J Food Sci Technol (August 2021) 58(8):2963–2972
https://doi.org/10.1007/s13197-020-04798-4

ORIGINAL ARTICLE

Cinnamon essential oil incorporated in shellac, a novel bio-product to maintain quality of 'Thomson navel' orange fruit

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Revised: 6 September 2020 / Accepted: 15 September 2020 / Published online: 21 September 2020

Abstract Green mold decay is considered as the main cause of postharvest loss in citrus fruits. With regard to safety concerns, this study was done to evaluate the efficacy of shellac as an edible coating and cinnamon essential oil (CEO) as alternative to synthetic fungicides to maintain quality of 'Thomson navel' oranges (*Citrus sinensis* L. Osbeck) inoculated with *Penicillium digitatum* spores. Fruit treated with distilled water (control), 1.5% ethanol (ET), 10% shellac (SH), commercial wax (CW), 0.5% commercial fungicide (Carbendazim), CF + CW, 0.3%, 0.4%, 0.5% and 0.6% CEO, 0.3%, 0.4%, 0.5% and 0.6% CEO + SH, SH enriched with 0.3%, 0.4%, 0.5% and 0.6% CEO (CEOSH) stored at 5 °C for up to 21 days. Fruit decay, weight loss, firmness, ascorbic acid were evaluated at 7 days interval, but scanning electron microscopy (SEM) images and sensory quality were evaluated at the end of storage. Shellac coating (10%) enriched with 0.5% CEO reduced weight loss by 52%, and firmness loss by 38%. The results showed that the incorporation of EOs into shellac could be a suitable treatment for maintenance of citrus fruit quality.

Keywords Coatings · Essential oils · Cinnamon · Disease · Quality

Abbreviations

ET	1.5% Ethanol
SH	10% Shellac
CW	Commercial wax
CF	0.5% Commercial fungicide
CEO	Cinnamon essential oil
CEO + SH	CEO and SH separately
CEOSH	SH enriched with CEO
SEM	Scanning electron microscopy

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Introduction

Fruit species are genetically very diverse group and grown in temperate, subtropical and tropical regions in the world and more recently they have been recognized for their human health benefits. Thus, interest to fruits has been increased. Most of the fruits have high content of non-nutritive, nutritive, and bioactive compounds such as flavonoids, phenolics, anthocyanins, phenolic acids, and as well as nutritive compounds such as sugars, essential oils, carotenoids, vitamins, and minerals (Vijayan et al. 2008; Colak et al. 2019; Senica et al. 2019; Gecer et al. 2020). Citrus fruit are produced worldwide in tropical and subtropical areas and largest fruit commodities in international trade (FAO 2018). After harvest, citrus fruit are susceptible to physiological disorders and microbial diseases that result in postharvest losses (Oviasogie et al. 2015). In addition, postharvest citrus decay is the most severe cause of wastage and quality deterioration since it reduces fresh fruit unsuitable for consumption, causing consequently heavy economic losses. Losses can reach 30% of the total production and 50% in less developed countries (Strano et al. 2017).

Fruit natural waxes may be removed during fruit cleaning and washing that results in greater water loss and lower fruit quality (Bajwa and Anjum 2007). The application of various types of coatings on the fruit surfaces could increase skin gloss, reduce water loss and prolong shelf-life (Contreras-Oliva et al. 2011). Citrus are also susceptible to decay (Tripathi and Dubey 2004) with green mold caused by *Penicillium digitatum* being a major concern. Mold leads to significant economic impact as the fungi can complete its life cycle in one week and rapidly infect adjacent fruit in a carton and the spores disseminate easily in storage rooms (Droby et al. 2008).

Synthetic fungicides are used widely used postharvest by the citrus industry due to their low price, ready availability, simple application method and fast effect (Kouassi et al. 2012). The fungicides are often incorporate with waxes and fruit coatings to give a more uniform coating in addition to reducing weight loss and gas exchange and increasing fruit gloss. Recent regulator controls have now been placed on synthetic fungicides and a number have been withdrawn from the market due to safety concerns (Antunes and Cavaco 2010; Porat et al. 2005).

Environmental concerns, public human health concerns and international trade regulations have resulted in a worldwide search for new and non-toxic alternatives to synthetic coatings and fungicides. Edible films and coatings are safe alternatives to synthetic materials for coating fruits (Contreras-Oliva et al. 2011). Also, plant extracts including essential oils (EOs), can be used as alternatives to control postharvest diseases (Klieber et al. 2002). Recently, researchers have used EOs or their volatile compounds to reduce postharvest diseases in several fruits (Pérez-Alfonso et al. 2012; Regnier et al. 2008, 2010). Yahyazadeh et al. (2008) showed that polyethylene film supplied with thyme or clove oil reduced green mold in oranges. Du Plooy et al. (2009) reported that carnauba commercial wax amended with *Lippia scaberrima* EO could control green mold on citrus fruit. *Cinnamomum zeylanicum* EO incorporated to carnauba wax also controls (90%) green and blue mold on citrus fruit (Kouassi et al. 2012).

