Combined effect of hot water dipping and *Cistus creticus* L. leaf extracts on the storage quality of fresh Valencia oranges

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ABSTRACT

This research was designed to test the combined efficacy of hot water dipping (HWD) and leaf extracts of *Cistus creticus* L. subsp. *creticus* on the storage quality of fresh Valencia oranges. Experiments were laid down according to a completely randomised design with 10 different treatments. Five replications, with five fruits in each replication, were used in the current study, and research was designed to continue for 150 days. Quality characteristics were observed with 30-days interval. The applications of this study were (1) Control [dipping in water at 25°C for 5 min]; (2) HWD at 50°C for 5 min; (3) HWD + Additives (A) [Arabic gum (0.2%), potassium sorbate (0.05%), citric acid (0.05%) and vitamin C (0.05%)] at 50°C for 5 min; (4) Additives alone at 25°C for 5 min; (5) 1.0% *C. creticus* leaf + HWD + A; (6) 1.0% *C. creticus* leaf + A; (7) 0.5% *C. creticus* leaf + HWD + A; (8) 0.5% *C. creticus* leaf + A; (9) 0.5% *C. creticus* leaf + HWD and (10) 0.5% *C. creticus* leaf. According to the results obtained, both the HWD and *C. creticus*, alone or in combination, were effective in preserving orange weight during storage, preventing pathogenic decay, maintaining visual quality and fruit firmness, delaying the reduction in titratable acidity, increasing ascorbic acid content and reducing respiration rate of the orange fruits. Results also suggested that the combined effect of HWD with *C. creticus* leaf extracts provided the highest efficacy.

Keywords: combined effect, hot treatment, pathogen control, plant extracts, postharvest storability

INTRODUCTION

Citrus fruits have been the most produced fruits products on the earth until today, with 138,550,381 tonnes of production in 2018. The percentage of oranges, mandarins (including tangerines, clementines and satsumas), lemons (including limes) and grapefruits (including pomelos) are 54.4%, 24.8%, 14.0% and 6.8%, respectively. The top three countries for orange production are Brazil, China and India, which cover about 45.5% of total orange production (FAO, 2020) in total. Besides the fresh consumption, citrus fruits are also

consumed as juice. They have been highly consumed throughout the world, while they have a unique flavour and are rich in minerals, phytochemicals and dietary fibre (Farg et al., 2020). Valencia oranges (*Citrus sinensis* L. Osbeck), with several bioactive compounds and rich nutritional contents, are among the most consumed citrus species (Albertini et al., 2006). A glass of orange juice (225 ml) was reported to contain about 1,225 mg of vitamin C (AsA, ascorbic acid), 5 mg of folic acid and 500 mg of potassium (Whitney and Rolfes, 1999). It is

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also well known that the pomological and biochemical characteristics of fruit crops significantly change among genotypes, growing conditions and cultural practices (Okatan et al., 2018; Çolak and Özoğul, 2020). However, the postharvest storability of Valencia oranges is limited to about 3 months and was noted to highly influence by pathogenic decay and weight loss (Alhassan et al., 2020). Most important pathogens causing postharvest decay are *Penicillium digitatum* and *Penicillium italicum* and storing the oranges at low temperatures is among the effective ways for controlling those pathogens. However, prolonged storage at low temperatures (<5–8°C) induces the reactive oxygen species (ROS) production and damage the cell wall of orange fruits, which reduce the postharvest storability of oranges (Lado et al., 2016; Wan et al., 2020).

