Assessment of the Potential of 1-Methylcyclopropene Treatments to Maintain Fruit Quality of the Common Fig (*Ficus carica* L. cv. 'Bursa Siyahi') during Refrigerated Storage

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Abstract

The fig fruit is a unique, climacteric, highly perishable subject to rapid physiological breakdown. Application of 1-methylcyclopropene (1-MCP) was tested to delay ripening of black fig (*Ficus carica* L. cv. 'Bursa Siyahi') during storage over two growing seasons. Fruits were pre-cooled to 1 °C for 6 hours and afterwards treated with 500 or 1000 nl l^{-1} of 1-MCP for 24 hours. Treated fruits were stored for 10 days at 1 °C, 90-95% RH and then evaluated. 1-MCP treatments showed that ethylene production, respiration rate, weight loss and concentrations of glucose, fructose and total soluble solids (TSS) were negatively correlated to the 1-MCP doses during cold storage (with the exception of TSS in the first year of experiment and respiration rate in the second year of the experiment). In contrast, pulp firmness and colour (h^{o}) during cold storage were positively correlated to the 1-MCP applied doses. Results of this study showed that although 1-methylcyclopropene applications slowed down fruit softening during the 10 days of storage, 1-methylcyclopropene appeared to have a relatively limited effect on slowing ripening of 'Bursa Siyahi' figs.

Keywords: fresh fig, quality, 1-MCP, shelf life

Introduction

Ficus carica L., the common fig, is a species of great commercial importance cultivated for its sweet fruits widely used both as a food and as medicine all over the world. Fresh and dried fig fruits are an excellent source of minerals, vitamins and dietary fiber (Solomon *et al.*, 2006; Veberic *et al.*, 2008). In addition, they contain high levels of polyphenols, flavonoids and anthocyanin, hence they are a good source of antioxidants for humans (Oliveira *et al.*, 2009). Figs have been traditionally used for their medicinal benefits as a laxative, for favouring cardiovascular circulation and providing anti-inflammatory properties. Fig fruits and latex have also been shown to reduce the risk of cancer (Rubnov *et al.*, 2001).

The fig fruit is a unique, highly perishable climacteric fruit subject to rapid physiological breakdown. The postharvest life of the fresh fig fruit typically does not exceed beyond 7-10 days even when low temperature storage is used (Chessa, 1997). Maintenance of the cold chain is important to slow down the deterioration of the fresh fig fruits. Basic studies on the processes that occur during ripening are essential for investigating systems in which the biological and physiological processes linked to maturation are involved in postharvest deterioration (Owino *et al.*, 2004) to determine more effective tools for the maintenance of postharvest life of fresh figs.

Ripening and senescence is mainly controlled by ethylene, one of several plant growth regulators involved in the growth and developmental processes, especially in climacteric fruits and vegetables (Abeles *et al.*, 1992). This simple hydrocarbon can diffuse into and out of plant tissues from both endogenous and exogenous sources and can greatly affect the quality of harvested products (Watkins, 2006). These effects can be beneficial or deleterious depending on the product, its ripening stage and its usage (Saltveit, 1999). Exogenous ethylene applications in bananas, for example, initiate uniform ripening. However, most commonly, commercial approaches for horticultural products are based on avoiding exposure to ethylene and/or attempting to minimize ethylene production and action during ripening, harvest, storage, transport and handling by temperature and atmosphere control (Watkins, 2002).

The discovery and commercialization of 1-MCP, an ethylene inhibitor, provided beneficial effects by suppressing the ethylene production and thus slowing down the ripening process and senescence of the fruits, especially climacteric ones. 1-MCP acts by blocking ethylene receptors (even at very low doses), thus ethylene cannot bid with the fruit (Sisler and Serek, 1997). Therefore, 1-MCP can be used as an effective tool for extending shelf-life and improving quality of fruits and vegetables (Blankenship and Dole, 2003). Several studies have successfully demonstrated that 1-MCP can extend shelf-life and quality of fruits and

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vegetables (Khan *et al.*, 2007; Özkaya and Dündar, 2009; Özkaya *et al.*, 2010; Valero *et al.*, 2003; Yuan *et al.*, 2010). However, there are very few reports on postharvest management of fresh fig cultivars.

The aim of these trials reported here was to evaluate the potential of 1-MCP to maintain the quality and extend the storage life of fresh figs. (*Ficus carica* L. cv. 'Bursa Siyahi'). Two different doses of 500 and 1000 nl l⁻¹ of 1-MCP applications were tested over two seasons.