In our preliminary studies, we investigated different edible coatings to find the best replacement for synthetic waxes and an effective EO as alternative to postharvest green mold control on citrus (Khorram et al. 2017) and cinnamon EO (*Cinnamomum cassia*) (Khorram et al. 2018). The objective of this study was to find an effective method of applying shellac edible coating in combination with cinnamon EO to control decay caused by green mold and preserve postharvest quality during storage of oranges inoculated with *Penicillium digitatum*.

Materials and methods

Plant materials and experimental design

'Thomson navel' oranges (*Citrus sinensis* L. Osbeck.) were harvested from an orchard in Jahrom, Fars, Iran (28°30′N, 53°31′E), and transported ~ 200 km to the postharvest laboratory at Shiraz University by a ventilated container. Uniform and undamaged fruit were immersed in water containing dish washing liquid (0.2%), rinsed with tap water, dried, and surface treated with 70% ethanol. Two wounds, (2 mm wide and 2 mm deep) were formed using a sterile needle on opposite side at the equatorial region of each fruit. The fruit were inoculated with 10 mL of conidial suspension solution (1×10^6 spores mL^{-1}) of *Penicillium digitatum* conidia concentration was determined using a haemocytometer (Chen and Zhu 2011), and allowed to air dry (20 °C) for 24 h. Thereafter, fruit were divided into sets of three replicates of three fruit for three sampling time, and treated by 18 treatments including: Distilled water (control), 1.5% ethanol (ET), 10% shellac (SH), (Sigma-Aldrich, USA), commercial wax (CW; Decco, Italy), 0.5% commercial fungicide (CF; Carbendazim), for 2 min, CF + CW for 2 min + 1 min, respectively, 0.3%, 0.4%, 0.5% and 0.6% cinnamon essential oil for 2 min (CEO), 0.3%, 0.4%, 0.5% and 0.6% CEO + SH, for 2 min + 1 min respectively (CEO + SH), SH enriched with 0.3%, 0.4%, 0.5% and 0.6% CEO (CEOSH) for 2 min.

After drying, fruit were placed into polyethylene plastic bags (25 × 35 cm with 0.02 mm thickness) having 16 pores with 5 mm diameter and kept at 5 °C for up to 3 weeks. In this research, we evaluated fruit following 21 days of storage and quality evaluation of inoculated oranges as the control had significant decay.

Preparation of coating and essential oil

The shellac (SH) was grounded into powder in a blender, then dissolved in 98% v/v ethanol with stirring until a homogenous dispersion of 10% (w/v) was obtained. The commercial wax was Decco Italia srl (the main components of CW were wood rosin, oxidized polyethylene, and shellac). The EO was extracted from cinnamon tree bark that was grounded into powder and hydro-distillation for 3 h using a Clevenger steam-distillation apparatus (Khorram et al. 2017).

Fruit quality studies

Fruit quality parameters were evaluated at 7 days interval during storage at 5 °C. Weight loss (%) was measured during storage from initial and final weight comparison (Razzaq et al. 2014). Fruit firmness was measured at the end of each storage period using a texture analyzer (TA-XT2, UK) fitted with P/35 probe and calibrated with 10 g compression force, 7 mm compression distance and expressed as Newton (Njombolwana et al. 2013). Ascorbic acid concentration (mg L^{-1}) was measured using 2, 6-dichlorophenol indophenol reagent (AOAC 2000) using XB-10 Spectrometer (Dynamica Scientific Ltd, UK). Fruit decay was evaluated every 7 days up to 4 weeks and disease incidence expressed as percentage (Jhalegar et al. 2015). Fruit rind, 1 × 1 cm rind section was immediately transferred to − 80 °C freezer, 24–48 h after coating application, then freeze dried for 3 h before gold coating was applied for SEM. Fruit rind imaging of the samples were captured at 500 × using a SEM (TESCAN vega3, Czech) (Khorram et al. 2017).

Sensory evaluations

Ten trained panelists were asked to evaluate fruit appearance and acceptability at the end of each storage period, based on both glossiness and the presence of visible spot on the orange skin due to using EOs. Panelists ranked on a 0–10 point intensity scale where 0 = not acceptable and 10 = acceptable (Khorram et al. 2017).

Statistical analysis

The experiment was analyzed as a split plot in time design and analyzed General Linear Model (GLM) (SAS software v. 9.1). Mean comparisons were conducted by LSD at $P = 0.01$ of probability.