Control of postharvest pathogens of orange fruits generally relies on the application of agrochemicals (Sharma et al., 2009). However, the acceptability of agrochemicals by the consumers has been decreasing due to scientific confirmation (Hussien et al., 2018) of their adverse effects on human health when they are misused or used in excessive amounts (Koch et al., 2017). Search for alternatives to the synthetic agrochemicals resulted in high success with different biomaterials, which have extended threshold for toxicity (Silvestre et al., 2011; Tomazoni et al., 2016). Coating of fruits with edible biomaterials provides a semi-permeable barrier for atmospheric gaseous and water vapour and reduces respiration and transpiration, which in turn prolongs the storability of fruits (Kahramanoğlu 2017; Riva et al., 2020). Biomaterial coating also helps to control pathogens with direct inhibition of pathogens or by indirect improvement of fruits' resistance (Ncama et al., 2019). Postharvest application of biomaterials (edible coatings and films, essential oils, jasmonic acid, plant-derived products, etc.) has been suggested by several studies to improve the storability of horticultural products (Hassanein et al., 2018; Ncama et al., 2019; Chen et al., 2019; Kahramanoğlu 2019; Troyo and Acedo, 2019; Xin et al., 2019; Zudaire et al., 2019; Riva et al., 2020; Elkhatabi et al., 2020; Poveda, 2020) and orange fruits (Palou et al., 2015; Chen et al., 2019; Moraes Bazioli et al., 2019; Moosa et al., 2019). Different works demonstrated the antifungal activity of different plant extracts against fungal pathogens of citrus fruit (Tayel et al., 2016; Karchoufi et al., 2018; Pinto et al., 2021). Filipiak and Weiner (2017) showed the capacity of these extracts to attract or repel insects. Recent studies also showed that the terpenoids of plant essential oils, i.e. citronellal, have a significant influence on the mycelial growth and spores' germination of *P. digitatum* (Wu et al., 2016). Most of the essential oil compounds are generally recognised as safe (GRAS) and they can be used in active packaging or edible coatings.

Search for new biomaterials from different plants has been the subject of current scientific studies. *Cistus creticus* L. is a widespread shrub plant found in the

Pinus sylvestris forests in the Mediterranean basin (Altay, 2019). Different sub-species of *C. creticus* genus, i.e. subsp. *eriocephalus* and *corsicus*, were previously noted to have diverse chemical composition. A total of approximately 164 compounds were identified from these two sub-species, and the most abundant compounds were terpenes noted as follows: δ -cadinene, β -caryophyllene, τ -muurolol, α -cadinol, manoyl oxide, 13-epi-manoyl oxide and manool (Paolini et al., 2009; Abu-Orabi et al., 2020; Lahcen et al., 2020). Essential oils of *C. creticus* plants were previously noted to have possible medical applications, i.e. against blood cancer (Dimas et al., 1999). Volatile profiles of *Cistus* genus have also been reported to have antimicrobial characteristics, which makes it useful for the industrial production of cosmeceuticals (Morales-Soto et al., 2015). Limited studies exist about the fungicidal activity of *Cistus* extracts (Jemia et al., 2013; Karim et al., 2017). In one of these studies, Karim et al. (2017) reported that the aqueous extracts of *Cistus* species provide significant efficacy for controlling Citrus sour rot. However, these studies were carried out in *in vitro* conditions.

Moreover, postharvest pre-conditioning of fruits with hot water dipping (HWD) or any other means of heat treatment has been reported to activate/deactivate PPO (polyphenoloxidase), POD (peroxidase) and/or SOD (superoxide dismutase) enzymes and positively affects the storability of fruits (Yun et al., 2013; Opio et al., 2017; Atrash et al., 2018; Kahramanoğlu et al., 2020a; Wan et al., 2020). In recent research, Wei et al. (2018) reported that the efficacy of heat treatment on the postharvest characteristics and storability of strawberry fruits could be increased with its combination of tea tree oil. However, there has not been any study about the combined efficacy of HWD with any biomaterials. In line with this knowledge, the present study was designed to test the combined efficacy of HWD and *C. creticus* leaf extracts on the postharvest storability and biochemical characteristics of fresh Valencia oranges (*C. sinensis* L. Osbeck).

MATERIALS AND METHODS

Experimental research

Valencia oranges originally bred in southern California but were named after the city of Valencia in Spain. They are medium-sized oranges with a bright orange colour and finely textured rinds. They are very juicy with a sweet-tart flavour. Valencia oranges of the current research were purchased on-tree from a local grower located in Northern Cyprus and hand-collected by the researchers at the commercial maturity. Harvesting was performed when the fruits reached above 12% soluble solids concentration (SSC) and <3.0 g · 100 g⁻¹ citric acid. Valencia oranges were quickly transferred to the laboratory and hand-selected to provide uniform size and colour and to eliminate damaged and diseased fruits. Leaves of *C. creticus* L. subsp. *creticus* were then collected from Yeşilirmak village of Northern Cyprus.

