JOURNAL OF HORTICULTURE AND POSTHARVEST RESEARCH
2025, VOL. 8(2), 245-258

Journal of Horticulture and Postharvest Research

Journal homepage: www.jhpr.birjand.ac.ir

University of Birjand

Avoiding endocarp lesion and abscission of pistachio nut using lecithin-enriched calcium nitrate

Mozhdeh Yousefi[1], Seyed Hossein Mirdehghan[1,*], Majid Esmaeilizadeh[1], Fatemeh Nazoori[1] and Seyyed Rasoul Sahhafi[2]

1, Department of Horticultural Sciences, Faculty of Agriculture, Vali-e-Asr University of Rafsanjan, Iran
2, Department of Genetics and Plant Production, Faculty of Agriculture, Vali-e-Asr University of Rafsanjan, Iran

ARTICLE INFO

Original Article

Article history:
Received 1 October 2024
Revised 29 December 2024
Accepted 31 December 2024

Keywords:
Early-split
Foliar spray
Physiological disorders
Quality

DOI: 10.22077/jhpr.2024.8220.1429
P-ISSN: 2588-4883
E-ISSN: 2588-6169

***Corresponding author:**
Department of Horticultural Sciences, Faculty of Agriculture, Vali-e-Asr University of Rafsanjan, Iran.

Email: mirdehghan@vru.ac.ir

ABSTRACT

Purpose: The pistachio nut is an important product primarily traded as dry nut in-shell kernels. Any damage to the shell during growth and development can cause shell staining and kernel decay in pistachios, rendering them unsuitable for sale. This study aimed to mitigate these issues by evaluating the effects of various calcium nitrate solutions. **Research method:** Fruit samples from two pistachio cultivars, 'Akbari' and 'Kaleh-Ghoochi,' were collected from 18-year-old trees with moderate tree vigor in a commercial orchard. The calcium nitrate solutions included a control sample (distilled water), 0.4% calcium nitrate, and 0.2% calcium nitrate enriched with lecithin, foliar applied two weeks after full bloom. **Findings:** Calcium nitrate treatments, both alone and enriched with lecithin, significantly reduced physiological disorders such as endocarp lesions and fruit abscission. In 'Akbari,' calcium nitrate treatments reduced issues such as nut ounce, shell staining, deformed nuts, blank nuts, endocarp lesions, early-split nuts, hull decay, and hull cracking. In contrast, Kaleh-Ghoochi also benefited from reduced occurrences of deformed nuts, early-split nuts, hull decay, and hull cracking. However, when treated with calcium nitrate enriched with lecithin, there was a notable reduction in blank nuts in Kaleh-Ghoochi, whereas calcium nitrate alone led to an increase in blank nuts. These calcium nitrate treatments resulted in positive outcomes and reduced fruit defects, thereby enhancing the overall quality and marketability of pistachios. Notably, the combination of calcium nitrate and lecithin had a more pronounced impact on Akbari, improving the pistachio nut's hull appearance, firmness, and reducing water activity. **Research limitations:** There were no limitations. **Originality/Value:** These findings suggest that calcium plays a significant role in enhancing the yield, quality, and marketability of pistachio fruit, providing practical insights for farmers aiming to improve their pistachio production practices.

INTRODUCTION

The pistachio nut is a valuable produce primarily traded as dry nut in-shell kernels (Sheikhi et al., 2019). Therefore, enhancing quality can create better consumption and marketing opportunities (Singh et al., 2022). The pistachio kernel is edible and sits in the center, encased by a hard, lignified shell and a green hull (Toghiani et al., 2023). Any damage to hull and shell during growth and development can cause shell staining and kernel decay in pistachio, rendering them unsuitable for sale (Hasanshahi et al., 2023).

