Shelf Life of Fresh Pistachio (Pistacia vera L.) upon Foliar Application of Sulfur as Pesticide

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Abstract

Application of sulfur as pesticide is a strategy in plant protection, but it is of great importance for a pesticide not to influence the quality of the product. In this study, movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L) and refinery micronized (R) and mineral (M) sulfur (30 and 60 kg/1000 L in water) were sprayed on pistachio trees of cultivar 'Ahmadaghaei' twice (in middle May and after 50 days) for controlling the psylla. Pistachios were harvested in late September and stored in 4 °C for 25 and 50 days in order to evaluate the effect of pesticides on the quality of hulls and kernels. Weight, taste, aroma, appearance, respiration rate, firmness of hull and kernel, phenolic content of kernel, anthocyanin, chlorophyll, carotenoid, a*, b* and chroma of hull and kernel declined over time, while phenolic content of hull, L* and hue of hull and kernel displayed an increasing trend. Antioxidant activity of hulls and kernels and ethylene production remained stable over time. Chemical pesticides stimulated loss of weight and hull firmness. Refinery micronized sulfur at both concentrations caused higher wight loss, higher chlorophyll of hull and kernel, lower carotenoid of hull and kernel, higher L* and hue and lower a*, b* and chroma of hull and kernel (lighter and greener color). All sulfur treatments reduced firmness and antioxidant activity of hull and kernel, while elevated the respiration rate, hull phenolics and hull anthocyanin. R30 saved the taste and aroma after 50 days. R30 and M30 showed higher ethylene production.

Introduction

Pistachio (*Pistacia vera* L.) tree produces popular nuts rich in nutritional components including fatty acids, vitamins, sterols and phenolics. Pistachio is among the most important and valuable nuts that is mainly traded as dry, in-shell kernels (Tsantili et al. 2011). But drying leads to various degrees of loss in nutrients and antioxidant components of pistachio, therefore, there has been an increasing demand for fresh pistachios due to health benefits (Sheikhi et al. 2019). Fresh pistachio can be stored in cold storage conditions for a short period of time, with different factors affecting its shelf life. Several fungi, bacteria and yeasts can infect the fresh pistachios causing postharvest spoilage, therefore, disinfection of fresh pistachios is a crucial step after harvest to reduce health risks and to prevent postharvest losses due to microbial decay (Sheikhi et al. 2020).

Application of different kinds of sulfur as a pesticide has been one of the strategies used in pistachio cultivation in the recent decades. Therefore, various forms of sulfur as a pesticide, especially against psylla, have been extensively produced and used in pistachio orchards. Sulfur in the commercial form is produced as a byproduct of coal, natural gas and petroleum refinement and mining process. Its effect is a non-systemic contact (Afrousheh and Hasheminasab 2018). Elemental sulfur is correlated with increased hydrogen sulfide (H_2S) and sulfurous off-aroma formation during fermentation, so is often used sparingly with long intervals. The advantages of sulfur over alternatives include its low cost, good efficacy, low risk of resistance development, and its acceptability within various production systems (Kwasniewski et al. 2014). The type, concentration and time of exposure should be determined for each crop in order to avoid the toxic and deleterious effects of sulfur. For example, fumigation of blueberries with high (250–350 μL L-1 h) concentration of SO_2 caused higher weight loss than control after 45 days of cold storage, but lower concentrations (50–200 μL L-1 h) had no adverse effects (Rivera et al. 2013). The phenolic content of wheat plants increased by 0.06 ppm SO_2 fumigation for 8 h daily (Agrawal and Deepak 2003), but 28 nLs^{-1} L^{-1} SO_2 fumigation did not influence the phenolic content of blueberries (Cantin et al. 2012).

Sulfur is used for several hundred kinds of foods and crops, ornamental plants, turfs, and residential sites. Besides pistachio psylla, sulfur is widely used for controlling brown rot of peaches (Holb and Schnabel 2008), powdery mildew of apples (Holb and Kunz 2016), peanut leaf spot (Culbreath et al. 2019), mildew on roses (Hosseininia et al. 2008) and etc.

The efficacy of sulfur on controlling pistachio pests, especially psylla, has been confirmed (Bakhtiari et al. 2016). But it is essential for a pesticide not to affect the quality of the product. Fortunately, the edible part of pistachio is its kernel that is covered by the shell and hull, protecting it from sulfur penetration. However, it is obvious that the kernels receive signals from their surrounding tissues and are under the influence of the physiological status of hull and the whole plant. Therefore, in this study, mineral and refinery micronized sulfur were applied on pistachio fruits of cultivar 'Ahmadaghaei' twice with a 50-day interval for controlling psylla. Then, it was aimed to investigate the effect of sulfurs on the physiology and quality of fresh pistachios (hull and kernel, separately) at harvest and two periods (45 and 90 days) of cold storage. The effects were also compared with two chemical pesticides, movento and confidor, which were previously applied against psylla.

Materials And Methods

Plant material and treatments

This project began in middle May 2019 in the orchards of Anar city, Iran. Pistachio trees of cultivar 'Ahmadaghaei' were sprayed with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L) and two types of sulfur, including refinery micronized (30 and 60 kg/1000 L in water) and mineral sulfur (30 and 60 kg/1000 L in water). The concentrations were chosen based the suggestions of farmers around the area. Control trees were not sprayed. The spraying was repeated after 50 days, in July. Each treatment consisted of three rows of trees, the replicates of which were selected in the middle row. Six neighboring trees were considered as one replication and the sampling was done from four sides of each tree. The spraying operation was carried out in the morning and ended before the weather warmed up. In late September and early October, at the time of pistachio harvest, the fruits were sampled and transferred to laboratory. A portion of fruits was used for obtaining the data of harvest time and the rest were kept in disposable tableware with closed lid and stored in 4°C. After 25 and 50 days, the fruits were analyzed again.

Moisture content

One kilogram of whole fruits of each replication was weighted at harvest, kept in disposable tableware with closed lid in 4°C and reweighted after 25 and 50 days. The weight loss was expressed as a percentage of the first weight (Cantin et al. 2012).

Firmness

Tissue firmness was evaluated using a Digital Force Tester (Lutron fg5020, Taiwan), fitted with a sharp 11 mm probe. Two different measurements were carried out on two opposite sides of the central zone of kernels and hulls. The values were expressed as kilogram-force (KgF).

Water activity

One g of kernels or hulls were used as replicates. Water activity was directly measured by a water activity meter (Novasina, Switzerland) and expressed as a_w.

Phenolic content

Total phenolic concentration was determined according to the Folin–Ciocalteu procedure, with absorbance measurement at 760 nm using gallic acid for preparing the standard curve. The results were expressed as mg of gallic acid in 100 g of fresh weight (Orthofer and Lamuela-Raventos 1999).

Antioxidant activity

Antioxidant activity was determined by the 2,2-diphenyl-1- picryl-hidrazil (DPPH) radical-scavenging method. The absorbance was measured at 517 nm, using a spectrophotometer (lambda-Elmer Perkin, American) and was expressed as the inhibition percentage of the DPPH radical (Serrano et al. 2005).