The fruits of the current research were first separated into 10 groups with 125 fruits in each group. These groups represent the 10 treatments of current studies. Then, the 125 fruits were separated into 25 sub-groups with 5 fruits in each group. After the application of the postharvest treatments, each group was separately stored in cold rooms at $6.0 \pm 1.0^\circ\text{C}$ and 90–95% RH (relative humidity); and five sub-groups (totally 25 fruits) from each group (treatment) were removed from the cold rooms with 30-days interval for the measurement of quality parameters. The treatments of current study were as follows: (1) control [dipping in water at 25°C for 5 min;]; (2) HWD at 50°C for 5 min; (3) HWD + Additives (A) [Arabic gum (0.2%), potassium sorbate (0.05%), citric acid (0.05%) and vitamin C (0.05%)] at 50°C for 5 min; (4) Additives alone at 25°C for 5 min; (5) 1.0% *C. creticus* leaf + HWD + A; (6) 1.0% *C. creticus* leaf + A; (7) 0.5% *C. creticus* leaf + HWD + A; (8) 0.5% *C. creticus* leaf + A; (9) 0.5% *C. creticus* leaf + HWD; and (10) 0.5% *C. creticus* leaf. Detailed explanations of the treatments are given in Table 1.

Data collection

Eight different quality parameters were regularly measured with 30-days interval during the 150 days

of storage. Both the initial and final weights of each fruit were measured with an electronic scale (± 0.01 g), and the values were used to calculate the weight loss in percentage (%) by following the standard ratio analysis. Then, the method of Fonseca et al. (2002) was used to measure the respiration rate (RR) of each replication (five fruits together) as the produced CO_2 ($\text{ml CO}_2 \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$). The standard method of Cao et al. (2011) was used to calculate decay incidence (DI) as a percentage by following the 0–3 scale and standard formula. The 0–5 scale of Silva et al. (2015) was then used to observe and score the visual quality of each fruit (0: worst, 5: best). The visual quality parameters included the observations about both browning and microbial decay.

A hand penetrometer with a probe diameter of 5 mm was used to assess the firmness ($\text{kg} \cdot \text{cm}^{-2}$) of orange fruits. The fruits were then half-cut and squeezed to obtain clear juice for further measurements. A hand refractometer was used to assess the fruit's SSC as % and the standard titration method with NaOH was followed for the determination of titratable acidity ($\text{TA} - \text{g} \cdot 100 \text{ g}^{-1}$ citric acid). Finally, the titrating with 2,6-dichlorophenol indophenols was followed for the