Materials and methods

Plant material

Black figs (*Ficus carica* L. cv. 'Bursa Siyahi') were hand-harvested at commercial ripening stage, from an orchard located at Adana-Turkey, over two seasons. After harvest, fruits were brought to the postharvest physiology laboratory of the Department of Horticulture, Faculty of Agriculture, Cukurova University. Figs were then selected according to their uniformity of size, colour and absence of defects, according to the exporting criteria of packing houses. Fruits were selected and divided randomly into 3 groups as control, 500 and 1000 nl l⁻¹ doses of 1-MCP treatments.

1-MCP treatments

Fruits were pre-cooled at 1 °C for 6 h before treatments. 1-MCP was used as powder, which after addition of warm water (40 °C) released the active ingredient as a gas. Different amounts of the powder were weighed and warm water was added to obtain the doses of 500 and 1000 nl l⁻¹. Treatments were performed in 0.1 m³ hermetically sealed containers through injection of 1-MCP using plastic syringes and air circulation inside the containers were done by a small ventilator that works with a battery. Duration of treatment was 24 h at 1 °C. Control fruits were kept in similar containers for 24 h at 1 °C without 1-MCP application.

Ethylene and respiration rate determination

Ethylene production was measured by enclosing 1 kg of fruits for each treatment in a 2.5 l airtight glass jar hermetically sealed with two rubber septa for 2 hours. The headspace air was mixed with a 20 ml syringe and 1-ml sample was withdrawn from each jar for ethylene analysis. Ethylene (C_2H_4) concentration was determined by using a gas chromatograph fitted with a flame ionization detector (FID) with a stainless steel column filled with Alumina GC (Gapper *et al.*, 2006). Ethylene production rate was expressed as nl g⁻¹ h⁻¹.

The CO_2 determination was made by CO_2 analyser by which gas sample was withdrawn from the headspace of the same jars which the samples were taken for ethylene, after two hour closing time and calculated as mg CO_2 kg⁻¹ h⁻¹.

Fruit quality assessment

Following 1-MCP applications, treated fig fruits together with untreated control fruits were stored at 1 °C, 90-95% RH for 10 days and fruit weight loss, firmness, total soluble solids concentration (TSS), titratable acidity (TA), colour change, individual sugars were determined after storage to assess fruit quality.

Fruits were weighed at harvest and at the end of the storage period and weight loss was determined. Fruit firmness of 30 fig samples per treatment were determined on opposite sides of the fruit, using a hand penetrometer with an 8-mm-diameter tip and expressed as Newton (N). Fruit juice was extracted and diluted with pure water (3x) to measure total soluble solids concentration (TSS), using a hand-held refractometer. Titratable acidity (TA) was determined by titration of juice (5 ml) with 0.1 N sodium hydroxide and measured with a pH meter and expressed as g malic acid/100 ml fruit juice.

Fruit skin colour was assessed using a CIE colorimeter after calibration with white tile and the results expressed as L, a*, b* and Hue angle (h °) [arctangent (b*/a*)] (Voss, 1992). Thirty fruits from each treatment were used for colour measurement. Each was characterized by using the average of 2 measurements at equidistant points around equatorial circumference of the fruits.

Fruit sugars (g/kg) were analysed by high-performance liquid chromatography equipped with an in-line degasser, pump, manual injection (20 µ injection volume) interfaced to a PC running Class VP chromatography manager software. Fruit juice for each 1-MCP treatment and control samples was prepared by dilution with ultra pure water (18.2 MΩ cm) and filtered (nylon syringe filters, 0.45 µm, 13 mm diameter) for the determination of individual sugars. Separations were performed on a 150 mm 4.6 mm i.d., 5 µm, reverse-phase analytical column at 40 °C oven temperature with a flow rate of 0.6 ml min⁻¹. Elution was isocratic with pure water. Components were identified by comparing the retention times with the retention time of standards run at the same time during the analysis. A 25 minutes equilibrium time was allowed between injections.

Statistical analysis

The experiment was set up as a completely randomized design with six replicates and 30 fruits comprised each replicate. The Statistical Analysis System (SAS) was used to analyse the data and means were compared with Tukey HSD multiple range test at significance level $P<0.05$.