Anthocyanin

Anthocyanin content was determined using Wanger method with absorbance measurement at 550 nm and was expressed as μmol g^{-1} of fresh weight (Wanger 1979).

Photosynthetic pigments

Chlorophyll and carotenoid content were measured according to Lichtenthaler's method with absorbance at 470, 646.8 and 663.2 nm using a UV-visible spectrophotometer. The concentrations were expressed as mg g^{-1} of fresh weight (Lichtenthaler 1987).

Color indicators

Color values of hulls and kernels (with testa) were directly measured with a color meter (Minolta Chroma Meter Model CR-400, Minolta, Japan). The color was measured as the lightness (L*), red-green (a*) and blue-yellow (b*). The chroma value and hue angle were calculated by the fallowing equations (Equations 2 and 3) [24].

Equation2: Chroma $=\sqrt{(a*)^2 + (b*)^2}$ Equation 3: hue angle $= \tan^{-1}(\frac{b*}{a*})$

Sensory evaluation

The sensory analysis included a panel test constituted of ten semi-trained panelists. The panelists evaluated the taste, aroma, appearance and general acceptance of fruit. Excellent was shown with five, very good with four, good with three, moderate with two, poor with one (Wang et al. 2006).

Ethylene production and respiration rate

15 g of whole pistachio fruits was placed in 1.6 L airtight respiration jars at 20°C and allowed to equilibrate for 2 h. 1 mL of head-space atmosphere was withdrawn using plastic syringes and injected into a gas chromatograph (Agilent 7890B, USA) equipped with a packed column and a thermal conductivity detector (TCD) for quantification of CO_2 or C_2H_4. Injector, detector and oven temperatures of gas chromatograph were set at 100, 120, 80°C respectively. Nitrogen was used as the carrier gas at the flow rate of 73.7 mL min^{-1}. The respiration rate and ethylene production were expressed as ng kg^{-1} s^{-1} (Gheysarbigi et al. 2020).

Statistical analysis

The study was a factorial experiment based on a completely randomized design with four replications. Sources of variation were storage time (0, 25 and 50 days), treatments (control, movento, confidor, R30, R60, M30, and M60) and their interaction. Mean values were calculated and reported as the mean ± standard error of means. Data were analyzed by SAS 9.1 statistical software package, and the least significant difference (LSD) test at P = 0.01 probability was used to compare the means. Where the interaction of factors was significant, the data was presented in graphs, and where the simple effect of factors was only significant, the data was presented in tables. The graphs were plotted in MS-Excel software package.

Results And Discussion

Weight loss

The interaction of storage time and treatments had significant (P = 0.01) effect on weight loss. This trait increased by time. Two chemical pesticides caused higher weight loss at both storage times comparing control. Refinery micronized sulfur at both concentrations (R30 and R60) caused higher wight loss than control on 25th day but was similar to it after 50 days (Fig. 1). Research shows that sulfur may have adverse effects on fruit weight loss, which is concentration dependent. For example, in blueberry cultivars ‘Brigitta’ and ‘ONeal’, fumigation with high (250–350 µL L^{-1} h) concentration of SO_2 caused higher weight loss than control after 45 days of cold storage, but lower concentrations (50–200 µL L^{-1} h) were similar to control (Rivera et al. 2013). In this study, 30 and 60 kg/1000 L of refinery micronized sulfur showed adverse effects on weight loss but mineral sulfur does not. Mineral sulfur at its lower concentration (M30) even showed less weight loss than control on day 50. This result may be due to the longer persistence of refinery micronized sulfur on fruit surface. In a study on grapes, residue concentrations generally were lower for a wettable powder of elemental sulfur versus a micronized formulation applied at the same rate and timing of the last application before harvest (Kwasniewski et al. 2014). On the other hands, our results indicated that the negative effects of sulfur on water loss was eliminated sooner than that of movento and confidor. It is well known that chemical pesticides have varied degrees of phytotoxicity along with their benefits. They can destruct the plant cell walls and membranes leading to elevated transpiration and water loss (Parween et al. 2014).

Firmness

The interaction of storage time and treatments had significant (P = 0.01) effect on hull firmness. This trait decreased by time. Movento and all sulfur treatments showed a reduction in hull firmness comparing control at harvest time, but not during storage (Fig. 2). The simple effects of treatments and storage time were significant on kernel firmness (P = 0.01). Day 50 and sulfur treatments caused a reduction in kernel firmness (Tables 1 and 2). Firmness is a major quality indicator for fruit marketability. Normally, when fruit water content decreases over time, a reduction in firmness is expectable. The lower firmness of sulfur-treated samples at harvest time indicates the lower water content comparing control. Comparably, application of sulfur (100–150 μL L^{-1} h) on blueberry through SO_2 pads inside the packaging, resulted in lower firmness than control (Rodrigues and Zoffoli 2016).

Table 1
The effect of chemical pesticides and different concentrations (kg/1000 L) of refinery micronized (B) and elemental (Z) sulfur on some physical and chemical properties of hull and kernel of pistachio cultivar Ahmadaghaei

Treatment	Kernel firmness (KgF)
Control	3.21 ± 0.19 a
Movento	2.88 ± 0.18 ab
Confidor	3.00 ± 0.26 ab
R30	2.55 ± 0.18
R60	2.65 ± 0.13 b
M30	2.71 ± 0.20 b
M60	2.77 ± 0.21 b

Table 2
The effect of storage time on some physical and chemical properties of hull and kernel of pistachio cultivar Ahmadaghaei

Storage time	Kernel firmness (KgF)	Hull WA (a_w)	Kernel WA (a_w)	Kernel phenolic content (mg in 100 g FW)
At harvest	3.05 ± 0.10 a	0.970524 ± 0.000001 a	0.971333 ± 0.000001 a	0.1402 ± 0.0001 a
Day 25	3.14 ± 0.11 a	0.973143 ± 0.000002 a	0.971571 ± 0.000001 a	0.0892 ± 0.0010 b
Day 50	2.28 ± 0.10 b	0.956952 ± 0.000001 b	0.960190 ± 0.000002 b	0.0928 ± 0.0100 b

Water activity

The simple effect of storage time was only significant of the water activity of hulls and kernels. This trait displayed a reduction on 50th day comparing control (Table 2). The growth of pathogens in foods is markedly affected by water activity (Romero et al. 2007). The water activity of both hulls and kernels was above 0.9 a_w which is high and suitable for the growth of most pathogens. The treatments did not influence the water activity because it is mostly dependent on temperature (Slade et al. 1991). All the samples had relatively the same temperature at harvest time and also at cold storage. Although the water content of a food does not necessarily determine the water activity, the severe water loss on 50th day resulted in a reduction in water activity.