Pistachio can be affected by various physiological disorders, including inflorescence bud and fruit abscission, blank nuts, non-split nuts, endocarp lesion, deformed nuts, early-split nuts, alternate bearing, and low productivity (Khezri et al., 2010; Pourahmadi et al., 2019). Some of these physiological disorders affecting pistachios occur within their skins. Therefore, maintaining the quality of the pistachio hull and shell can help address many physiological disorders. Nutrient deficiency is associated with increased physiological disorders in pistachio trees (Tadayon & Hosseini, 2022). Calcium is generally recognized as safe (GRAS) and is used to reduce physiological disorders in fruits (Mirshekari & Madani, 2022). Products with low calcium content are more susceptible to physiological disorders (Khademi & Khoveyteri-Zadeh, 2022). It plays a crucial role in various aspects of plant growth, including cell division, cell elongation, and fruit development (Sadr et al., 2019). Therefore, foliar application should be considered during the period of peak nutrient demand. This is based on the premise that soil supply and root uptake may be inadequate to meet demands, even with adequate soil-applied fertilizer (Tadayon & Hosseini, 2022). Moreover, the presence of essential nutrients, particularly calcium, plays a crucial role in fruit development during the initial growth stages (Sen et al., 2010; Zeraatgar et al., 2019). Remarkably, the thickening process of the fruit surface can impact nutrient absorption when employing foliar application (Madani et al., 2014). Calcium is transported through the xylem via the transpiration stream (Sajadian & Hokmabadi, 2011). In fact, the competition between leaves and fruit for calcium significantly affects the amount of calcium acquired by the fruit (Sen et al., 2010). Interestingly, despite leaves not exhibiting symptoms of calcium deficiency, the fruit (particularly the endocarp) can still suffer from severe calcium deficiency and lead to endocarp lesion in pistachio nuts. Furthermore, an imbalance in the calcium-to-magnesium ratio results in inadequate calcium absorption by the plant (Sajadian & Hokmabadi, 2011). Calcium nitrate has been used in various studies as a source of calcium (Khademi & Khoveyteri-Zadeh, 2022).

Fruit abscission in pistachio trees is an important problem that leads to significant economic losses in pistachio orchards. It occurs from the millet stage until the hardening of the endocarp. Fruit abscission in pistachio trees starts with the browning and blackening of the skin of the tip of the fruit. This complication is known as endocarp lesion (Sajadian & Hokmabadi, 2011). The inner endocarp surface becomes white, while the border between healthy and infected regions turns brown. Infected pistachios often shrink and drop due to endocarp damage, with fruit abscission occasionally exceeding 80% of the total. As the endocarp hardens and cotyledons begin to develop, the infected endocarp area becomes soft and flexible, potentially leading to deformation during harvesting. A characteristic symptoms of pistachio endocarp lesion is the blackening of the endocarp from the top to the bottom, with black spots appearing on the green pericarp (Adibfar et al., 2012; Sadr et al., 2019) (Fig. 1). Normally, pistachio trees produce abundant flowers and pollen grains. However, during early fruit development, numerous flowers and fruits fall and only a few remain on pistachio clusters. The physiological states and nutrient availability from the previous year have a significant effect on fruit preservation. Previous research has shown that calcium deficiency can lead to endocarp lesion and fruit abscission in pistachio nuts (Sajadian & Hokmabadi, 2011).

The formation and strength of the pistachio endocarp depend significantly on the availability of calcium ions (Adibfar et al., 2012; Sadr et al., 2019; Sadr et al., 2020). Calcium plays a crucial role in maintaining the texture and firmness of fruits by forming calcium pectate, which stabilizes the cell walls (Hossain et al., 2021). When administering calcium nitrate and calcium chloride sprays to pistachio fruit, they effectively reduce the incidence of endocarp lesion disorder. Calcium treatments help fortifies the structural integrity of the endocarp (Pourahmadi et al., 2019). Similarly, the study by Sajadian and Hokmabadi (2011) and Sajadian (2016) demonstrated that the incidence of endocarp lesion decreases with the application of calcium treatments, including calcium sulfate, calcium nitrate (soil application), and calcium chelate foliar spray, during the rapid growth of the endocarp. Adibfar et al. (2012) reported that spraying a calcium chloride solution in pistachio orchards reduces endocarp lesion.

Recent studies by Pourahmadi et al. (2019) have shed light on the role of calcium in the development of deformed nuts. Microscopic observations indicate that pistachio deformation occurs approximately two weeks after full bloom, coinciding with the destruction of parenchymal cells in the endocarp (Pourahmadi et al., 2019). Calcium plays a crucial role in cell division and elongation, and it is essential for maintaining the integrity of the plant cell wall (Tapia-Rodriguez et al., 2021). Additionally, calcium plays a crucial role in influencing the activity of auxin, a plant hormone. Auxin, in turn, plays a significant role in shaping the fruit.