Results

Fruit weight loss, ethylene production and respiration rate

Significantly more weight loss occurred in the 1-MCP treatments compared with the control fruit, except in the 1000 nl treatment in the first year (Fig. 1). At the end of cold storage control figs lost 7.27% in first year, 6.72% in second year, whereas 500 nl l⁻¹ 1-MCP treated fruits lost 6.26% in first year, 5.70% in second year and 1000 nl l⁻¹ figs lost 5.97% in the first year, 6.48 % in the second year, of their initial weight.

No significantly differences were found in ethylene production after 10 days of storage in both years of storage in the 1-MCP and control treatments (Fig. 2). However, there was a trend in both years for reduced ethylene production in the 1-MCP treatments respectively. The respiration rate was increased by 40% in control fruits after 10 days of storage, whereas it was decreased by 21% and 25% in 500 and 1000 nl l⁻¹ 1-MCP treatments respectively, during the first year. The respiration rate was 9.65 mg CO_2 kg⁻¹ h⁻¹ in the second year at the harvest day and it decreased in control and other treatments 1%, 21% and 22% in control, 500 and 1000 nl l⁻¹ 1-MCP treatments respectively (Fig. 3).

Fruit quality parameters

1-MCP treated figs maintained firmness better than the

control after 10 days of storage during both the first year and second year (Fig. 4). Contrarily, in control figs firmness decreased in the first year treatment with 30% than the harvest one measured. 1-MCP treated figs exhibited a sharp decrease in firmness, although levels were higher than in control figs, for both 1-MCP treatments in the second year.

There were no significant differences between control and 1-MCP treatment in regard of TSS in the first year, whereas the 1000 nl l^{-1} 1-MCP treatment produced significantly higher TSS levels in the second year (Fig. 5). There were slight decreases in TA in both years; the changes in TA were not found to be significantly difference between treatments in the first year, however they were significantly different in the

second year (Fig. 6).

Fig skin colour did not significantly change in control and 1-MCP treatments for both years of the experiment during cold storage. There was more sharp decrease in the first year storage period regarding h° value of fig skins than in the second year storage period (Fig. 7).

Differences between the glucose content of fig flesh between treatments and control were not significantly important. However, it was found significantly important the increase between treatments in the second year of the experiment after 10 days of storage (Fig. 8). The fructose content of figs was increased in both storage period and the differences between control and 1-MCP treatments (Fig. 9) were not significantly different.

To check the effect of the 1-MCP applied dose on fruit quality parameters during cold storage, linear regressions were performed taking into account the experimental data for storage period. Thus, ethylene production (Fig. 10a), respiration rate (Fig. 10b), weight loss (Fig. 10c), glucose (Fig. 10h), fructose (Fig. 10i) and TSS (Fig. 10e) were negatively correlated to the 1-MCP dose during cold storage (with the exception of TSS in the first year respiration rate for stage 2 of ripeness) or shelf life. Contrarily, pulp firmness (Fig. 10d) and colour (h°) (Fig. 10g) during cold storage were positively correlated to the 1-MCP applied dose.
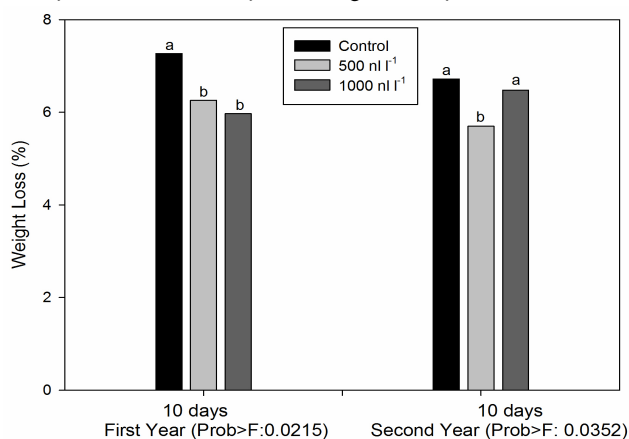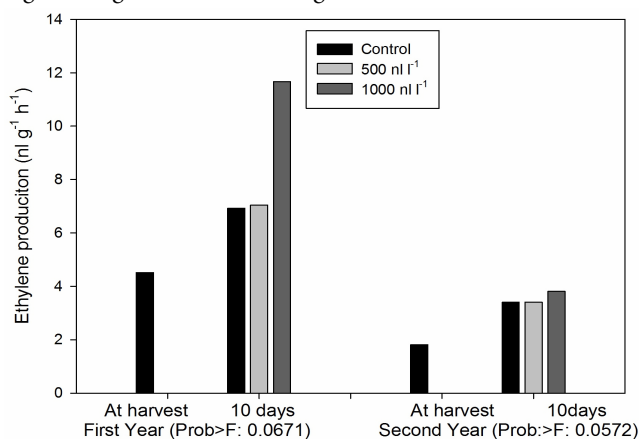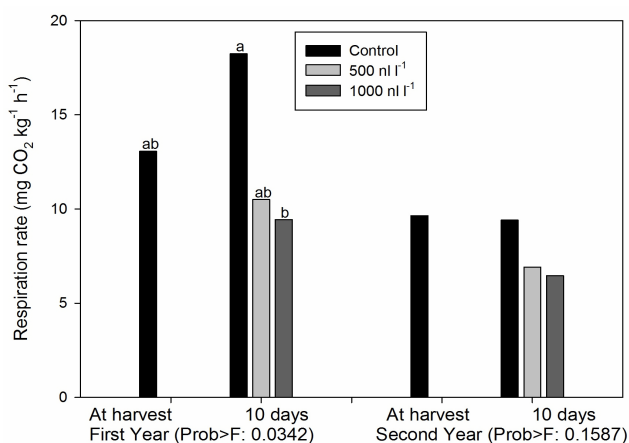
Discussion