Table 1. Detailed explanations of the 10 experimental treatments

Treatment name	Short name – description
Control	Control – Valencia oranges of this group were dipped into water (25°C) for 5 min
HWD	HWD at 50°C for 5 min – Fruits of this group were dipped into hot water at 50°C for 5 min.
HWD + A	HWD + Additives (A) – First, water was heated until 100°C , then 2:1,000 (w/v) Arabic gum was added and cooled down to 50°C . Next, 0.5:1,000 (w/v) citric acid, 0.5:1,000 (w/v) potassium sorbate and 0.5:1,000 (w/v) vitamin C were added and cooled down to 50°C . Finally, the fruits were immersed in this solution for 5 min at a constant temperature of 50°C .
Additives (A)	Additives alone at 25°C for 5 min – This treatment is the same as above described HWD + A treatment; however, the temperature of the solution was cooled down to 25°C and fruits were immersed in this solution for 5 min.
HWD + CC (1%) + A	1.0% <i>C. creticus</i> leaf + HWD + A – Leaves of <i>C. creticus</i> and water in a ratio of 10:1,000 (w/v) were first heated until 100°C , kept hot at 100°C for 30 min and filtered, then 2:1,000 (w/v) Arabic gum was added and cooled down to 50°C . Next, 0.5:1,000 (w/v) citric acid, 0.5:1,000 (w/v) potassium sorbate and 0.5:1,000 (w/v) vitamin C were added. Finally, the fruits were immersed in this solution for 5 min at 50°C . Steam distillation is a widely used method for obtaining the volatile fraction of <i>Cistus</i> spp. (Oller-López et al., 2005).
CC (1%) + A	1.0% <i>C. creticus</i> leaf + A – Preparation of this treatment is similar to the HWD + CC (1%) + A, where the only difference is the solution temperature. In this treatment, the solution was cooled down to 25°C , and fruits were immersed in this solution for 5 min at 25°C instead of 50°C .
HWD + CC (0.5%) + A	0.5% <i>C. creticus</i> leaf + HWD – This treatment is similar to the HWD + CC (1%) + A treatment, where the concentration of the <i>C. creticus</i> leaves was the half of it, as 5:1,000 (w/v).
CC (0.5%) + A	0.5% <i>C. creticus</i> leaf + A – This treatment is similar to the CC (1%) + A treatment, where the concentration of the <i>C. creticus</i> leaves was the half of it, as 5:1,000 (w/v).
HWD + CC (0.5%)	0.5% <i>C. creticus</i> leaf + HWD – Leaves of <i>C. creticus</i> and water in a ratio of 5:1,000 (w/v) were first heated until 100°C , kept hot at 100°C for 30 min and filtered, and then cooled down to 50°C . Finally, the fruits were immersed in this solution for 5 min at 50°C .
CC (0.5%)	0.5% <i>C. creticus</i> leaf – Leaves of <i>C. creticus</i> and water in a ratio of 5:1,000 (w/v) were first heated until 100°C , kept hot at 100°C for 30 min and filtered, and then cooled down to 25°C . Finally, the fruits were immersed in this solution for 5 min at 25°C .

CC, *C. creticus*; HWD, hot water dipping.

assessment of AsA contents as $\text{mg} \cdot 100 \text{ g}^{-1}$ (Youssef and Hussien, 2020).

Statistical analysis

Raw data of each treatment at each measurement point were summarised in Microsoft Excel, and line figures were prepared with the means and standard deviations of the data. Hereafter, the raw data were analysed in SPSS 22.0 software to compare treatments with one-way analysis of variance (ANOVA), and the statistical separation of means from each other was then performed with Tukey's HSD test ($p < 0.05$).

RESULTS

Influence of C. creticus leaf extracts and HWD on weight loss

The findings of the present study showed that, as usual, weight loss of the Valencia oranges increases during cold storage (Table 2).

Furthermore, findings showed that the highest weight loss was observed from the control treatment; and all other test applications are effective in preventing weight loss (Figure 1). Among the test treatments, Additives (A) alone had the least effect and no significant difference was noted among the control and Additives. At the first measurement point (30 days after cold storage), the highest weight loss was observed from the control treatment with 5.38% and the lowest weight loss was found to be 2.99% from the HWD + CC (0.5%) treatment. The same trend was continued till the end of the storage period, but the difference between the HWD + CC (0.5%) treatment and the others decreased. Thus, at the 150th day of storage, no significant difference was found among the HWD and *C. creticus* leaf extracts treatments and any of their combinations. Although no significant difference was noted for those of the test treatments, the best treatment in terms of the prevention of the weight loss was found to be HWD + CC (0.5%) treatment.

Influence of C. creticus leaf extracts and HWD on fruit firmness

The general efficacy of the tested treatments on the firmness of orange fruits was found to be in conjunction with the efficacy of weight loss. However, some of the treatments were found to have lower efficacy on firmness than weight loss prevention. These treatments are the HWD, HWD + A and Additive (Figure 2). The firmness of orange fruits decreased during the storage, and at the end of the 150 days of cold storage, the lowest fruit firmness was noted from these four treatments (control, HWD, HWD + A and Additive), which varied from 0.54 to $0.57 \text{ kg} \cdot \text{cm}^{-2}$. Furthermore, no significant difference was noted among the other six treatments (HWD + CC (1%) + A, CC (1%) + A, HWD + CC (0.5%) + A, CC (0.5%) + A, HWD + CC (0.5%) and CC (0.5%)). The fruit firmness of these treatments was found to vary from 0.65 to $0.69 \text{ kg} \cdot \text{cm}^{-2}$. Results showed that treatments with *C. creticus* leaf extracts have higher efficacy than the other treatments. Thus, current findings reveal that the efficacy of the treatments on fruit firmness is due to the *C. creticus* leaf extracts.