It has been shown that the primary cause of blank pistachio nut is associated with inadequate differentiation and damage to various components of the embryo sac, leading to embryo miscarriage during the growing season (Mohammadi et al., 2017; Pourahmadi et al., 2019). Interestingly, the application of calcium appears to mitigate blank nut formation by safeguarding the embryo sac (Desouky et al., 2009). The occurrence of non-split nuts and early-split nuts is also associated with optimal nutrition and kernel development in pistachio (Khezri et al., 2010). Early-split nuts refer to pistachio nuts in which the hulls and shells have split prematurely (Pourahmadi et al., 2019). This rupture of the hull often results in dark staining of the shell (Sedaghati & Alipour, 2005). External calcium application plays a crucial role in mitigating fruit cracking (Mohammadi et al., 2017). Approximately 60% of calcium is present in the cell wall. Calcium acts as an intermolecular connector, stabilizing the pectin complex in the middle lamella of plant cells. By inhibiting ethylene production, calcium prevents the activation of cell wall hydrolysis enzymes. Consequently, it contributes to maintaining cell wall integrity and firmness in fruits (Sajadian & Hokmabadi, 2011).

According to Adibfar et al. (2012), the hardiness of pistachio endocarp is influenced by the availability of calcium in fruit. One effective method for enhancing the calcium status of fruit involves using substances that facilitate calcium absorption. Lecithin, acting as a natural emulsifier, assists calcium in better penetrating plant cells. This strategy can be particularly beneficial for fruit like pistachio, which heavily depend on calcium for their growth and development (Pirozzi et al., 2020). Lecithin role is to limit spray drifting, reduce surface tension, and prevent droplet evaporation by encapsulating the active ingredient within each droplet (liposomes), thereby enhancing assimilation (Vannini et al., 2021). It is a highly polar compound with a lipophilic fatty acid backbone and a hydrophilic choline head could potentially facilitate the movement of calcium through the waxy cuticle of the apple. However, lecithin formulations dry into a thin, even film after application, and it is possible that the close contact between the calcium and the fruit’s surface aids in calcium movement (Reid & Padfield, 1975). Pistachio producers worldwide encounter various physiological disorders that impact performance and quality. However, there is limited evidence regarding the pistachio tree's response to calcium nitrate in controlling these disorders. The lack of crucial information represents the main limiting factor in this context. The objective of this study is to assess the effectiveness of foliar calcium nitrate and lecithin application as a pre-harvest treatment for controlling pistachio physiological disorders during the initial growth stages.

Fig. 1. Symptoms of endocarp lesion on a pistachio cluster (Iran-Rafsanjan, June).

MATERIALS AND METHODS

Plant material and experiments

Fruit samples from two pistachio cultivars (Akbari and Kaleh-Ghoochi) were collected from 18-year-old trees with moderate tree vigor in a commercial orchard at Rafsanjan, Iran (30.41334539°N, 55.98884582°E). These trees are grafted onto the Badamizarand rootstock and are planted at an optimal distance of 1.6 meters from each other. The trees receive irrigation once every 45 days and are trained in an open center formation. The samples underwent the following treatments: control samples (distilled water), calcium nitrate (0.4%), and calcium nitrate (0.4%) with lecithin (0.2%) two weeks after full bloom, with three trees per treatment. Spraying was done in the early morning using a backpack sprayer. Calcium nitrate was dissolved in a 0.5% solution of Tween 20 (v/v) and used immediately. Approximately 1.5 liters of solution was used per tree.