Fruit ethylene evolution regulates the ripening process of climacteric fruits by initiating a wide range of physical and chemical changes such as tissue softening, pigment degradation and changes in sugar and organic acid levels in the fruit (Giovannoni, 2001). Although ethylene production is inhibited by 1-MCP application in most climacteric fruits (Blankship and Dole, 2003; Watkins, 2006) it was not inhibit in firm mature figs. When fruit were treated with 1-MCP the ethylene climacteric was delayed by 6 days and reduced in magnitude over 50% in avocado (Jeong *et al.*, 2002) and it was also reduced in plums (Abdi *et al.*, 1997) and apricots (Fan *et al.*, 2000). In contrast, 1-MCP treated pineapple fruit produced more ethylene than the control (Selvarajah *et al.*, 2001). Ethylene production was also increased by 1-MCP treatment in coriander (Jiang *et al.*, 2002). The ethylene production in first year was higher in both 1-MCP doses than in control fruits and 1000 nl l^{-1} dose of 1-MCP also had higher amount than control fruits after 10 days of storage in the second year. These results may indicate that 1-MCP may affect normal feedback regulation in cooled and low temperature application of 1-MCP treated figs.

The respiration rate varied depending on the 1-MCP dose in this study. The respiratory climacteric onset in plums was delayed by 1-MCP (Abdi *et al.*, 1997; Dong *et al.*, 2002). Respiration rate was reduced in apricots treated with 1-MCP (Fan *et al.*, 2000). However, 1-MCP treatment had no effect on nectarine (Dong *et al.*, 2001) and apricot (Dong *et al.*, 2002). The respiration rate of figs were not significantly differenced after 10 days of storage, however the respiration rate was lower in 1-MCP treated fruits. The differing results in climacteric fruits might be due to fruit maturity, cultivar, or some other unknown factors that influence the climacteric onset.

Fig. 1. Weight losses after storage

Fig. 2. Fruit ethylene production during storage

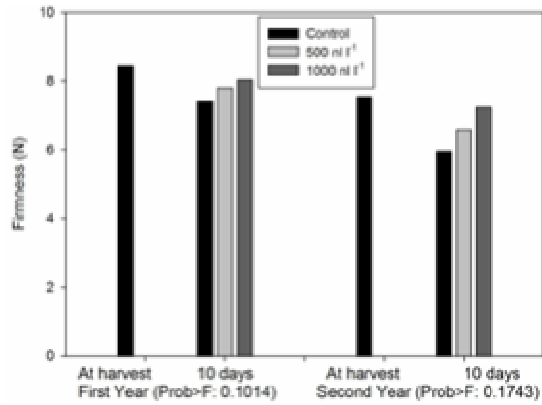Fig. 3. Respiration rate of fruits during storage