Phenolic content

The interaction of storage time and treatments was significant (P = 0.01) on the content of phenolics of hull. In control, this trait remained statistically stable, but sulfur-treated samples revealed an increasing trend over time so that R30, R60 and M60-treated samples had 57.3%, 38.4% and 40.3% higher phenolic content of hull respectively, on 50th day comparing harvest time (Fig. 3). Pistachio hulls are a rich source of phenolic compounds being ranked among the first 50 food products highest in antioxidant potential (Tomaino et al. 2010). The increasing effect of sulfurs on phenolic content of hulls is somehow related to the higher water loss which causes a higher drought stress. The phenolic content of wheat plants significantly increased after they were fumigated by 0.06 ppm SO_2 for 8 h daily from germination to grain maturity (Agrawal and Deepak 2003). But SO_2 fumigation did not influence the phenolic content of blueberries (Cantin et al. 2012). Bolling et al. (2010) found that total phenolics of almond skins stayed constant or increased progressively during 15 months storage at 4 or 23°C.

The simple effect of storage time was significant (P = 0.01) on phenolic content of kernels. The phenolic content of kernels was totally lower than that of hulls which has been reported in previous studies (Tomaino et al. 2010). Phenolic content of kernels declined at both storage times comparing harvest time, which indicates the difference in metabolic status between hulls and kernels (Table 2). In another study, the phenolic content of pistachio kernels measured by DPPH method, showed a 12.2% decrease after high water loss (Tsantili et al. 2011).

Antioxidant activity

The interaction of storage time and treatments was significant (P = 0.01) on the antioxidant activity of hulls and kernels. Pesticides-treated hulls were similar to control, however, sulfur-treated hulls had lower antioxidant activity than control at all storage times (Fig. 4a). In kernels, sulfur treatments had lower antioxidant activity than control, while movento showed a more similar effect with control (Fig. 4b). These results are not in agreement with the results of phenolic content and imply that in sulfur treatments, a significant decrease must have occurred in the content of other molecules with antioxidant properties, probably antioxidant enzymes, vitamins or carotenoids (carotenoid content was lower in R30 and R60 sulfur treatments (Fig. 7)). In another study, the antioxidant activity of 10 different fruit extracts was mostly correlated to the content of vitamin C and carotenoids rather than phenolics (Olsson et al. 2004). Similar to hulls, the antioxidant activity of kernels remained stable over time for most samples except the samples that were treated with confidor and R30, in which a decrease was observed on 50th day comparing harvest time. The stability of antioxidant activity over time is probably due to the low temperature (4°C) during storage in which the antioxidant enzymes have low activity. The antioxidant activity of strawberry fruits remained stable during storage as a result of cold temperature (Jin et al. 2011).

Anthocyanin

The interaction of storage time and treatments was significant (P = 0.01) on anthocyanin content of hulls and kernels. Refinery micronized sulfur at both concentrations (R30 and R60) and mineral sulfur at high concentration (M60) showed a higher anthocyanin content of hulls than other samples. A slight decreasing trend for hull anthocyanin content was observed during storage (Fig. 5a). Research shows various effects of SO_2 on anthocyanin content of fruits. For example, when blubbery cultivar 'Emerald' was stored in controlled atmosphere after SO_2 fumigation, it revealed higher content of anthocyanins comparing controlled atmosphere alone (Cantin et al. 2012). Timberlake and Bridle (1967) believe that SO_2 directly reacts with anthocyanins rendering them colorless and stabilizing them against degradation. Another study indicated that the content of anthocyanins in longan pericarp decreased after SO_2 fumigation (Han et al. 2001). The highest anthocyanin content of kernels was related to harvest time for control. Some treatments revealed a decreasing trend over time (Fig. 5b). Most of the kernel anthocyanins are present in its testa which is a thin layer on the green seed. The testa dries rapidly by time and the anthocyanins get out of the vacuoles and may be degenerated by polyphenol oxidase.

Chlorophyll

The interaction of storage time and treatments was significant (P = 0.01) on chlorophyll content of hulls and kernels. Refinery micronized sulfur at both concentrations (R30 and R60) showed the highest chlorophyll content than other samples. Chlorophyll content of some samples had a slight decrease during storage (Fig. 6a,b). Since all the pistachios were completely ripe at harvest time, the high chlorophyll content in sulfur treatments is not due to the difference in ripening process. Chlorophylls are responsible for harvesting light quanta and transferring energy during photosynthesis. The way that the plants response to SO_2 stress depends on the specific physiological state of them and their need to energy (Li and Yi 2020). Usually, the studies report the negative effect of SO_2 on photosynthesis and chlorophyll content, but some reveal the stimulation of chlorophyll synthesis under SO_2 treatments. For example, the total chlorophyll content was significantly increased in the leaves of Arabidopsis plants exposed to 30 mg/m^3 SO_2 for 72 h (Li and Yi 2020). In green gram, 200 µg (active ingredient) kg^{-1} of sulfosulfuron stimulated the chlorophyll synthesis in fresh leaves (Khan et al. 2006).

Carotenoid

The interaction of storage time and treatments was significant (P = 0.01) on carotenoid content of hulls and kernels. Refinery micronized sulfur treatments (R30 and R60) showed a lower carotenoid content of hull at harvest time. The carotenoid content of hulls showed a decreasing trend over time for most samples, fallowed by a slight increase on 50th day (Fig. 7a). Similar to hulls, R30 and R60 caused a lower carotenoid content of kernels at harvest time. The carotenoid content of kernels remained stable during storage for some samples while some others showed a slight decreasing trend (Fig. 7b). Apart from antennae function, carotenoids also act as natural defense under stress condition (Parween et al. 2014). The reduction in carotenoid content by SO_2 has been reported in other plants such as rice (Agrawal et al. 1982) and strawberry (Muneer et al. 2014). Lower carotenoid content in R30 and R60 treated hulls may show the decoloring property of sulfur as well. In figs cultivar 'Brown Turkey', 50–100 (µL/L) h SO_2 caused bleaching of fruits with a concentration-dependent trend in cold storage (Cantin et al. 2011). Movento-treated hulls had the highest carotenoid content at harvest which can be related to the higher water loss and more phytotoxic effect of this pesticide.

Color indicators

The interaction of storage time and treatments was significant (P = 0.01) on the color indicators of hull. At harvest time, refinery micronized sulfur-treated samples (R30 and R60) had higher L* value but lower a* and b* values of hull than others (Fig. 8a,b,c). This means that R30 and R60 treated hulls were lighter and greener than others. In coordination, these two treatments had different hue (basic color) and chroma (color intensity) values (Fig. 8d,e). Lower hue again shows the greener color and less red and yellow pigments, while higher chroma value reveals more intense color of these two treatments. This is coordinated with the results of chlorophyll and carotenoid content. Similarly, SO_2 treatment caused a greener color in Arabidopsis leaves (Li and Yi 2020). Totally, L* value of hull showed an increasing trend in 25th day fallowed by a slight decrease in some samples. This increasing trend can be due to the gradual synthesis of cuticle on hull epidermal cells and also the gradual removal of sulfur particles. Likewise, fresh cut apples treated with 50% sodium sulfite were lighter than control after 5 days of cold storage (Ortzi et al. 2018). a* and b* values revealed a decreasing trend during storage which is in agreement with the decreasing trend of carotenoids. In a similar way, the hue value of most samples increased on 50th day which shows the gradual loss of red and yellow pigments. The chroma value revealed a reduction over time that again shows the loss of pigments and loss of color intensity.