Results and discussion

Weight loss and firmness

Fruit appearance and firmness is an important citrus quality parameter as they significantly impact consumer acceptability. Loss in weight results in shrivelled appearance, loss of gloss and shorter shelf life and hence lower price in the market chain (Sogvar et al. 2016). After 21 days of storage at 5 °C, a significant difference in weight loss was found between the coating treatments and the uncoated control ($P = 0.01$) (Table 1). The lowest fruit weight loss occurred in fruit treated with 0.5% CEOSH (0.83%); although, it was not significantly different from fruit treated with SH, CW, CF + CW, 0.3, 0.4, 0.5 and 0.6% CEO + SH, 0.3, 0.4 and 0.6% CEOSH (Table 1). The greatest fruit weight loss occurred in the uncoated control fruit (1.76%) with no significant difference from other uncoated treatments such as ET, CF, 0.3, 0.4, 0.5 and 0.6% CEO. The addition of EOs to the coatings and increasing the EO concentration did not significant impact weight loss. Overall, the 0.3, 0.4, 0.5 and 0.6% CEOSH treatments had reduced weight loss at each sampling time. Commercial wax coatings are effective inhibitor of weight loss (Porat et al. 2005). Resin coatings such as SH are as effective at reducing weight loss commercial coating used in this research (Khorram et al. 2017). Use of an SH composite coatings on apples similarly reduced weight loss during storage (Togrul and Arslan 2005). Fruit weight loss during storage is due mainly to water loss and is a function of the vapor pressure difference between inside the fruit and the storage atmosphere (Yaman and Bayoindirli 2002). Weight loss reduction in coated fruit is due to the creation of an additional gas barrier between fruit and atmosphere (Meighani et al. 2015) as occurs for citrus (Chauhan et al. 2013).

Fruit firmness declined with longer storage times at 5 °C (Table 2, $P = 0.01$). The fruit with the lowest firmness loss occurred when coated with 0.5% CEOSH (34.10 N), and showed no significant difference from CF + CW and 0.5% CEO treatments. The greatest firmness loss was measured in control fruit (21.10 N), though it was not significantly different from fruit treated with ET at the end of the four weeks storage at 5 °C. EOs alone did not retain fruit firmness, but coatings alone or in combination with EOs were effective. Coating such as SH have been reported to help retain firmness in apples (Bai et al. 2002) and delay softening in tomatoes with or without *Aloe vera* gel (Chauhan et al. 2013). Carbon dioxide modified atmospheres limit the activities of pectic enzymes and delay softening during storage (Maftoonazad and Ramaswamy 2005). Firmness is one of the main factors in determining fruit quality and coating fruit effectively maintains firmness that results in greater consumer acceptance (Chauhan et al. 2013).

Ascorbic acid

Ascorbic acid is the dominant form of vitamin C in citrus and greatly impacts the antioxidative system by reducing ROS and protecting membranes against the oxidative injury that can result in reduced postharvest life (Razzaq et al. 2014). Ascorbic acid content declined in both treated and control fruit during storage (Table 3, $P = 0.01$). At the end of storage, the greatest ascorbic acid content was measured at 0.6% in the CEOSH treatment (357 mg L^{-1}), with no significant difference with 0.5% CEOSH and 0.6% CEO + SH treatments. The lowest ascorbic acid content occurred in control (278 mg L^{-1}), and showed no significant difference from ET, CW, CF + CW and 0.3% CEO treatments. The 0.5%, 0.6% CEOSH and 0.6% CEO + SH treatments showed the lowest loss in ascorbic acid content

Table 1 Effect of different treatments on 'Thomson navel' orange fruit weight loss (%) during storage at 5 °C