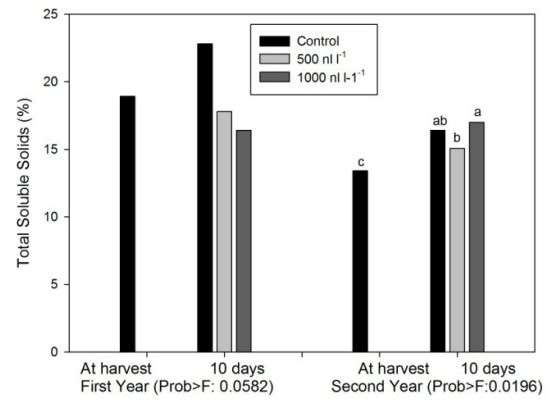Fig. 4. Fruit firmness changes during storage

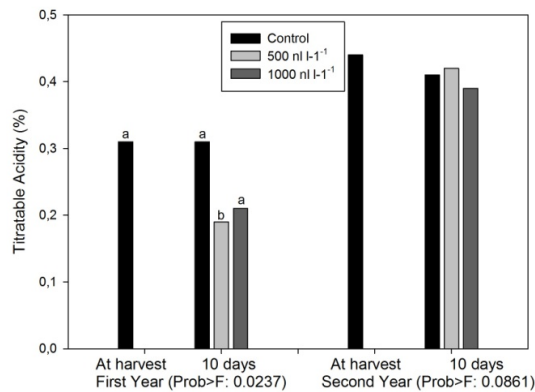Fig. 5. Total soluble solid changes during storage
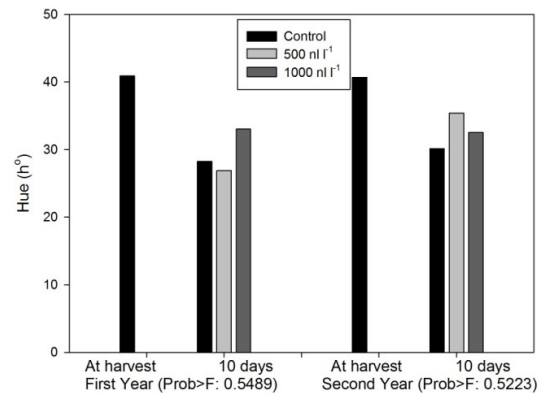

Fig. 6. Titratable acidity changes during storage

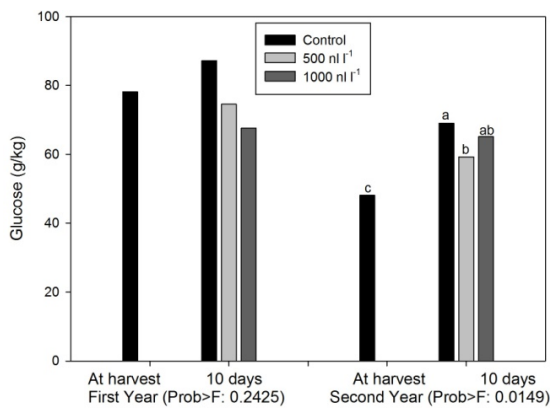Fig. 7. Skin colour changes during storage
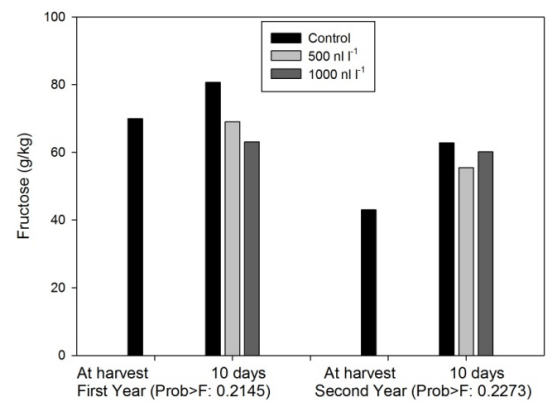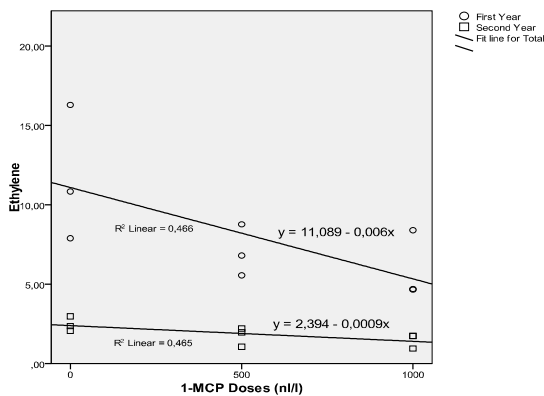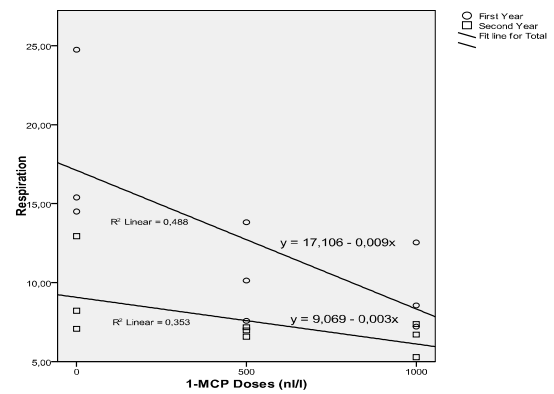