Influence of C. creticus leaf extracts and HWD on visual quality

Visual quality is an important parameter for the marketability of fresh horticultural products and is known to decrease during storage. As expected, the visual quality of the Valencia oranges showed a decreasing trend during the 150 days of cold storage (Table 2). In the beginning of the experiments, the fruits were all selected to have the best quality for each group of treatments (Figure 3). Thus, the initial quality of all treatments was 5.00. The visual quality of the control fruits showed the highest reduction during the first 30 days of storage and the visual quality score was decreased to 3.20. At the same time, the visual quality score of the fruits treated with Additives and CC (1%) + A was noted as 4.40. Similar to the fruit firmness, results suggested that the HWD treatment

Table 2. Influence of storage duration (days) on the means of observed quality parameters of Valencia oranges

Quality parameters	Time					
	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150
Weight loss (%)	0.00 f	4.50 e	6.42 d	8.46 c	10.84 b	11.92 a
Firmness ($\text{kg} \cdot \text{cm}^{-2}$)	0.72 a	0.67 b	0.67 b	0.64 bc	0.63 c	0.62 c
Decay incidence (%)	0.00 e	2.93 de	5.87 cd	10.45 bc	13.93 ab	17.87 a
Visual quality (1–5)	5.00 a	3.94 b	3.90 bc	3.58 cd	3.28 d	2.80 e
Soluble solid content (%)	12.08 d	12.33 c	12.45 bc	12.85 a	12.65 ab	12.53 bc
Titrateable acidity ($\text{g} \cdot 100 \text{ g}^{-1}$)	2.75 a	2.63 b	2.46 c	2.05 d	1.71 e	1.52 f
Ascorbic acid ($\text{mg} \cdot 100 \text{ g}^{-1}$)	37.30 e	54.00 d	63.68 ab	66.38 a	62.05 b	58.27 c
Respiration rate ($\text{ml CO}_2 \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$)	23.29 a	12.34 c	6.24 de	4.82 e	7.26 d	14.35 b

Means of quality characteristics at the different storage time were compared with Tukey's HSD test ($p \leq 0.05$) where means with different letters differ significantly ($p \leq 0.05$).

Figure 1. Effects of *C. creticus* leaf extracts, hot water dipping and their combination on the weight loss of Valencia oranges. Means of different treatments at the same storage time were compared with Tukey's HSD test ($p \leq 0.05$) where means with the same letter or letters are statistically similar.

Figure 2. Effects of *C. creticus* leaf extracts, hot water dipping and their combination on the fruit firmness of Valencia oranges. Means of different treatments at the same storage time were compared with Tukey's HSD test ($p \leq 0.05$) where means with the same letter or letters are statistically similar.

Figure 3. Effects of *C. creticus* leaf extracts, hot water dipping and their combination on the visual quality of Valencia oranges. Means of different treatments at the same storage time were compared with Tukey's HSD test ($p \leq 0.05$) where means with the same letter or letters are statistically similar.

alone is not so effective in the prevention of the loss in visual quality. Moreover, the combination of HWD with Additives and/or *C. creticus* leaf extracts was noted to have a high influence on the prevention of quality loss. A similar trend was found to continue till the end of the experiments, and at the end of the studies, the highest visual quality score was noted from the CC (0.5%) + A treatment with a score of 3.40. This was found to be above the acceptable marketability quality score of 3.00. The visual quality score of the control fruits was recorded as 2.00 and was followed by the HWD treatment with a score of 2.20.