Treatments	Storage time (day)			Mean
	7	14	21	
Control	0.63±0.60 a*	1.15±0.14 a	1.76±0.38 a	1.18±0.53 A†
ET	0.51±0.01 a–c	1.03±0.17 a–d	1.67±0.24 a	1.07±0.46 AB
SH	0.43±0.14 a–c	0.93±0.12 a–e	1.24±0.34 b–d	0.86±0.31 B–E
CW	0.52±0.14 a–c	0.74±0.17 c–e	1.10±0.24 b–d	0.79±0.30 B–E
CF	0.50±0.10 a–c	1.11±0.11 ab	1.42±0.18 a–c	1.01±0.47 AB
CF+CW	0.52±0.14 a–c	0.81±0.14 a–e	1.20±0.75 b–d	0.84±0.31 A-D
0.3% CEO	0.50±0.19 a–c	0.99±0.19 a–d	1.43±0.44 a–c	0.97±.46 A–D
0.4% CEO	0.48±0.40 a–c	0.79±0.50 b–e	1.57±0.15 ab	0.95±0.95 A–D
0.5% CEO	0.50±0.10 a–c	0.98±0.19 a–d	1.44±0.34 a–c	0.97±0.43 A–D
0.6% CEO	0.52±0.19 a–c	1.06±0.11 a–c	1.56±0.15 ab	1.05±0.45 AB
0.3% CEO+SH	0.44±0.80 a–c	0.90±0.21 a–e	1.16±0.01 b–d	0.83±0.35 B-E
0.4% CEO+SH	0.53±0.07 a–c	0.82±0.33 a–e	1.20±0.07 b–d	0.85±0.41 B–E
0.5% CEO+SH	0.43±0.11 a–c	0.87±0.27 a–e	1.24±0.34 b–d	0.85±0.31 B–E
0.6% CEO+SH	0.56±0.12 ab	1.08±0.13 a–c	1.19±0.01 b–d	0.94±0.47 A–D
0.3% CEOSH	0.41±0.07bc	0.80±0.27 b–e	1.01±0.22 cd	0.74±0.28 C–E
0.4% CEOSH	0.39±0.08bc	0.75±0.17 c–e	1.01±0.24 cd	0.72±0.33 C–E
0.5% CEOSH	0.32±0.14 c	0.59±0.25 e	0.83±0.24 d	0.58±0.29 E
0.6% CEOSH	0.35±0.03 c	0.70±0.09 de	1.11±0.06 b–d	0.72±0.30 CDE
Mean	0.47±0.11 C†	0.89±0.21 B	1.28±0.32 A	
A of V GLM	DF	Mean Sq	Significance	
Treatment (T)	17	0.19**	$P = 0.01$	
Storage duration (Sd)	2	8.28**	$P = 0.01$	
T × Sd	34	0.03**	$P = 0.01$	
Error b	68	0.02	–	

ET 1.5% ethanol, *SH* 10% shellac, *CW* commercial wax, *CF* 0.5% commercial fungicide, *CEO* cinnamon essential oil, *CEO + SH* CEO and SH separately, *CEOSH* SH enriched with CEO

*Similar letters (lower case) in the same column are not significantly different according to LSD test ($P = 0.01$).

†Values with capital letters show the differences for mean of treatments and times. The results are presented as the mean ± standard deviation.

at all sampling times. At the end of storage, all treatments that contained EOs (except 0.3% CEO) and SH, alone or in combination, had higher ascorbic acid content in comparison with the control. This supports the proposal of a possible role of EOs or SH coating in retention of ascorbic acid content. In this respect, Ramezanian et al. (2016) observed an increase in ascorbic acid content in 'Washington Navel' orange fruit treated by *Thymus vulgaris* and *Zataria multiflora* EOs compared to control and reported that it may be due to antioxidative effects of these EOs. CW had no significant effect on the total ascorbic acid content (Table 3). Similar result has been reported that CW did not maintain ascorbic acid content after 40 days, and SH coating maintained ascorbic acid after 60 days of storage compared to control in 'Valencia' oranges (Khorram et al. 2017).

Evaluation of fruit decay

No decay symptoms were observed during the first week of storage in all treatments (Table 4). Thereafter, synthetic chemicals and EOs, significantly ($P = 0.01$) decreased the decay percentage until the end of storage. The first symptoms of decay were observed after 14 days of chilled storage when almost 50% of the control and ET treatments were decayed. After 21 days of storage, green mold decay was observed in SH treated fruit (66.67%), although the severity less than control. Based on the results, coatings alone, were insufficient to control decay in inoculated fruit and the addition of fungicide, whether natural or synthetic was crucial.

At the end of the storage at 5 °C (28 days), the highest fruit decay incidence was observed in the non-coated control fruit (control and ET) (100%) and the lowest level

Table 2 Effect of different treatments on 'Thomson navel' orange fruit firmness (*N*) during storage at 5 °C