Fig. 8. Glucose content change during storage

Fig. 9. Fructose content change during storage

(a)

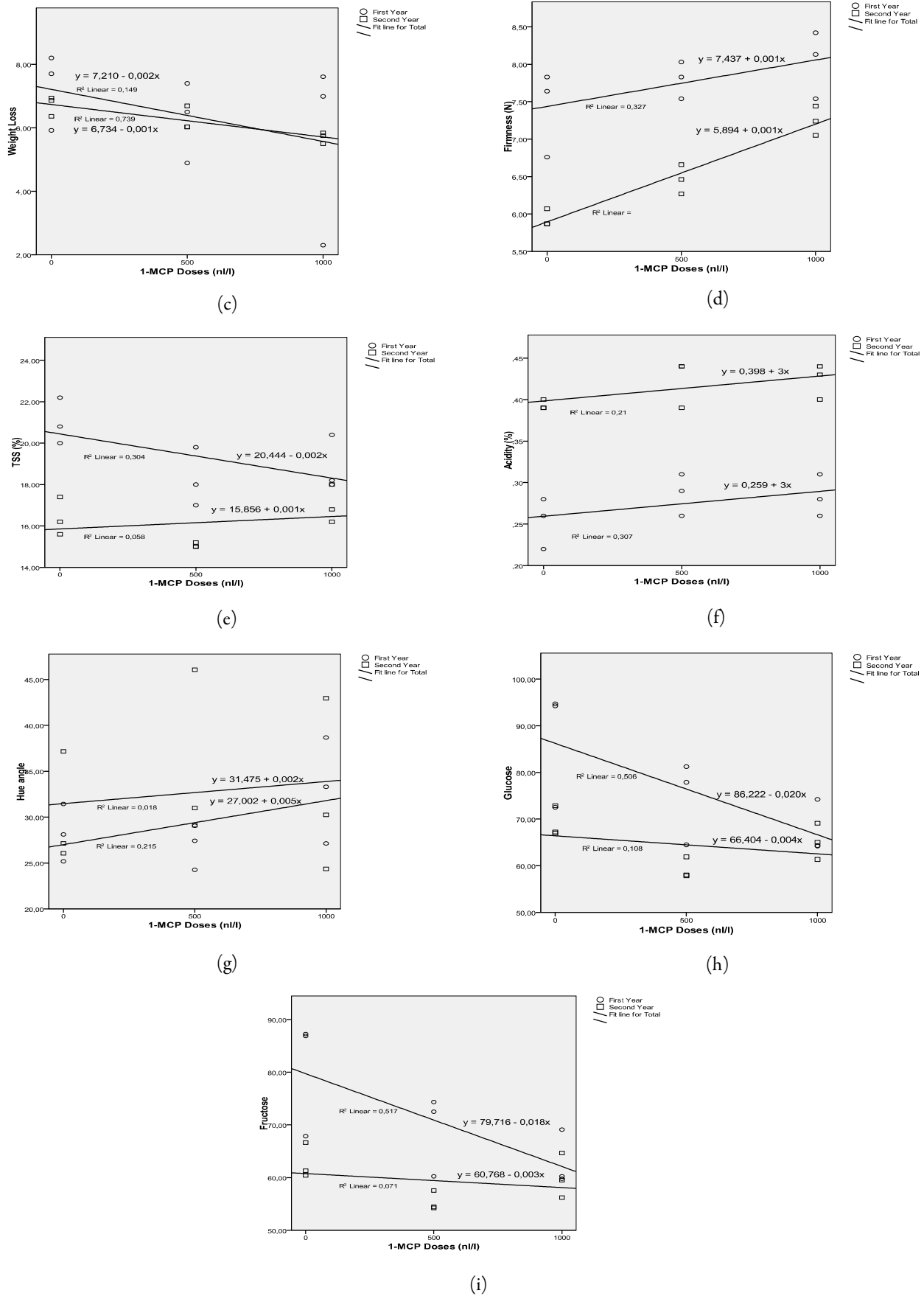(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

