea* and *R. stolonifer* on Nectarines fruits, during the market life at 25°C for 5 days in two seasons.

Combination of tested essential oils with modified atmospheres resulted in higher effectiveness to control decay incidence on nectarine fruits. Generally, data clarified that no decay was found on nectarines treated with a combination treatment of carnation oil with 10% $O_2$ + 5% $CO_2$ + 85% $N_2$ in season 2017. Meanwhile, cinnamon oil combined with 10% $O_2$ + 5% $CO_2$ + 85% $N_2$ caused complete inhabitation of decay development on naturally infected nectarines as well as artificially inoculated ones with *B. cinerea* during market life at 25°C for 5 days in season 2017 and on naturally infected nectarines in season 2018. Similar approach of combination was suggested by Sellamuthu *et al.* (2013) who found that combination of MA (8% $CO_2$, 2% $O_2$) and thyme oil significantly reduced the incidence and severity of anthracnose, grey pulp, vascular browning, weight loss, and loss of fruit firmness of avocado cvs 'Fuerte', 'Hass' and 'Ryan'. Also, Taheri *et al* (2018) reported that essential oil positively affected the storage life of Peach fruits by reducing decay content. In this respect Almenar *et al* (2006) monition that using of controlled atmosphere containing 11%$CO_2$ and 10% $O_2$ caused inhibiting the development of *Botrytis cinerea* on wild strawberry fruit during storage.

**Table 3. Comparative effectiveness of plant oils at 100 µl/L space size and modified atmosphere on disease incidence of naturally infected nectarines or artificially inoculated with *B. cinerea*, and *R. stolonifer* kept at 25°C for 5 days as market life following the long cold storage.**

| Treatments | Disease incidence (%) 2017 season | | | | | | Disease incidence (%) 2018 season | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Artificially inoculated | | | | Natural infection | | Artificially inoculated | | | | Natural infection | |
| | *B. cinerea* | | *R. stolonifer* | | | | *B. cinerea* | | *R. stolonifer* | | | |
| | D.I.% | E % | D.I.% | E % | D.I.% | E % | D.I.% | E % | D.I.% | E % | D.I.% | E % |
| Cinnamon oil | 1.0 | 98.2 | 0.3 | 96.6 | 2.0 | 81.8 | 0.7 | 99.0 | 1.3 | 92.7 | 1.0 | 90.7 |
| carnation oil | 2.7 | 95.1 | 0.6 | 93.8 | 0.0 | 100.0 | 1.3 | 97.9 | 1.7 | 90.4 | 1.3 | 87.9 |
| MA 1 | 14.0 | 74.2 | 3.7 | 62.1 | 4.0 | 63.6 | 10.3 | 83.0 | 3.0 | 83.1 | 2.3 | 78.5 |
| MA 2 | 1.7 | 96.9 | 1.0 | 89.7 | 2.7 | 75.8 | 6.3 | 89.6 | 2.0 | 88.7 | 0.7 | 93.5 |
| MA 3 | 5.0 | 90.8 | 2.0 | 79.3 | 4.3 | 60.6 | 8.3 | 86.3 | 2.7 | 84.7 | 2.0 | 81.3 |
| Cinnamon oil + MA1 | 5.7 | 89.6 | 1.7 | 82.7 | 2.0 | 81.8 | 4.7 | 92.3 | 2.7 | 84.7 | 2.0 | 81.3 |
| Cinnamon oil + MA2 | 0.0 | 100.0 | 0.7 | 93.1 | 0.0 | 100.0 | 1.3 | 97.9 | 1.3 | 92.7 | 0.0 | 100.0 |
| Cinnamon oil + MA3 | 3.7 | 93.2 | 1.3 | 86.2 | 1.0 | 90.9 | 3.0 | 95.1 | 3.3 | 81.4 | 1.3 | 87.9 |
| Carnation oil + MA1 | 4.0 | 92.6 | 0.0 | 100.0 | 2.0 | 81.8 | 5.3 | 91.3 | 2.3 | 87.0 | 2.0 | 81.3 |
| Carnation oil + MA2 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 2.7 | 95.6 | 1.0 | 94.4 | 1.0 | 90.7 |
| Carnation oil + MA3 | 2.0 | 96.3 | 0.0 | 100.0 | 0.0 | 100.0 | 4.3 | 92.4 | 2.3 | 87.0 | 2.0 | 81.4 |
| Control | 54.3 | | 9.1 | | 21.0 | | 60.7 | | 17.7 | | 10.7 | |
| LSD at 5% | 1.60 | | 2.21 | | 0.82 | | 2.34 | | 1.98 | | 1.91 | |