Treatments	Storage time (day)			Mean
	7	14	21	
Control	27.76 ± 0.78 e*	23.48 ± 1.22 d	21.10 ± 0.76 f	24.11 ± 3.03 F†
ET	27.49 ± 0.85 e	24.33 ± 2.04 d	22.12 ± 1.28 ef	24.65 ± 2.66 F
SH	39.94 ± 1.48 a	36.13 ± 1.79 ab	30.88 ± 0.86 bc	35.65 ± 4.01 AB
CW	39.10 ± 0.87a	35.20 ± 1.47ab	31.18 ± 0.61 bc	35.16 ± 3.55A–C
CF	32.56 ± 1.80 cd	28.61 ± 1.34 c	24.99 ± 1.20 d	28.72 ± 2.25 E
CF + CW	39.63 ± 0.91 a	35.74 ± 1.79 ab	32.25 ± 2.44 ab	35.87 ± 3.47 AB
0.3% CEO	33.17 ± 0.66 c	30.19 ± 0.90 c	28.70 ± 1.87 c	30.69 ± 2.25 D
0.4% CEO	31.55 ± 1.06 cd	28.78 ± 1.01 c	25.16 ± 1.44 d	28.50 ± 2.95 E
0.5% CEO	31.80 ± 1.80 cd	28.52 ± 1.34 c	24.97 ± 1.20 d	28.43 ± 3.22 E
0.6% CEO	31.06 ± 0.11 d	28.22 ± 1.10 c	24.67 ± 1.29 de	27.98 ± 2.90 E
0.3% CEO + SH	36.79 ± 0.91 b	33.76 ± 2.21 b	30.32 ± 0.51 bc	33.62 ± 3.34 C
0.4% CEO + SH	39.48 ± 1.03 a	35.27 ± 1.16 ab	31.13 ± 0.54 bc	35.29 ± 3.71 A–C
0.5% CEO + SH	39.30 ± 1.03 a	35.74 ± 1.79 ab	32.58 ± 2.99 ab	35.87 ± 3.56 AB
0.6% CEO + SH	39.61 ± 0.80 a	35.48 ± .065 ab	30.61 ± 0.39 bc	35.23 ± 3.94 A–C
0.3% CEOSH	39.59 ± 1.27 a	34.66 ± 2.21 ab	30.69 ± 0.72 bc	34.98 ± 4.08 C
0.4% CEOSH	40.07 ± 0.80 a	35.66 ± 1.08 ab	30.61 ± 1.25 bc	35.45 ± 4.20 A–C
0.5% CEOSH	40.13 ± 0.93 a	36.82 ± 1.30 a	34.10 ± 2.72 a	37.02 ± 3.05A
0.6% CEOSH	39.78 ± 0.72 a	36.27 ± 0.32 ab	31.01 ± 0.87 bc	35.69 ± 3.86 AB
Mean	36.05 ± 4.59 A†	32.38 ± 4.91 B	28.73 ± 4.52 C	
A of V GLM	DF	Mean Sq	Significance	
Treatment (T)	17	183.425**	*P* = 0.01	
Storage duration (Sd)	2	789.942**	*P* = 0.01	
T × Sd	34	3.778**	*P* = 0.01	
Error b	68	1.294		

ET 1.5% ethanol, *SH* 10% shellac, *CW* commercial wax, *CF* 0.5% commercial fungicide, *CEO* cinnamon essential oil, *CEO + SH* CEO and SH separately, *CEOSH* SH enriched with CEO

*Similar letters (lower case) in the same column are not significantly different according to LSD test (*P* = 0.01).

†Values with capital letters show the differences for mean of treatments and times. The results are presented as the mean ± standard deviation.

was observed in the coatings with 0.5% and 0.6% CEO + SH, CW, CF and CF + CW (0%); although, severe surface burn was found at 0.5% and 0.6% CEO + SH treatments. Fruit disease severity was reduced in the coatings with 0.5% and 0.6% CEO, 0.4% CEO + SH, 0.5% and 0.6% CEOSH treatments by almost 90% (Table 4).

Decay by green mold is a major cause of citrus postharvest loss (Droby et al. 2008). The application of EOs to inoculated oranges resulted in significant decay control after 4 weeks of storage at 5 °C. This result agrees with those reported by Plaza et al. (2003) and confirms that EOs have the potential to control citrus decay. Fungal cytoplasmic membrane damage due to EOs (Bakkali et al. 2008) leads to reduced electron transportation, a loss membrane integrity and leakage of protein, potassium and phosphate from the skin epidermal cells (Tassou et al. 2000).

The fruit in all EOs treatments except CEOSH, showed quality loss due to severe fruit surface burn (Fig. 1). The 0.5% and 0.6% CEOSH treatments were the best treatments at reducing decay incidence and maintaining visual quality. Decay in these treatments was reduced by almost 90% and thus extended the shelf life of coated fruit stored at 5 °C without negative impact on the fruit appearance and overall acceptability. Edible coating besides enhancing gloss and reducing water loss serve as useful carrier for antimicrobial compounds to reduce pathogen growth (Pavlath and Orts 2009; Kouassi et al. 2012). The advantage of the incorporation of EOs into fruit coatings is in achieves a more uniform coating of the fruit, retaining moisture and also providing closer contact between fruit

Table 3 Effect of different treatments on 'Thomson navel' orange fruit ascorbic acid content (mg L^{-1}) during storage at 5 °C