***Influence of C. creticus* leaf extracts and HWD on DI**

Pathogenic decay is so important for the protection of postharvest storability of fresh horticultural products. Elimination of the decay improves the storability and the acceptability of the products by the consumers. The present study resulted in meaningful findings for the elimination of the DI. It was noted that all test applications, even the Additives alone, are effective in the prevention of the DI. The increasing trend of the DI can be followed from Table 2 and/or Figure 4. DI of control fruits increased from 13.33% at day 30 to 48.00% at day 150 (Figure 4). It is clear from the results that about half

of the fruits were lost during the 150 days of storage if they were not treated with any of the treatments. The second highest fruit loss (caused by DI) was noted from the Additives treatment as 22.67% and followed by CC (0.5%) with a DI of 18.67%. The findings of the present study revealed that the HWD application is effective in the prevention of the DI and the lowest DI score of 9.33% was noted from the combination of HWD with CC (1.0%) and Additives. However, no significant difference was noted with the other treatments, showing significant differences only with the control fruit.

***Influence of C. creticus* leaf extracts and HWD on SSC**

Fruit SSC is an important internal quality characteristic for the consumers, which together with TA determines the fruit flavour. Present findings showed that the SSC content of the fruits had an upward tendency during the first 90 days of storage and then had a decreasing trend. The initial SSC of Valencia oranges was recorded as 12.08% and increased to 12.85% in 90 days of storage. The final SSC content of the mean of all treatments was 12.53% on the 150th day of cold storage (Table 2). On the other hand, the treatments were noted to have no significant influence on the fruit SSC. At the end of the 150 days of cold storage,

Figure 4. Effects of *C. creticus* leaf extracts, hot water dipping and their combination on the decay incidence of Valencia oranges. Means of different treatments at the same storage time were compared with Tukey's HSD test ($p \leq 0.05$) where means with the same letter or letters are statistically similar.

Figure 5. Effects of *C. creticus* leaf extracts, hot water dipping and their combination on the soluble solids concentration of Valencia oranges. Means of different treatments at the same storage time were compared with Tukey's HSD test ($p \leq 0.05$) where means with the same letter or letters are statistically similar.

the highest SSC was measured from the HWD + CC (0.5%) + A treatment with 12.94% and the lowest SSC was recorded from the similar treatment (HWD + CC (1%) + A) as 12.32% (Figure 5). However, as described above, no significant difference was noted among the treatments.

Influence of C. creticus leaf extracts and HWD on TA

The TA content of the Valencia oranges was found to have a decreasing trend during cold storage (Table 2 and Figure 6). The initial TA content was $2.75 \text{ g} \cdot 100 \text{ g}^{-1}$ and it decreased to $1.52 \text{ g} \cdot 100 \text{ g}^{-1}$ in 150 days of cold storage. The TA of oranges was observed to be significantly affected by the different treatments (Figure 6). This significant influence had begun to be observed after 90 days of cold storage. At that time, the highest TA content ($2.24 \text{ g} \cdot 100 \text{ g}^{-1}$) was noted from HWD + CC (0.5%) application and the lowest TA content ($1.84 \text{ g} \cdot 100 \text{ g}^{-1}$) was observed from the control fruits. A similar trend was then continued till the end of the storage period. At the end of the 150 days of storage, the highest TA content was found to be $1.79 \text{ g} \cdot 100 \text{ g}^{-1}$ from the fruits treated with HWD + CC (0.5%). Results

suggest that both the HWD and *C. creticus* leaf extracts are effective in delaying the reduction of TA and their combination provides the best results. Moreover, the Additives alone treatment was found to have a slight effect on delaying the decrease in TA, but the highest efficacy was noted from the combination of HWD and *C. creticus* leaf extracts, without the Additives.