**D.I. = Disease incidence & E. = Efficiency MA = Modified atmosphere MA1 = 5 $O_2$ + 5 $CO_2$ + 90 $N_2$ & MA2 =10 $O_2$ + 5 $CO_2$ + 85 $N_2$ & MA3 =5 $O_2$ + 10$CO_2$ + 85 $N_2$**
**Control, artificially inoculated nectarine fruits with *B. cinerea* or *R. stolonifer* or without infection and untreated**

**Effect of plant oils and modified atmosphere treatments on maintain nectarine fruit quality:**

**Firmness:**

Firmness is very important characteristics of nectarine to determine of harvest time and fresh market. Data in table (4) cleared that, at harvest, firmness of nectarine fruit was 14.45 lb/in2 and 14.70 lb/in2 in seasons 2017 and 2018, respectively. In general, fruit firmness was decreased of all treatments of natural and inoculated fruits during storage. The softening of flesh during storage could be due to the degradation of soluble pectin by high activity of endopolygalacturonase enzyme in fruits (Martin-Cabrejas *et al.,* 1994). Combination of carnation oil and MA (10 $O_2$ + 5 $CO_2$ + 85 N) has kept the firmness of nectarine fruits under naturally and artificially inoculated with *B. cinerea* and *R. stolonifer*, where it gave the highest fruit firmness compared with other treatments during two seasons. MA delayed the decline of firmness due to a direct effect of high CO2 and low O2 on inhibiting of the enzymes responsible for the decomposition of the walls cells, since delay in softening under MA conditions (Akbudak and Eris, 2004).

**Table 4. Changes in firmness (lb/in2) of natural and inoculated nectarine fruits with *B. cinerea* and *R. stolonifer* and treated with some safe treatments.**

| Treatments | Season 2017 | | | Season 2018 | | |
|---|---|---|---|---|---|---|
| | Artificially inoculated | | Natural infection | Artificially inoculated | | Natural infection |
| | *B.cinerea* | *R. stolonifer* | | *B.cinerea* | *R. stolonifer* | |
| Cinnamon oil | 8.3 | 7.0 | 12.8 | 8.0 | 7.3 | 11.2 |
| Carnation oil | 5.7 | 6.4 | 11.0 | 6.1 | 6.8 | 10.7 |
| 5% O2 +5% CO2 +90%N2(MA1) | 4.67 | 2.67 | 5.13 | 5.00 | 3.53 | 5.40 |
| 10% O2 +5% CO2 +85%N2(MA2) | 6.5 | 4.7 | 6.1 | 6.7 | 5.1 | 6.3 |
| 5% O2 + 10% CO2+85%N2(MA3) | 3.7 | 2.8 | 4.6 | 4.3 | 3.1 | 4.9 |
| Cinnamon oil + MA1 | 3.7 | 4.6 | 5.9 | 4.2 | 3.5 | 6.9 |
| Cinnamon oil + MA2 | 6.0 | 6.1 | 11.3 | 5.7 | 6.5 | 11.7 |
| Cinnamon oil + MA3 | 4.3 | 4.4 | 6.8 | 5.2 | 5.1 | 7.1 |
| Carnation oil + MA1 | 4.3 | 5.1 | 8.9 | 4.8 | 5.5 | 9.3 |
| Carnation oil + MA2 | 10.3 | 7.4 | 10.3 | 10.4 | 7.8 | 13.1 |
| Carnation oil + MA3 | 4.1 | 3.1 | 5.6 | 4.7 | 5.4 | 5.9 |
| Control | 2.5 | 2.8 | 6.7 | 2.8 | 3.4 | 6.9 |
| AH | 14.5 | | | 14.7 | | |
| LSD at 5% | 2.33 | 1.42 | 3.12 | 2.16 | 1.16 | 2.67 |