Treatments	Storage time (day)			Mean
	7	14	21	
Control	434.94 ± 6.36 b–e*	375.24 ± 2.28 e	278.88 ± 5.81 g	363.02 ± 74.24 FG†
ET	411.91 ± 12.88 g	343.98 ± 2.89 h	294.64 ± 3.96 fg	350.18 ± 51.45 H
SH	433.73 ± 8.82 b–f	390.39 ± 1.89 a–c	307.34 ± 1.81 d–f	377.15 ± 48.29 CD
CW	422.82 ± 10.24 fg	386.76 ± 3.78 bc	294.64 ± 4.16 fg	368.07 ± 57.54 EF
CF	426.15 ± 4.57 d–f	384.33 ± 2.77 cd	294.94 ± 8.39 fg	368.47 ± 58.26 EF
CF + CW	430.09 ± 0.90 d–f	388.88 ± 2.60 a–c	294.94 ± 4.19 fg	371.30 ± 60.04 DE
0.3% CEO	425.85 ± 4.57 ef	357.06 ± 5.32 g	296.15 ± 1.38 e–g	359.69 ± 56.30 G
0.4% CEO	435.85 ± 8.82 a–e	378.88 ± 6.38 de	311.85 ± 5.57 d–f	375.53 ± 54.08 DE
0.5% CEO	432.21 ± 15.91 c–f	377.36 ± 1.89 e	305.55 ± 1.81 d–f	371.71 ± 55.08 DE
0.6% CEO	429.79 ± 4.57 d–f	384.64 ± 4.16 cd	319.12 ± 091 c–e	377.85 ± 48.29 CD
0.3% CEO + SH	446.76 ± 2.77 a	385.55 ± 1.57 c	323.12 ± 2.87 cd	385.14 ± 53.57 BC
0.4% CEO + SH	431.30 ± 15.91 d–f	373.12 ± 2.28 e	315.38 ± 2.32 c–f	373.27 ± 50.84 DE
0.5% CEO + SH	424.94 ± 3.44 ef	362.52 ± 6.57 fg	323.12 ± 2.28 cd	370.19 ± 44.63 D–F
0.6% CEO + SH	444.33 ± 2.92 ab	394.33 ± 4.19 a	337.67 ± 4.31 a–c	392.11 ± 46.33 AB
0.3% CEOSH	424.94 ± 3.44 ef	356.58 ± 2.34 g	325.85 ± 1.38 b–d	369.12 ± 43.98 EF
0.4% CEOSH	426.76 ± 2.77 d–f	364.33 ± 3.19 f	324.52 ± 0.73 b–d	371.87 ± 44.68 DE
0.5% CEOSH	443.42 ± 4.57 a–c	392.21 ± 4.57 ab	347.06 ± 2.28 ab	394.23 ± 41.89 A
0.6% CEOSH	437.36 ± 0.90 a–d	393.12 ± 2.92 a	357.36 ± 1.81 a	395.95 ± 34.75 A
Mean	431.29 ± 10.14 A†	377.18 ± 14.77 B	314.01 ± 23.41 C	
A of V GLM	DF	Mean Sq	Significance	
Treatment (T)	17	1257.509**	*P* = 0.01	
Storage duration (Sd)	2	187,527.780**	*P* = 0.01	
T × Sd	34	450.430**	*P* = 0.01	
Error b	68	93.038		

ET 1.5% ethanol, *SH* 10% shellac, *CW* commercial wax, *CF* 0.5% commercial fungicide, *CEO* cinnamon essential oil, *CEO + SH* CEO and SH separately, *CEOSH* SH enriched with CEO

*Similar letters (lower case) in the same column are not significantly different according to LSD test (*P* = 0.01).

†Values with capital letters show the differences for mean of treatments and times. The results are presented as the mean ± standard deviation

surfaces and the EOs (Du Plooy et al. 2009), and reducing EOs volatilization (Kouassi et al. 2012). In the past decades, coatings amended with EOs has been widely used to control decays in fruit such as mango, avocado, and citrus (Pérez-Alfonso et al. 2012; Regnier et al. 2008, 2010).

Sensory evaluation

Coatings and EOs treatments tested in this study affected sensorial quality of inoculated oranges (Fig. 1). Increasing fruit gloss is one of the reasons for using coating in citrus industry as it enhances external appearance an important consumers appeal (Contreras-Oliva et al. 2011). SH and other resins impart a glossy appearance to fruit and are thus added to coating formulations (Baldwin et al. 1997).

All concentrations of CEOSH were the most effective treatments for increasing orange appearance acceptability, and given a highest sensory score (10). Present results showed that CEOSH treatments effectively provided highest sensory acceptability similar to that achieved with the use of CW in 'Thomson navel' orange fruit. The EOs incorporated in these coatings did not negatively impact fruit quality and no visible skin damage was observed.

All concentrations of CEO without SH treatments were unacceptable to the panelists as these treatments had no gloss and severe fruit surface burn (Fig. 1). Several reports in the literature have also reported the damaging effects of high concentrations of EOs (Liu et al. 2002; Ramezanian et al. 2016).