The interaction of storage time and treatments was also significant (P = 0.01) on the color indicators of testa of kernel. The results of testa were very similar to the results of hulls. So that, R30- and R60-treated samples had higher L* and hue values but lower a*, b* and chroma values of testa at harvest time (Fig. 8f,g,h,i,j) which means that they were lighter and greener with less red and yellow pigments. These treatments provided a more intense color. L* and hue values showed increasing but a*, b* and chroma values showed decreasing trends over time. We are of this opinion that sulfur particles do not penetrate to the kernel if the hull is intact. But the kernels are certainly influenced by the physiological status of hulls and get signals from them through metabolic pathways. This can be the reason why the kernels changed their color in a way that the hulls did.

Sensory evaluation

The interaction of storage time and treatments was significant (P = 0.01) on taste, aroma and appearance of pistachios. As expected, all three parameters displayed a decreasing trend during storage, but in some cases, this decrease was not statistically significant. R30 treatment could maintain the taste and aroma of pistachios even after 50 days (Fig. 9a,b). Sulfur, in certain concentrations and application times, is applied as a preservative in food technology because it keeps the quality of food constant, meeting market requirements (Rossello et al. 1994). For example, in wine industry, small doses of SO_2 is required to extend the sensory quality (Wyk et al. 2018). Herein, the panelists did not record any off-flavor for the treatments. Comparably, no off-flavor was developed after SO_2 fumigation in blueberries (Cantin et al. 2012). All sulfur treatments showed a higher degree of appearance at harvest time (Fig. 9c), which is related to the antimicrobial effect of sulfur, keeping the fruit surface safe from disease damages. The lighter and more intense color of sulfur-treated hulls were other reasons for the higher degree of appearance in these treatments

Ethylene production and respiration rate

The interaction of storage time and treatments was significant (P = 0.01) on both ethylene production and respiration rate of pistachios. All sulfur treatments had higher respiration rate than control, which might be the result of high energy consumption for protection mechanisms activation under SO_2 stress. The respiration rate declined by time as the result of lowered metabolism under cold temperatures (Fig. 10a). The respiration rate of wheat plants increased by 0.06 ppm SO_2 fumigation for 8 h daily. It was claimed that the detoxification reactions against SO_2 are ATP mediated which is provided by respiration (Agrawal and Deepak 2003). In the present study, a probable toxification to hulls resulted in respiration elevation.

Sulfur treatments at lower concentration (R30 and M30) showed higher ethylene production than others. After 25 days, no significant difference was observed between the samples (Fig. 10b). Tomato plants fumigated by SO_2 for 1 h showed enhanced ethylene production and when the treatment prolonged for 4 h, ethylene production was also enhanced. It was concluded that ethylene might play an important role in SO_2-induced plant injuries at relatively short terms of SO_2 fumigation (Gong Young et al. 1995). Alfalfa plants fumigated by 0.7 μL/L SO_2 for 8 h, increased ethylene production 10 times greater than control plants (Peiser and Yang 1979). Ethylene production of bean plants treated with elemental sulfur increased before full bloom and before fruit set, and flowering occurred earlier because a slow oxidation of elemental sulfur in air produced SO_2 which enhances ethylene evolution from leaves (Recalde-Manrique and Diaz-Miguel 1981).

Conclusion

Practical evidence shows that sulfur application on pistachios is very effective on controlling the pests such as psylla that cause huge losses to the yield annually. At the same time, it is important to optimes the type and concentration of sulfur to prevent the influence on product quality. The kernel which is the edible part of pistachio is covered by the shell and hull, so sulfur cannot easily penetrate to the kernel. However, the physiological status of hull and the whole plant may influence the kernels and the yield. Yield weight, firmness, color, taste and aroma are some indicators for marketability and they were declined over time. Some sulfur treatments, especially refinery micronized type, provided lighter and greener color and could preserve the traste and aroma of pistachios over time, but at the same time, they reduced the weight, firmness and carotenoid content. Therefore, the gardeners should take this into account that besides the benefits on controlling the pest, sulfur may have some effects on the product quality.

Abbreviations

R30: Refinery micronized sulfur (30 kg/1000 L); R60: Refinery micronized sulfur (60 kg/1000 L); M30: Mineral sulfur (30 kg/1000 L); M60: Mineral sulfur (60 kg/1000 L)

Declarations

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Conflicts

of interest/Competing interests: All authors agree on the content of the paper and have no conflict of interest to disclose.