Assessment of nut disorder status and nut characteristics

Six relatively homogeneous shoots on each tree are selected and labeled to monitor the fruit abscission, hull decay, hull cracking, early-split disorder, and endocarp lesion. Each selected shoot contains one cluster. Two weeks after full bloom, the number of fruit in each cluster is counted. To evaluate the effect of treatments on endocarp lesions, six pistachio clusters were sampled from each randomly selected tree within each treatment group. Both non-contaminated and contaminated nuts were counted in mid-June with three replications (Sajadian & Hokmabadi, 2011). The percentage of early split nut disorders, hull cracking, and hull decay in each cluster was calculated four weeks before harvest, by quantifying the proportion of fruit with abnormalities relative to the total number of fruit sets (Pourahmadi et al., 2019). Additionally, the fruit abscission percentage was determined by dividing the number of fallen fruit in each shoot by the initial number of fruits set in that shoot (Tadayon & Hosseini, 2022). Other pistachio disorders were evaluated at the time of harvest for each cluster. Pistachio nuts were harvested when the nut-shells were easily detached from the endocarp (Ferguson & Haviland, 2016). After harvest, all fruit were removed from the clusters and manually sorted into categories: blank, deformed, and those with internal shell staining. The internal shell staining refers to the endocarp with white and brown halos within the shell. The disorders are quantified as the percentage of fruits with abnormalities out of the total number of fruit sets (Tadayon & Hosseini, 2022). To calculate the pistachio nut ounce for each replicate, the number of fruits per 28.3 grams of dry fruit is determined, following the method described by Tadayon and Hosseini (2022).

At harvest, external shell staining was assessed by examining 20 fruits per replicate. Superficial brown spots on the outer skin were identified as indicators of browning. The severity of symptoms was visually assessed based on a six-stage scale: 0 (no browning), 1 (browning covering ≥20% of the fruit surface), 2 (browning covering ≥20% but <40% of the fruit surface), 3 (browning covering ≥40% but <60% of the fruit surface), 4 (browning covering ≥60% but <80% of the fruit surface), and 5 (browning covering ≥80% of the fruit surface). The browning index (BI) was calculated as follows (1) (Wang et al., 2006):

$$BI = [(BI\ level) \times (number\ of\ fruit\ at\ the\ BI\ level)] / (6 \times total\ number\ of\ fruit\ in\ the\ treatment) \quad (1)$$

Statistical Evaluation

The experiment is designed as a factorial, considering two variables: cultivar and treatments. It follows a randomized complete block design with three repetitions. Data analysis is performed using SAS software, employing analysis of variance (ANOVA). To compare the means, Duncan's multiple range tests at the 5% probability level was used. Graphs are created using Excel software.

RESULTS

Endocarp lesion

As shown in Table 1, endocarp lesion was influenced by the simple effects of cultivar and treatment. All applied calcium nitrate treatments, when as compared to control samples, reduce the occurrence of endocarp lesion. The lowest level is observed in lecithin-enriched with calcium nitrate, which does not exhibit a statistically significant difference with calcium nitrate (Fig. 2a). Additionally, Akbari shows a higher amount of endocarp lesion as compared to Kaleh-Ghoochi (Fig. 2b).

Table 1. Variance analysis of physiological disorders in pistachio cultivars under different calcium nitrate treatments.

		Mean squares									
Sources of variation	df	Endocarp lesion	Blank nut	Deformed nut	Early-split nut	Internal shell staining	External shell staining	Hull cracking	Hull decay	Fruit abscission	Pistachio nut ounce
block	2	3.61	11.93	0.02	0.13	0.15	0.0002	8.94	0.62	1.45	7.76
C	1	56.60*	34.72*	0.08ns	25.52**	0.34*	0.0008ns	43.58ns	11.10**	67.74**	66.90*
T	2	499.80**	117.48**	3.38**	21.45**	0.73**	0.0020*	522.59**	188.19**	531.60**	52.70*
C×T	2	5.28ns	95.57**	0.60**	20.17**	0.34*	0.0018*	85.41**	12.53**	2.54ns	58.70*
Error	10	7.61	6.29	0.02	0.06	0.06	0.0003	9.89	0.51	6.38	10.18
Coefficient of variation		18.60	29.45	27.21	20.44	28.24	11.63	23.75	17.88	16.85	9.07

* and ** show significance at the 5% levels, and ns means no significant difference.