**MA = Modified atmosphere & MA1 = 5 $O_2$ + 5 $CO_2$ + 90 $N_2$ & MA2 =10 $O_2$ + 5 $CO_2$ + 85 $N_2$ & MA3 =5 $O_2$ + 10$CO_2$ + 85 $N_2$ &**
**Control, artificially inoculated nectarine fruits with *B. cinerea* or *R. stolonifer* or without infection and untreated**
**AH = Un-treated, Un-inoculated and At harvest time**

Meanwhile, the lowest fruit firmness was determined in the control fruits after inoculated with *B. cinerea* (2.47 lb/in2 and lb/in2 during sessions 2017 and 2018, respectively) and *R. stolonifer* (2.80 lb/in2 and 3.37 lb/in2 during sessions 2017 and 2018, respectively). Also, data showed that, cinnamon oil significantly maintained on firmness parameter and it was the better effective on inoculated fruits with *B. cinerea. R. stolonifer* and natural infection fruits for keeping fruit firmness followed by carnation oil and interaction between cinnamon oil and MA containing 10 $O_2$ + 5 $CO_2$ + 85 $N_2$ at end of storage period during both seasons. Essential oils work as a protective layer of against different bactria and fungi and therefore stopped up of damaged fruits (Şerban *et al*., 2011). Also, controlled atmosphere containing 5.0 kPa $CO_2$ : 1.5 kPa $O_2$ and 10.0 kPa $CO_2$ : 1.5 kPa $O_2$ treatments (higher $CO_2$ concentrations)

maintained flesh firmness in peach after 28 days of cold storage (Santana *et al.*, 2011). Present findings were consistent with that of MAP maintained fruit flesh firmness of, peach and nectarine (Zoffoli *et al*., 1998). Also,The maintenance of fruit firmness by using MAP was also reported by Samar and Nagy (2017).The high firmness was showed in naturally infected fruits compared with infected fruits with *B. cinerea* and *R. stolonifer* with all treatments. In control treatment, inoculated nectarine fruits with *B. cinerea* and *R. stolonifer* gave less firmness percentage than natural infection fruits. In this respect, firmness was decreased in nectarine fruits after inoculated with *B. cinerea* and *R. stolonifer* and treated with the level of modified atmosphere containing 5 $O_2$ + 10 $CO_2$ + 85 $N_2$ and combination of cinnamon oil and modified atmosphere containing 5 $O_2$ + 5 $CO_2$ + 85 $N_2$ compared with other treatments.

**Total soluble solids:**

High consumer acceptance in nectarines is related on fruit with high soluble solid content (Carlos and Kader, 2000). The effect of essential oils and / or modified atmosphere on TSS is shown in table (5) Significant differences in TSS were observed between treated and control fruits. TSS was increased in nectarine fruits with all treatments towards the end of the storage and these increases could be due to moisture loss and hydrolysis of polysaccharides. At harvest time, fruit TSS content was 9.20% and 9.30% in seasons 2017 and 2018, respectively. Meanwhile, at end of the storage period, the highest TSS was noticed in control treatment (natural and inoculated fruits with *B. cinerea* and *R. stolonifer* and un-treated), It reaching the maximum values at the end of storage period (45 days) as previously detected by Davarynejad *et al*. (2013). On the other hand, carnation oil was the best effective in increasing the total soluble solids in inoculated fruits with *R. stolonifer* at end of the storage during two seasons compared with other treatments. While the lowest TSS values were determined in fruits infected with *R. stolonifer* and treated with cinnamon oil during two season. However, Hassani *et al*. (2012) reported that Thyme oil had significant effect on apricot fruit quality retention as total soluble solids. And, Taheri *et al* (2018) found that Found that treated peach fruits with essential oil kept their marketable qualities with lower decay severity scores and increased total soluble solids. In these respect, keeping inoculated nectarine fruits with *R. stolonifer* during cold storage under MA containing 10% O2 , 5% CO2 and 85 $N_2$ highly significantly TSS % followed by MA containing 10% O2 , 5% CO2 and 85 $N_2$ combined with cinnamon oil and MA containing 5% O2 , 10% CO2 and 85 $N_2$ combined with carnation oil at end of the storage period in seasons 2017 and 2018 compared with TSS content of fruits at harvest time. These data confirm previous reports about MA storage slowed down compositional changes associated with ripening as delayed the increase in TSS of peach and nectarine (Zoffoli *et al.*,1998 ;Akbudak and Eris, 2004). In the study, TSS changes in inoculated nectarines with *B. cinerea* were not significant during storage period and no regular trend was observed in table (5). In control treatment, inoculated nectarine fruits with *B. cinerea* and *R. stolonifer* caused higher TSS percentage than natural infection fruits.