Influence of C. creticus leaf extracts and HWD on AsA

AsA is among the most important quality parameters of Valencia oranges. It is so important for consumers because of its confirmed health benefits and high antioxidant activity. The AsA values of Valencia oranges in the present study showed a similar trend with SSC during the cold storage period (Table 2). It was noted to have an increasing trend during the first 90 days of storage and then it decreased. However, the final AsA content of the Valencia oranges was recorded as higher than the initial value. On the other hand, findings of current work showed that all test applications, alone or in combination, have a significant influence on the AsA content. As seen from Figure 7, the lowest AsA content was measured from the control oranges and was followed

Figure 6. Effects of *C. creticus* leaf extracts, hot water dipping and their combination on the titratable acidity of Valencia oranges. Means of different treatments at the same storage time were compared with Tukey's HSD test ($p \leq 0.05$) where means with the same letter or letters are statistically similar.

Figure 7. Effects of *C. creticus* leaf extracts, hot water dipping and their combination on the ascorbic acid of Valencia oranges. Means of different treatments at the same storage time were compared with Tukey's HSD test ($p \leq 0.05$) where means with the same letter or letters are statistically similar.

by the oranges treated with Additives. This treatment was followed by HWD and HWD + A treatments. Results also suggested that there is no any significant difference among the other treatments. At the 150th day of cold storage, the highest AsA content was noted from the HWD + CC (1%) + A and HWD + CC (0.5%) + A treatments with the same value as $65.41 \text{ mg} \cdot 100 \text{ g}^{-1}$.

***Influence of C. creticus* leaf extracts and HWD on RR**

RR is an important parameter determining the storage duration and quality of fresh horticultural products. Cold storage, HWD and coatings, alone or in combination, are known to reduce the RR and improve the storability of products. The findings of current work showed that RR has a decreasing trend during the first 90 days of storage and then increased. This trend is different from that detected for SSC and AsA contents and is explaining the changes in SSC and TA. The RR was noted to be higher in the control groups, which clearly explains the quality loss in these untreated fruits (Figure 8). All of the test treatments were found to be efficient in reducing the RR as compared with the control treatment. The highest influence was noted from the HWD + CC (0.5%), followed by the applications of CC (0.5%) + A and HWD + CC (1%) + A. All of these results suggest that the HWD is effective in reducing RR, but

its efficacy is increasing with the Additives and/or *C. creticus* leaf extracts.

DISCUSSIONS

Results of current research suggested that the *C. creticus* leaf extract is effective in preserving the postharvest storability of Valencia oranges and a combination of this treatment with HWD provides the highest efficacy. The high efficacy of *C. creticus* leaf extract may be a result of its diverse and abundant chemical composition. Several previous studies have reported that the phytochemical composition of the plant extracts is responsible for their postharvest efficacy (Paolini et al., 2009; Abu-Orabi et al., 2020; Lahcen et al., 2020). Application of different biomaterials (edible coatings and films, essential oils, jasmonic acid, plant-derived products, etc.) has been previously recommended by several studies to preserve postharvest storability of fresh horticultural products (Chen et al., 2019; Kahramanoğlu 2019; Xin et al., 2019; Elkhatabi et al., 2020; Poveda, 2020; Riva et al., 2020). In most of those studies, the high efficacy of the plant extracts was correlated with the reduction in the RR of the products. In the present study, both the *C. creticus* leaf extract and HWD were found to reduce the RR of the fresh Valencia oranges and help to preserve the postharvest storability of fresh oranges.

Figure 8. Effects of *C. creticus* leaf extracts, hot water dipping and their combination on the respiration rate of Valencia oranges. Means of different treatments at the same storage time were compared with Tukey's HSD test ($p \leq 0.05$) where means with the same letter or letters are statistically similar.

Respiration determines the loss of sugars, promoting the deterioration of the fruit (Kahramanoğlu, 2017).

Summary of the results suggested that both *C. creticus* leaf extract and HWD, alone or in combination, are effective in reducing weight loss, preserving fruit firmness, maintaining visual quality, preventing DI, delaying the loss of TA and increasing AsA content. The results of the current study are found to be better than the findings of Rehman et al. (2018) who recommended 90 days of storage for the Valencia oranges with the application of methyl jasmonate. The higher efficacy of *C. creticus* leaf extract and HWD can be explained by their efficacy in reducing RR due to the modulation of gas exchange (Kator et al., 2018; Kahramanoğlu et al., 2019). The efficacy of HWD for reducing RR and weight loss of fruits is a well-known phenomenon, which was suggested by several studies (Yun et al., 2013; Opio et al., 2017; Atrash et al., 2018; Kahramanoğlu et al., 2020a; Wan et al., 2020). In a different study, Wei et al. (2018) noted that the efficacy of heat treatment for preserving the storability of strawberry fruits can be increased with the combination of heat treatment with tea tree oil. This report is in accordance with the findings of current work, where the efficacy of HWD was increased by its combination with *C. creticus* leaf extract.