Fig. 10. Linear regressions figures between fruit quality parameters and 1-MCP dose; (a): Ethylene production; (b): Respiration rate; (c): Weight loss; (d): Fruit firmness; (e): Total soluble solid; (f): Titratable acidity; (g): Skin colour; (h): Glucose content; (i): Fructose content

Weight loss is one of the most important causes responsible for fruit quality deterioration. The findings of the present study revealed that weight loss was slightly reduced in 'Bursa Siyahı' fig treated with both 1-MCP doses, the effect being independent of the applied concentration. As shown in this study, 1-MCP inhibited ethylene evolution and decreased fruit respiration, which likely resulted in less weight loss in the 1-MCP treated fruit. Other studies in apple, kiwi etc. fruits, however, have reported no effect of 1-MCP application on fruit weight loss (Watkins *et al.*, 2006). Fruit weight loss can vary depending on the maturity stage, ventilation of cold store and epicular wax metabolism during ripening and cold storage (Valero *et al.*, 2003).

The fruit firmness observed in fruits subjected to both 1-MCP dose treatments was higher than control fruits in the first year and it was significantly different than control in the second year. Reduction in loss of firmness with 1-MCP treatment has been reported in tomato (Wills and Ku, 2002), apple (Watkins *et al.*, 2006) and other climacteric fruits. 1-MCP treatments have significantly lowered polygalacturonase (PG) and cellulose activities in avocado fruits, which may explain the increased fruit firmness (Feng *et al.*, 2000). Even though ethylene production of figs was not affected by 1-MCP treatment, the retard in softening of 1-MCP treated fruits indicate that 1-MCP might play a role retarding some enzyme activity in cell wall construction that influence fruit softening.

TSS varied between 1-MCP and control treatments in both years. 1-MCP application might not directly affect TSS levels, but it can indirectly, by influencing the maturity stage of the stored fruits. Soluble solids were higher in 1-MCP treated pineapple (Selvarajah *et al.*, 2001), papaya (Hofman *et al.*, 2001) and apples (Fan *et al.*, 1999). However, soluble solids were reduced in 1-MCP treated strawberries regardless of the presence or absence of exogenous ethylene (Tian *et al.*, 2000). Soluble solids were unaffected by 1-MCP in oranges (Porat *et al.*, 1999), apricots and plums (Dong *et al.*, 2002).

In general, fruits lost acidity during cold storage and even more following ripening at room temperature. The effect of 1-MCP on TA is mixed, with some crops being affected and others unaffected. 1-MCP completely inhibited TA loss in tomatoes (Wills and Ku, 2002), delayed TA loss in apples (Özkaya and Dündar, 2009). The results of the present research showed that TA was affected by 1-MCP treatments in the first year whereas the acidity loss was not affected in the second year.

The association between colour changes and ethylene varies with the type of pigment, the species and the tissue which the pigment is being produced (Abdi *et al.*, 1997). 1-MCP resulted in lowered phenylalanine ammonia lyase activity and anthocyanin production in strawberries (Jiang *et al.*, 2001). Nevertheless, the application of up to 1000 nl l^{-1} was insufficient to prevent changes of h° in figs. The inherent variability of samples may partially mask the effect of 1-MCP.

Glucose and fructose content of control and 1-MCP treatments were increased during storage. As it is mentioned, individual sugars are affected by physiological maturation levels. These effects change in different ways, depending on cultivar. The results of this experiment showed that both glucose and fructose level were in an increase trend.

Conclusion

It is very important for both exporters and consumers to purchase a good quality fruit with acceptable price. Reducing fruit losses is one of the main key during postharvest practices to supply the market with lower priced fruits and balance the marginal income. The results of the presented study showed that 1-MCP have a limited effect on fresh fig fruit to slow down the initial ethylene production depending on physiological process.

Acknowledgement

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