**Table 5. Changes in TSS percentage of natural and inoculated nectarine fruits with *B. cinerea* and *R. stolonifer* and treated with some safe treatments.**

| Treatments | Season 2017 | | | Season 2018 | | |
|---|---|---|---|---|---|---|
| | Artificially inoculated | | Natural infection | Artificially inoculated | | Natural infection |
| | *B.cinerea* | *R. stolonifer* | | *B.cinerea* | *R. stolonifer* | |
| Cinnamon oil | 10.6 | 9.3 | 10.0 | 10.8 | 9.5 | 10.3 |
| carnation oil | 10.0 | 14.3 | 10.3 | 10.5 | 14.3 | 10.7 |
| 5% O2 +5% CO2 +90%N2(AM1) | 10.3 | 10.9 | 10.3 | 10.6 | 10.5 | 11.0 |
| 10% O2 +5% CO2 +85%N2(AM2) | 10.3 | 12.7 | 10.3 | 10.5 | 12.9 | 10.7 |
| 5% O2 + 10% CO2+85%N2(AM3) | 9.3 | 11.7 | 10.9 | 9.7 | 12.0 | 10.7 |
| Cinnamon oil + MA1 | 10.2 | 12.1 | 11.4 | 10.5 | 12.4 | 11.7 |
| Cinnamon oil + MA2 | 10.3 | 12.1 | 9.8 | 10.5 | 12.5 | 10.1 |
| Cinnamon oil + MA3 | 8.9 | 10.5 | 9.5 | 9.3 | 10.8 | 10.0 |
| Carnation oil + MA1 | 11.3 | 11.0 | 9.4 | 11.6 | 11.2 | 9.7 |
| Carnation oil + MA2 | 11.3 | 10.3 | 9.5 | 11.6 | 11.1 | 9.9 |
| Carnation oil + MA3 | 11.7 | 12.1 | 10.5 | 12.0 | 12.4 | 10.7 |
| Control | 12.9 | 14.3 | 12.2 | 13.2 | 14.5 | 12.5 |
| AH | | 9.2 | | | 9.3 | |
| LSD at 5% | 1.37 | 1.24 | 0.86 | 3.13 | 1.16 | 0.78 |

**MA = Modified atmosphere & MA1 = 5 $O_2$ + 5 $CO_2$ + 90 $N_2$ & MA2 =10 $O_2$ + 5 $CO_2$ + 85 $N_2$ & MA3 =5 $O_2$ + 10$CO_2$ + 85 $N_2$**
**Control, artificially inoculated nectarine fruits with *B. cinerea* or *R. stolonifer* or without infection and untreated**
**AH = Un-treated, Un-inoculated and At harvest time**

**Titrable acidity (TA):**

Results in table (6) illustrated that, control treatment gave the lowest value of nectarine acidity in both seasons. The main control of natural infection fruits had the highest Titrable acidity % (TA %) than other control of the artificially inoculated fruits with fungi. Also, Titrable acidity (TA) in control nectarine fruits inoculated with *B.cinerea* was higher than TA in control nectarine inoculated with *R. stolonifer*. On other hand, fruit acidity was increased in nectarine fruits with all treatments towards the end of the storage and these increases could be due to moisture loss and hydrolysis of polysaccharides. Similar results were found on nectarines (Bahar and Dundar, 2003; Celik *et al*., 2006; Bal, 2012). Also, on apricot detected a decrease in acidity of fruits during storage (Davarynejad *et al*, 2013). In these respect, all treatments delayed the decrease in concentrations of titratable acidity. This could be due to the delaying in physiological ageing and alteration in metabolism, which ultimately resulted in higher retention of acidity. The combination of MA (5 $O_2$ + 10 $CO_2$ + 85 $N_2$) and cinnamon oil were the best effective in decreasing the TA content of inoculated nectarine fruits with *B. cinerea* followed by fruits