Both the HWD and *C. creticus* leaf extract were found to maintain the visual quality of Valencia oranges

in the present study. The postharvest application of biomaterials, which was previously recommended, provides favourable conditions for the horticultural products and helps to maintain their visual quality (Mohebbi et al., 2014; Sophia et al., 2015; Supapvanich et al., 2016). HWD and plant extracts can inhibit the polyphenol oxidase (PPO) and peroxidase (POD) enzymes in the fruit tissues and this helps to reduce chilling injury and browning (Sharma and Rao, 2015; Murmu and Mishra, 2017; Tahir et al., 2018). Similar to weight loss and visual quality, the results of the current research showed that the HWD and *C. creticus* leaf extract treatments are effective in preventing pathogenic decay. The efficacy of HWD was well known, which was reported by several studies (Yun et al., 2013; Opio et al., 2017; Atrash et al., 2018; Kahramanoğlu et al., 2020a; Wan et al., 2020). However, current results are novel for the *C. creticus* leaf extract. Kahramanoğlu et al. (2020b) suggested the mechanism for the control of postharvest pathogens by biomaterials. They are (i) improvement of fruits' resistance by the biosynthesis of some secondary metabolites and (ii) direct prevention of the spore and/or pathogen development with the inducement of ROS. Some other studies have also reported that the application of HWD, light and/or plant extracts may induce some pathogenesis-related proteins (PRs), which improve the products' tolerance (Hu et al., 2014; Wan et al., 2020). On the other hand, the results

of the present study are in conjunction with the notes of Jemia et al. (2013) and Karim et al. (2017) who reported fungicidal activity for *Cistus* extracts.

Besides the above-discussed effects, both the *C. creticus* leaf extract and HWD were found to be effective for the prevention of changes in TA and AsA. TA, together with SSC, is the most important determinant of flavour, while the AsA is the most attractive characteristic of oranges by the consumers (Albertini et al., 2006). AsA is also an antioxidant and improves products' tolerance to oxidative stress and their storability. Previous studies have also suggested that the HWD treatment is effective for the prevention of changes in AsA contents (Imahori et al., 2016; Huan et al., 2017). The increase in AsA found in heat-treated fruits is probably due to the activation of the genes related to the AsA biosynthesis (Massot et al., 2013). Similarly to the present study, Erkan et al. (2005) reported that the HWD application helps to maintain the AsA content of mandarins.

CONCLUSIONS

The current research suggested that the application of HWD and *C. creticus* leaf extracts, alone or in combination, was effective in preserving orange weight during storage, preventing pathogenic decay, maintaining visual quality, keeping fruit firmness, delaying the reduction in TA, increasing ascorbic acid content and reducing RR of the orange fruits. The highest efficacy was obtained from the combination of these two treatments, and the postharvest storability of Valencia oranges was found to be increased up to 150 days at $6.0 \pm 1.0^\circ\text{C}$ and 90–95% RH. The weight loss of the HWD + CC (0.5%)-treated Valencia oranges was found to be 9.91% in 150 days of storage, which was noted as 16.83% for the untreated control fruits. The visual quality of these fruits has obtained a score of 3.20 in 150 days of storage, which is acceptable for marketability.

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AUTHOR CONTRIBUTIONS

All authors decided and conceptualised the experiments. İ.K., S.U. and T.A. collected the materials, designed the experiments and collected the data. İ.K., V.O. and C.W. performed the statistical analysis. İ.K. and C.W. wrote the initial draft of the paper. All authors edited the paper and give the final approval.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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