Based on the sensory evaluation results, all concentrations of CEO + SH treatments provided gloss due to SH

Table 4 Effect of different treatments on 'Thomson navel' orange fruit decay (%) during storage at 5 °C

Treatment	Storage time (day)				Mean
	7	14	21	28	
Control	0.0±0.00 a*	55.6±38.49 a	77.8±19.24 b	100.0±0.00 a	58.3±42.93 AB†
ET	0.0±0.00 a	55.6±19.24 a	88.8±19.24 a	100.0±0.00 a	61.1±42.24 A
SH	0.0±0.00 a	0.0±0.00 b	66.7±0.00 c	88.8±19.24 a	38.8±42.24 B
CW	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	0.0±0.00 c	0.0±0.00 D
CF	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	0.0±0.00 c	0.0±0.00 D
CF+CW	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	0.0±0.00 c	0.0±0.00 D
0.3% CEO	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	33.3±0.00 b	8.3±15.07 C
0.4% CEO	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	33.3±0.00 b	8.3±15.07 C
0.5% CEO	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	11.1±19.24 c	2.8±9.62 CD
0.6% CEO	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	11.1±19.24 c	2.8±9.62 CD
0.3% CEO+SH	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	33.3±0.00 b	8.3±15.07 C
0.4% CEO+SH	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	11.1±19.24 c	2.8±9.62 CD
0.5% CEO+SH	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	0.0±0.00 c	0.0±0.00 D
0.6% CEO+SH	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	0.0±0.00 c	0.0±0.00 D
0.3% CEOSH	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	33.3±0.00 b	8.3±15.07 C
0.4% CEOSH	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	33.3±0.00 b	8.3±15.07 C
0.5% CEOSH	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	11.1±19.24 c	2.8±9.62 CD
0.6% CEOSH	0.0±0.00 a	0.0±0.00 b	0.0±0.00 d	11.1±19.24 c	2.8±9.62 CD
Mean	0.0±0.00 D†	6.2±19.32 C	12.9±29.68 B	28.4±34.77 A	
A of V GLM	DF	Mean Sq	Significance		
Treatment (T)	17	4639.312**	*P*=0.01		
Storage duration (Sd)	3	7002.743**	*P*=0.01		
T × Sd	51	829.904**	*P*=0.01		
Error b	102	64.653			

ET 1.5% ethanol, *SH* 10% shellac, *CW* commercial wax, *CF* 0.5% commercial fungicide, *CEO* cinnamon essential oil, CEO + SH, CEO and SH separately *CEOSH* SH enriched with CEO

*Similar letters (lower case) in the same column are not significantly different according to LSD test (*P* = 0.01).

†Values with capital letters show the differences for mean of treatments and times. The results are presented as the mean ± standard deviation.

coating, however they were not acceptable to the panel of experts, because of severe fruit surface burn. High concentration of EOs used alone caused skin burn and made the fruit unacceptable to the panel. All concentrations of the CEOSH treatment can successfully be used as a natural fungicide coating instead of synthetic fungicides and waxes.

Scanning electron microscopy

Relevant SEM micrographs at 500 × magnification are shown in Fig. 2a–f. The surface of control fruit displayed a natural wax layer on the fruit rind surface while stomatal pores are visible (Fig. 2a), and no difference could be detected with the EO treated fruit (Fig. 2d) in which stomata not occulted by wax were visible. This status can influence on physiological processes of fruit such as respiration rate and water loss as previously reported (Khorram et al. 2017). In contrast, fruit coated with CW or SH, had a uniform coating layer on the fruit rind surface, and appeared more homogenous than control fruit (Fig. 2b–f). Changes in their micromorphology were more evident. The differences among treated fruit peel was negligible in which some stomatal openings were occluded with coating and creating a smoother appearance. A similar behaviour involving formation of a uniform layer without fissures in SH coatings have been previously reported (Khorram et al. 2017).

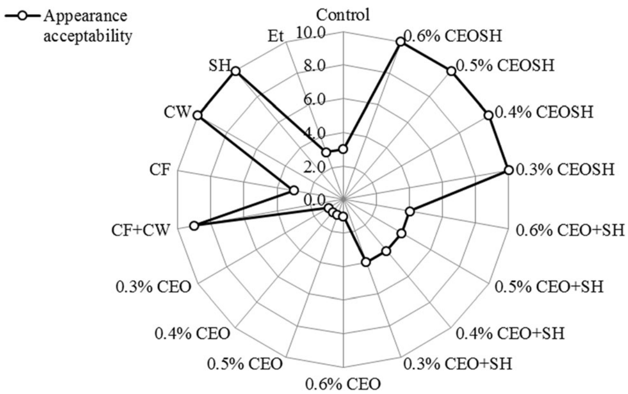

Fig.1 Effect of different treatments on fruit appearance acceptability of 'Thomson navel' orange according to a 0–10 point intensity scale in which 0 = no acceptability and 10 = high acceptability. Descriptive sensory evaluations were conducted by trained panelists after 21 days of storage at 5 °C. *ET* 1.5% ethanol, *SH* 10% shellac, *CW* commercial wax, *CF* 0.5% commercial fungicide, *CEO* cinnamon essential oil, *CEO + SH* CEO and SH separately, *CEOSH* SH enriched with CEO