treated with MA (5 $O_2$ + 5 $CO_2$ + 90 $N_2$) combined with cinnamon oil compared with other treatments. Also, results showed that, carnation oil combined with the levels of modified atmosphere containing 5 $O_2$, 5 $CO_2$ and 90 $N_2$ or 10 $O_2$ + 5 $CO_2$ + 85 $N_2$ achieved lower acidity of nectarine fruits infected with *R. stolonifer* at the end of storage period in both seasons. These results are in line with those obtained by Samar and Nagy (2017) who reported that modified atmosphere packaging showed a slight decrease of Titrable acidity in pomegranate fruits that was less than control at the end of the storage period. On the other hand, Hassani *et al*.(2012) reported that Thyme oil had significant effect on fruit quality retention as with titratable acidity. Bergamot oil treatment was the most effective in decreasing titratable acidity in nectarine fruits (Abd El wahab, 2015). Meanwhile. artificial inoculation of nectarine fruits with *R. stolonifer* caused less TA percentage than that inoculated with *B. cinerea* after it treated with individual treatment of plant oils and carnation oil combined with all tested of modified atmosphere in two seasons. The findings are in agreement with studies on MAP retarded the decrease in titratable acidity of several fruits such as peach and nectarine (Akbudak and Eris, 2004), and Cherry (Khorshidi *et al*, 2011and Serradilla *et al*.,2013).

**Table 6. Changes in Titrable acidity (TA) percentage of natural and inoculated nectarine fruits with *B. cinerea* and *R. stolonifer* and treated with some safe treatments.**

| Treatments | Season 2017 | | | Season 2018 | | |
|---|---|---|---|---|---|---|
| | Artificially inoculated | | Natural infection | Artificially inoculated | | Natural infection |
| | *B.cinerea* | *R. stolonifer* | | *B.cinerea* | *R. stolonifer* | |
| Cinnamon oil | 0.94 | 0.93 | 0.64 | 0.96 | 0.94 | 0.68 |
| carnation oil | 0.96 | 0.88 | 0.98 | 0.93 | 0.91 | 0.99 |
| 5% O2 +5% CO2 +90%N2(AM1) | 0.79 | 0.96 | 0.99 | 0.77 | 0.98 | 0.96 |
| 10% O2 +5% CO2 +85%N2(AM2) | 0.75 | 0.88 | 0.96 | 0.78 | 0.90 | 0.97 |
| 5% O2 + 10% CO2+85%N2(AM3) | 0.43 | 0.85 | 1.00 | 0.45 | 0.87 | 1.00 |
| Cinnamon oil + MA1 | 0.55 | 0.94 | 0.91 | 0.56 | 0.97 | 0.92 |
| Cinnamon oil + MA2 | 0.69 | 0.97 | 0.95 | 0.70 | 0.98 | 0.97 |
| Cinnamon oil + MA3 | 0.54 | 0.89 | 0.92 | 0.56 | 0.92 | 0.95 |
| Carnation oil + MA1 | 0.87 | 0.58 | 0.81 | 0.88 | 0.60 | 0.83 |
| Carnation oil + MA2 | 0.98 | 0.58 | 1.08 | 0.97 | 0.61 | 0.99 |
| Carnation oil + MA3 | 0.97 | 0.94 | 0.70 | 0.97 | 0.97 | 0.72 |
| Control | 0.57 | 0.54 | 0.58 | 0.59 | 0.56 | 0.60 |
| AH | | 1.11 | | | 1.13 | |
| LSD at 5% | 2.27 | 2.88 | 2.79 | 2.11 | 2.54 | 2.59 |

**MA = Modified atmosphere & MA1 = 5 $O_2$ + 5 $CO_2$ + 90 $N_2$ & MA2 =10 $O_2$ + 5 $CO_2$ + 85 $N_2$ & MA3 =5 $O_2$ + 10$CO_2$ + 85 $N_2$ & Control, artificially inoculated nectarine fruits with *B. cinerea* or *R. stolonifer* or without infection and untreated**
**AH = Un-treated, Un-inoculated and At harvest time.**