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Figures

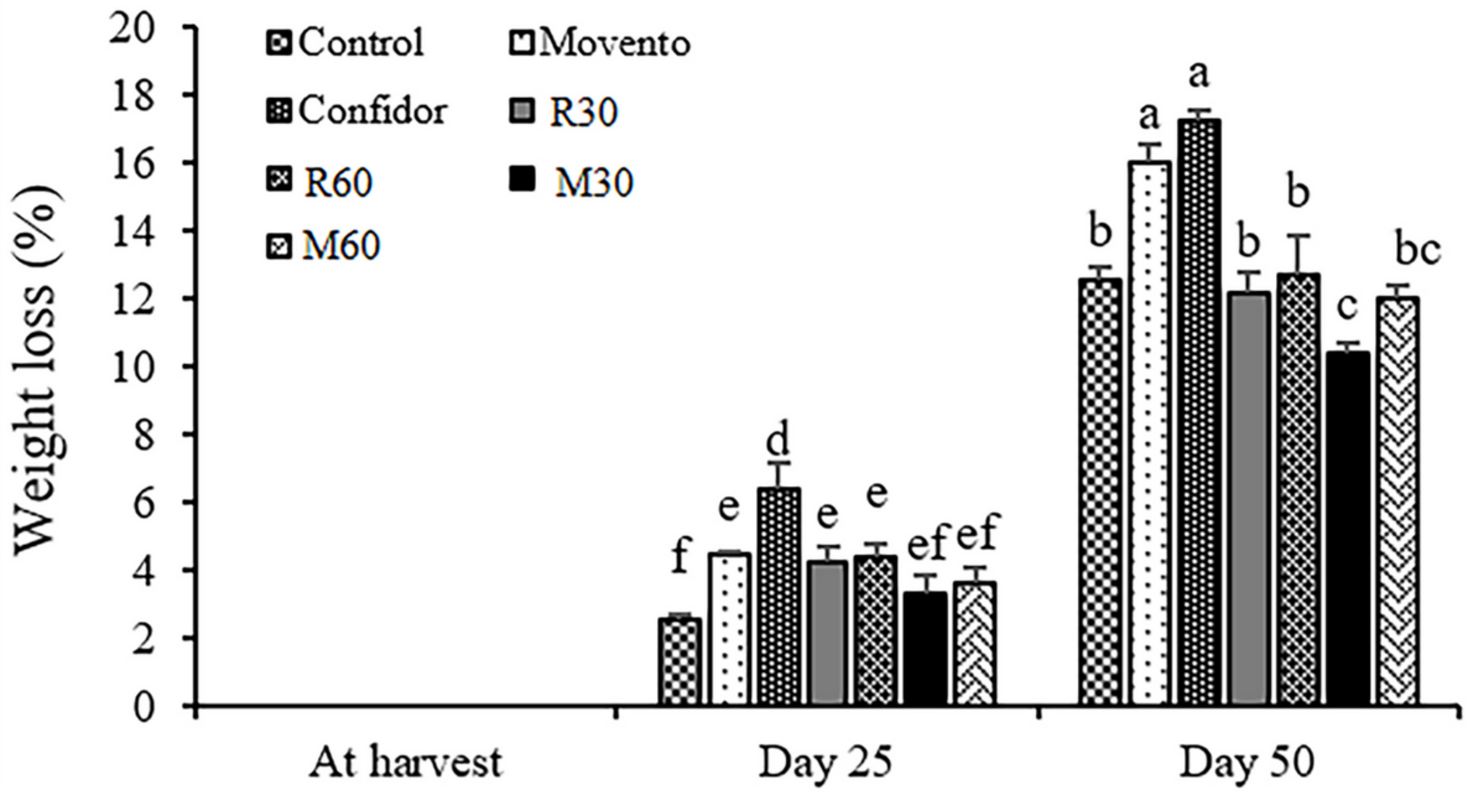

Figure 1

Weight loss of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage

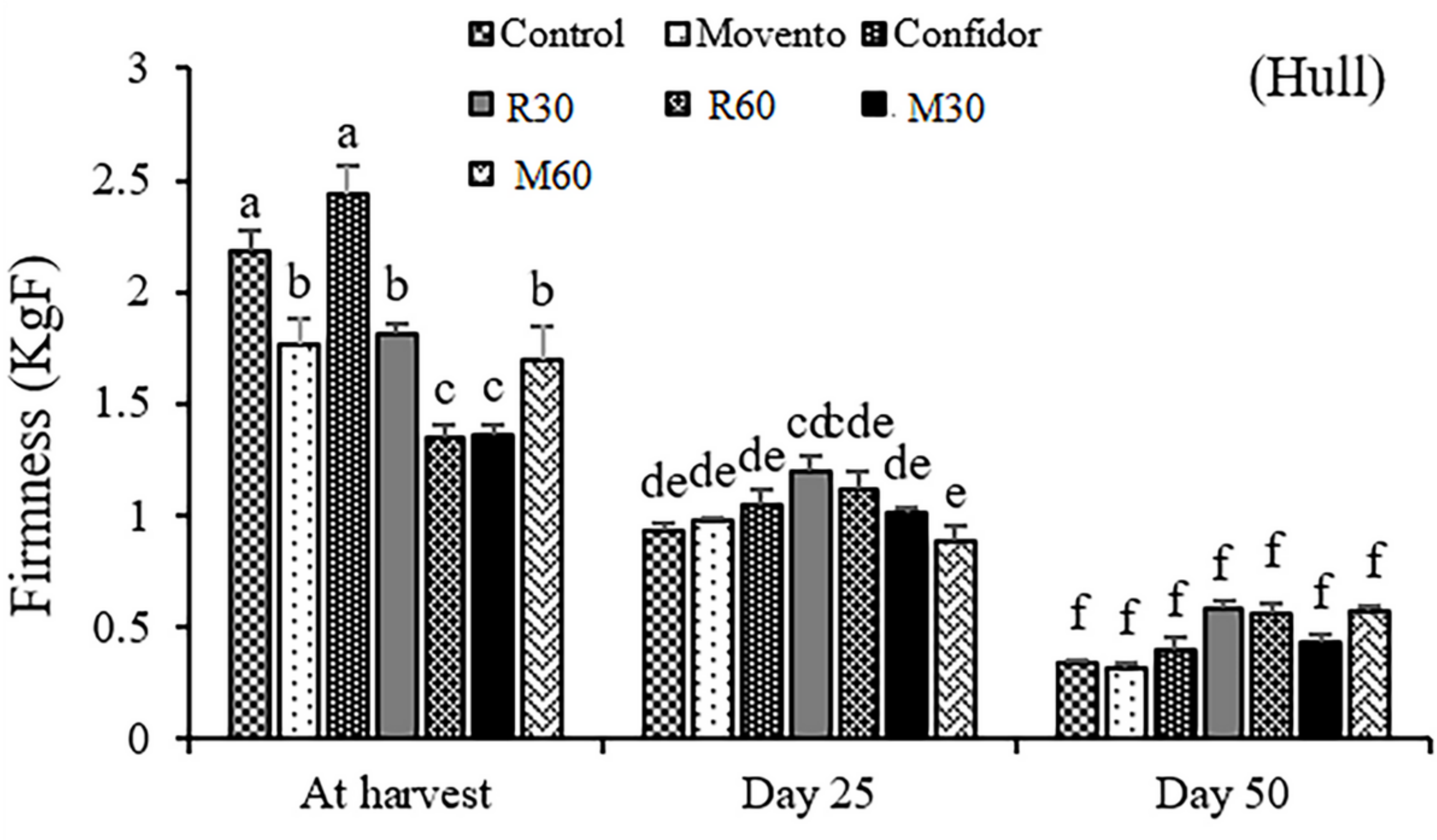

Figure 2

Hull firmness of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage

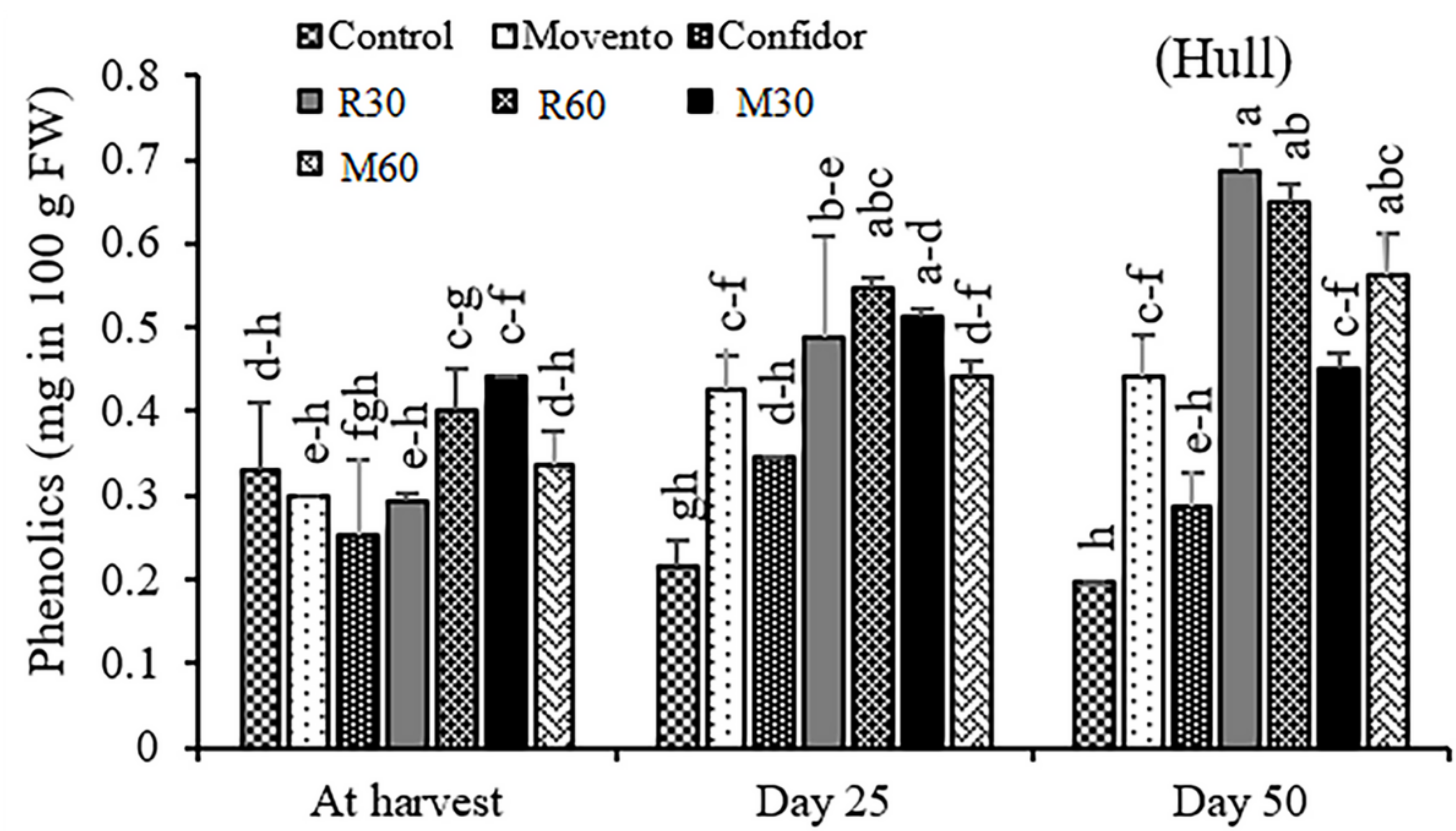

Figure 3