Conclusion

In conclusion, results of this study revealed that SH as an edible coating in combination with cinnamon EO were effective alternative to synthetic fungicides as an efficient formulation to control green mold decay in citrus. In addition, it could be a suitable treatment instead of artificial waxes and chemical fungicides that can maintain both quantitative and qualitative parameters of 'Thomson navel' orange fruit during storage. Incorporation of EOs into coating formulations appeared to have good commercial potential to minimize green mold by almost 90%. Overall, 0.5% CEOSH treatment was the best treatment to control weight loss and to maintain firmness, and ascorbic acid content. Therefore, this treatment not only was able to control fruit decay, but also maintained the edible quality, and fruit visual acceptability. Overall, our approach can be applied as a safe strategy for the postharvest citrus industry. Our recommendations and future prospects are using the nano and/or microencapsulation techniques for increasing essential oils effects.

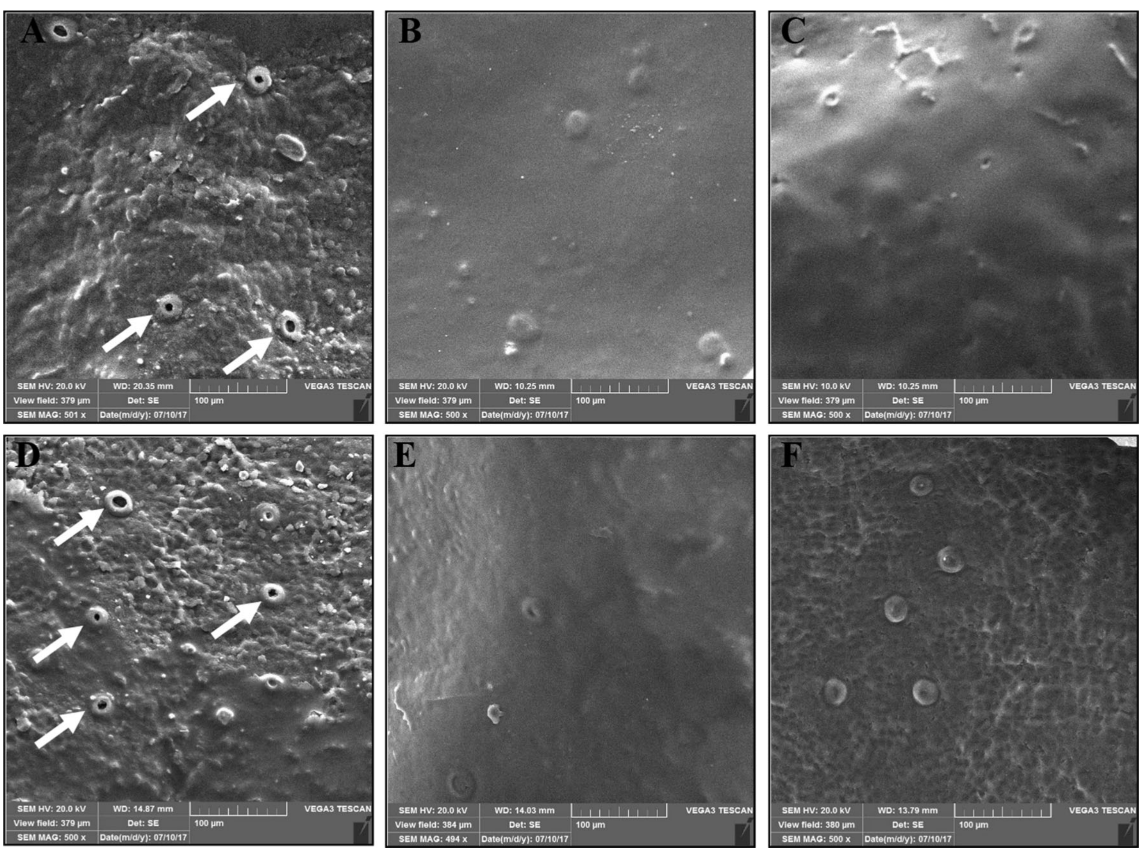

Fig.2 SEM micrographs (500 ×) of 'Thomson navel' orange fruit surface, showing an un-waxed fruit as a control (**a**), fruit treated with SH (**b**), CW (**c**), CEO (**d**), CEO + SH (**e**) and CEOSH (**f**). The arrows (a and d) show visible stomatal pores without coating. *SH* 10% shellac, *CW* commercial wax, *CEO* cinnamon essential oil, *CEO + SH* CEO and SH separately, *CEOSH* SH enriched with CEO

Acknowledgements We thank Shiraz University for financial supports, Fars Agricultural and Natural Resources Research Center for technical assistance, and Central Laboratory of Shiraz University for SEM. Dr. Robert Paull, University of Hawaii at Manoa editorial help is greatly appreciated.

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