## CONCLUSION

The results show that it is possible to control postharvest Gray mold (*B. cinerea*) and *Rhizopus* rot (*R. stolonifer*) on nectarine fruits using some essential oils and some levels of modified atmospheres without a significant loss of fruit quality. *In vitro* studies, growth of *B. cinerea* and *R. stolonifer* were completely inhibited by the application of cinnamon and carnation oils at concentrations of 50, 75 and 100 µl/L air. *In vivo* studies, individual treatments of nectarines with cinnamon, carnation oils and modified atmosphere containing 10% $O_2$ + 5% $CO_2$+ 85$N_2$ or combination of either cinnamon oil or carnation oil accompanied with modified atmosphere at the level of 10% $O_2$+ 5% $CO_2$+85% $N_2$ were the most suppressive treatments against gray mold and Rhizopus rot on nectarine fruits and simulated market life.

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## أستخدام التبخير بواسطة الزيوت الطياره مع التخزين فى الجو الهوائى المعدل لمكافحة أعفان مابعد الحصاد فى ثمار النكتارين والمحافظة على صفات الجودة.

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العفن الرمادي المتسبب عن الفطر *Botrytis cinerea* وعفن الريزوبس والمتسبب عن الفطرى و *Rhizopus stolonifer* يسببان خسائر كبيرة فى ثمار النكتارين صنف (فلوردا) بعد الحصاد وأثناء التخزين المبرد. وتهدف هذه الدراسة ألى الحد من خطورة هذه المسببات بإستخدام بعض الزيوت الطيارة والجو الهوائى المعدل كمعاملات أمنه لمكافحة أعفان ثمار النكتارين بعد الحصاد وتحسين مواصفات الجودة. حيث تم أستخدم زيت القرفه والقرنفل بتركيزات 25 و 50 و75 و100 ميكرولتر/لتر الى جانب استخدام ثلاث مستويات من الجو الهوائى المعدل (5% $O_2$+ 5% $CO_2$ + 90% $N_2$, 10% $O_2$ + 5% $CO_2$ + 85% $N_2$ or 5% $O_2$ +10% $CO_2$ + 85% $N_2$), كل معاملة على حدا أو متحدين (الزيوت مع الجو الهوائى المعدل). وقد أظهرت النتائج المعملية أن التبخير بزيت القرفة والقرنفل بتركيزات 50 و 75 و 100 ميكرولتر / لتر ادى الى تثبيط النمو الميسليومى تماما لكلا الفطرين . وتحت ظروف التخرين كانت المعاملات الفردية لثمار النيكتارين بواسطة التبخير بزيت القرفة والقرنفل بتركيز100 ميكرولتر/لتر والمستوى من الجو المعدل (10% $O_2$ + 5% $CO_2$+ 85$N_2$) الأفضل فى مقاومة العفن الرمادي وعفن الريزوبس على ثمار النكتارين تحت ظروف التخزين المبرد على درجة 0 م$^{O}$ لمدة 45 يومًا خلال مواسم 2017 و 2018. كما أعطى زيت القرفة أعلى مكافحة ضد كلا الفطرين أثناء فترة التسويق خلال موسمى الأختبار . ايضاً أظهرت النتائج أن الثمار التي عوملت بواسطة زيت القرفة أو زيت القرنفل متحدة مع المستوى من الجو الهوائى المعدل (10% $O_2$+ 5% $CO_2$+85% $N_2$) أعطت أعلى مكافحة ضد فطرى *B. cinerea* و*R. stolonifer* خلال فترت التخزين المبرد على درجة 0 م$^{O}$ وأيضاً فترة التسويق مقارنة مع المعاملات الفردية. كما احتفظ المزيج من الأجواء الهوائية المعدلة المختلفة مع زيت القرفة أو القرنفل بأعلى خصائص جودة للثمار مثل صلابة الثمار والمواد الصلبة الذائبة الكلية والحموضة وتقليل الخسائر فى الثمار.