Hull phenolic content of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage

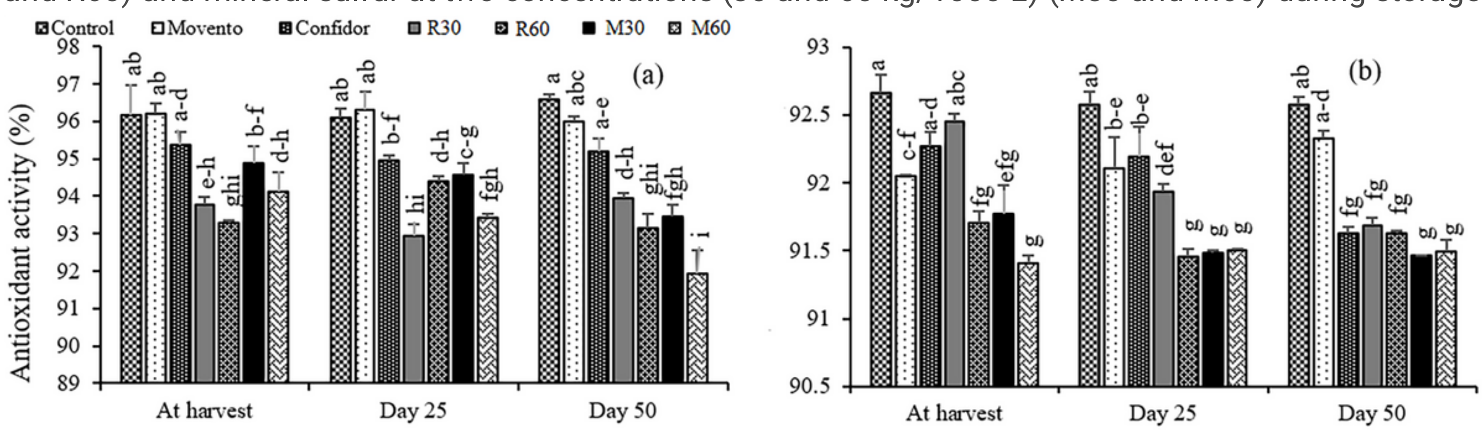

Figure 4

Antioxidant activity of (a) hulls and (b) kernels of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage

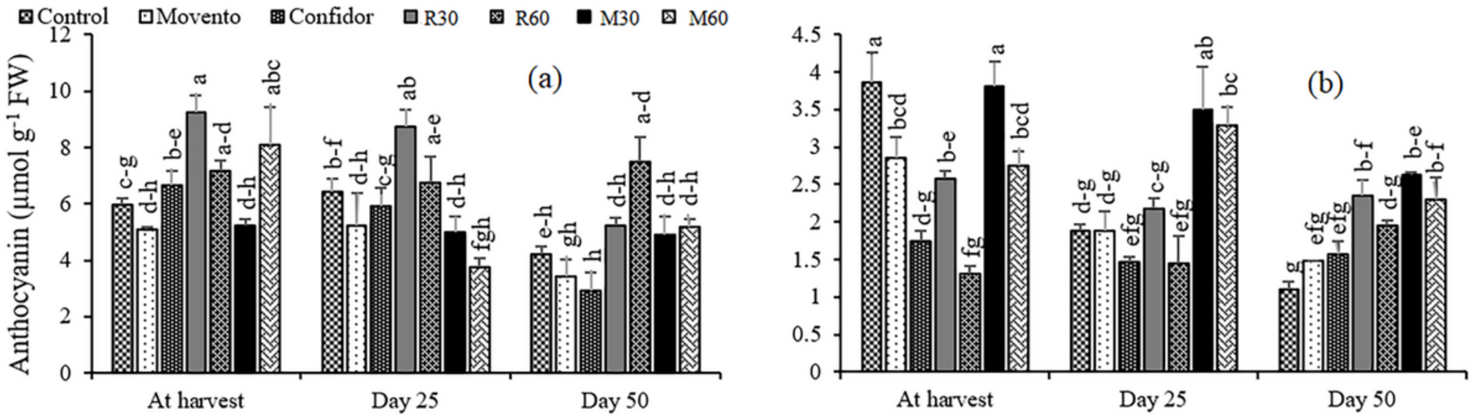

Figure 5

Anthocyanin content of (a) hulls and (b) kernels of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage

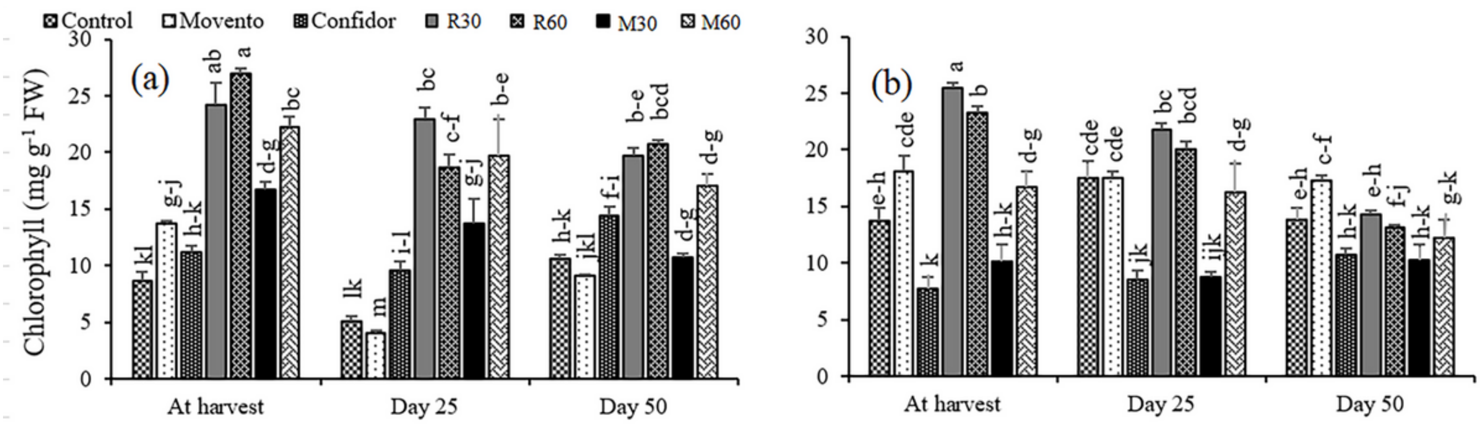

Figure 6

Chlorophyll content of (a) hulls and (b) kernels of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage

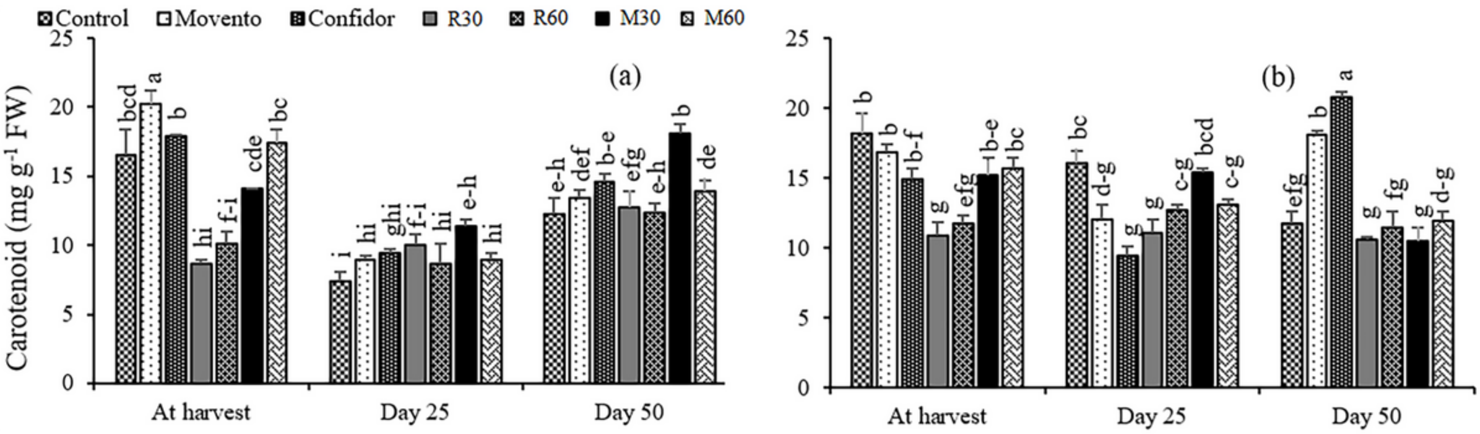

Figure 7

Carotenoid content of (a) hulls and (b) kernels of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage

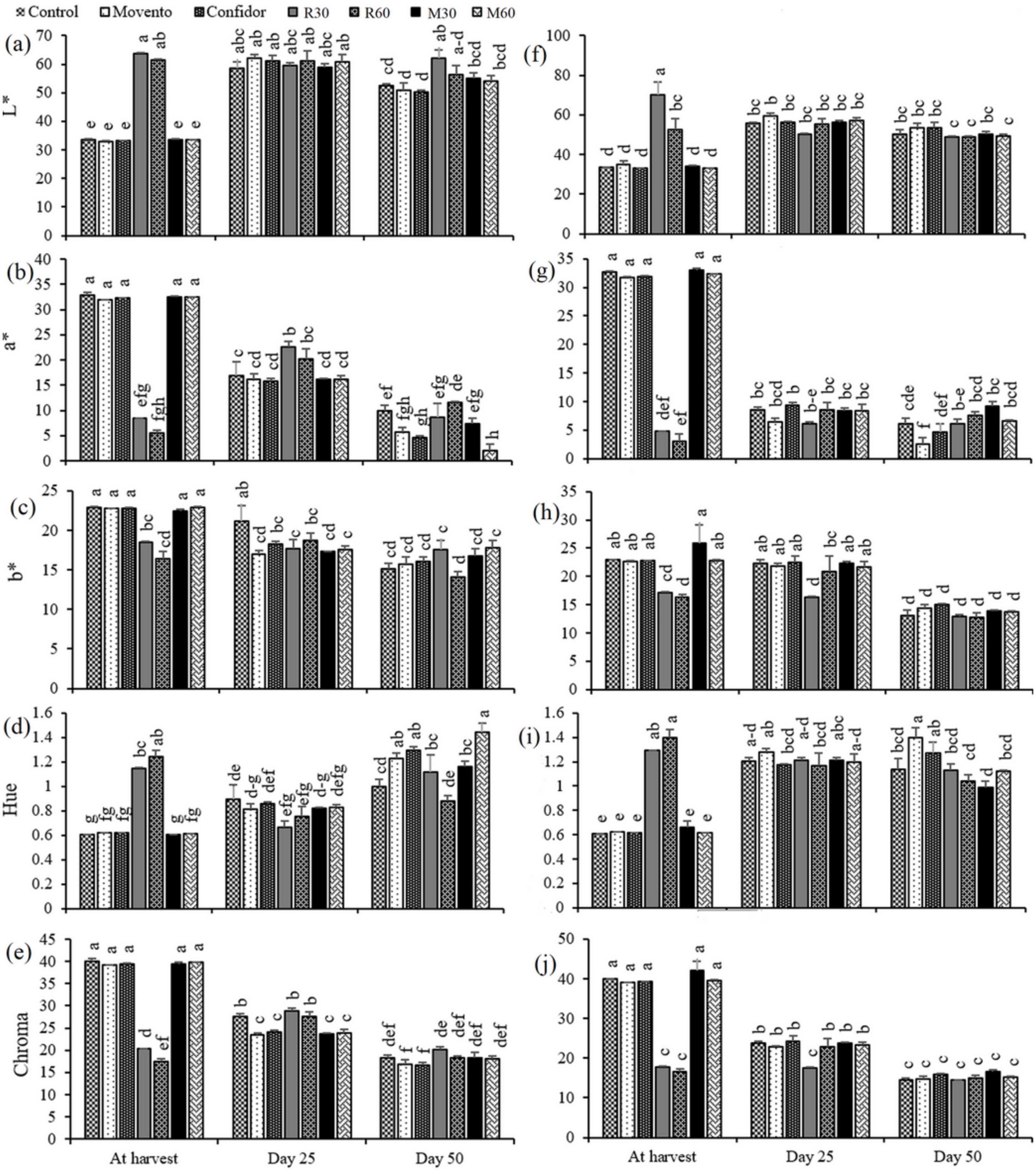

Figure 8

Color indicators of (a-e) hulls and (f-j) kernels of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage

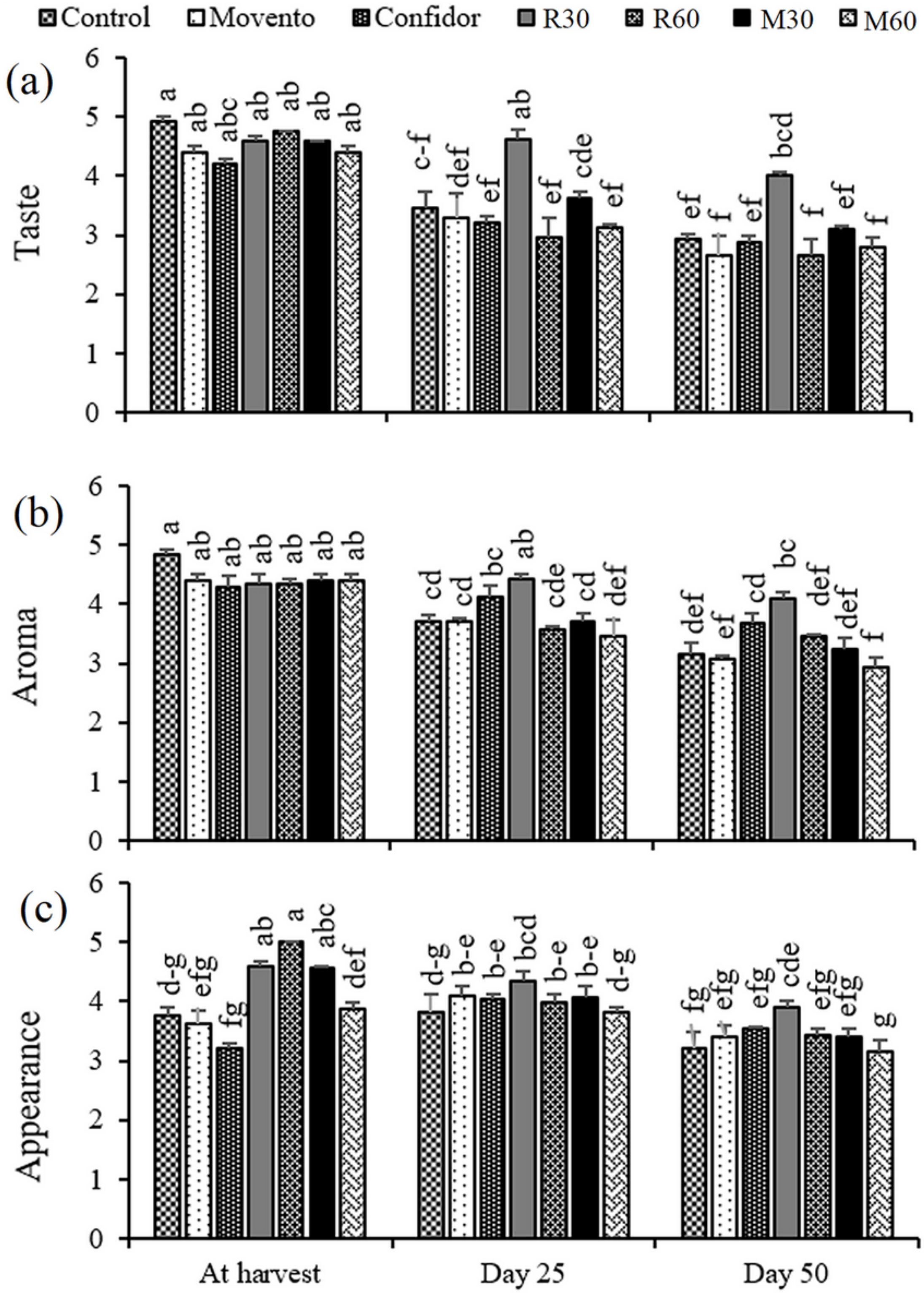

Figure 9

Sensory indicators of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage

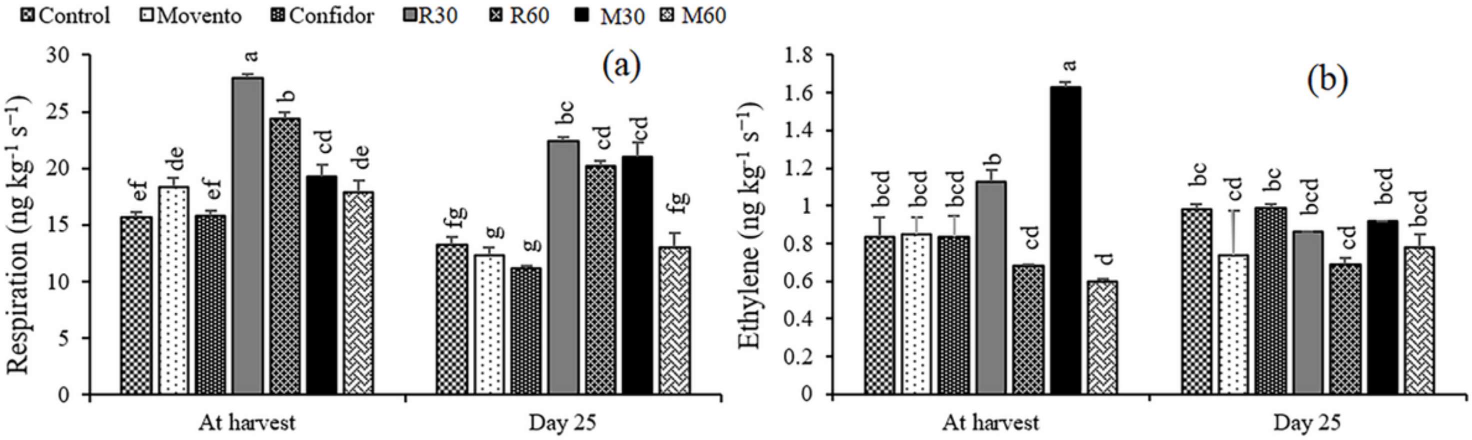

Figure 10

Ethylene production (a) and respiration rate (b) of pistachio cultivar ‘Ahmadaghaei’ treated preharvest with movento (0.5 kg/1000 L), confidor (0.4 kg/1000 L), refinery micronized sulfur at two concentrations (30 and 60 kg/1000 L) (R30 and R60) and mineral sulfur at two concentrations (30 and 60 kg/1000 L) (M30 and M60) during storage