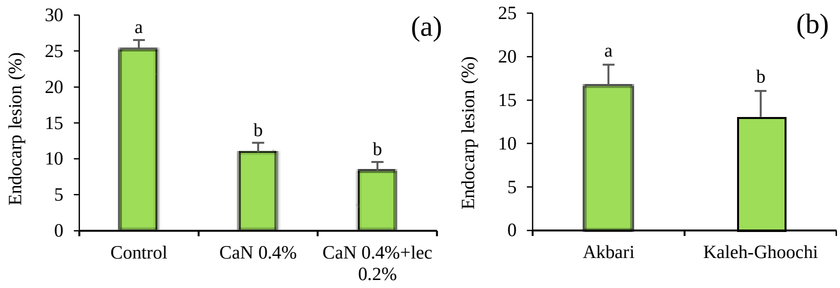

Fig. 2. Endocarp lesion of pistachio fruit treated with CaN and CaN + lec (a), and in different cultivars (b). The same letters indicate no significant difference in the 5% probability level for Duncan's multiple range tests. Vertical bars represent the SE.

Blank nut

As shown in Table 1, blank nut was influenced by the simple effects of cultivar, treatment, and their interaction. In Akbari, calcium nitrate and calcium nitrate enriched with lecithin reduced the occurrence of blank nut as compared to control samples. However, no significant difference was observed within the calcium nitrate treatments. In contrast, in Kaleh-Ghoochi, only calcium nitrate enriched with lecithin effectively reduced the occurrence of blank nuts. Interestingly, calcium nitrate increases the occurrence of blank nuts as compared to control samples (Fig. 3a).

Deformed nut

Table 1 indicated that the simple effects of treatment and their interaction significantly influenced deformed nut ($P \leq 0.01$). In Fig. 3b, it is clear that applying calcium nitrate and calcium nitrate enriched with lecithin effectively reduces the occurrence of deformed nut as compared to the control in Akbari cultivar. Notably, a similar effect was observed in Kaleh-Ghoochi, that calcium nitrate treatments also reduced deformed nut. Interestingly, calcium nitrate enriched with lecithin exhibited the lowest incidence of deformed nuts.

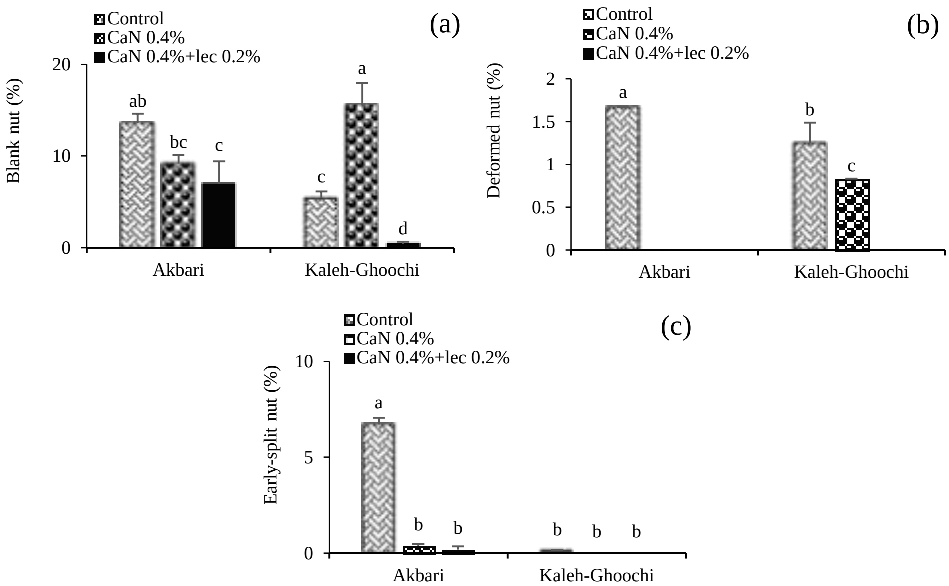

Fig. 3. Blank nut (a), deformed nut (b), and early-split nut (c) of pistachio fruit treated with CaN and CaN + lec. The same letters indicate no significant difference in the 5% probability level for Duncan's multiple range test. Vertical bars represent the SE.

Early-split nut

As shown in Table 3, early-split nut was affected by the simple effects of cultivar, treatment, and their interaction ($P \leq 0.01$). The application of calcium nitrate treatments, both alone and with lecithin, significantly reduced the percentage of early-split nut in Akbari pistachios as compared to control samples. Although there was no statistically significant difference between the calcium nitrate treatments, the mean of these treatments was lower than the control samples. In contrast, there was no significant difference between the calcium nitrate treatments and control samples regarding the occurrence of early-split nut in Kaleh-Ghoochi pistachios. However, early-split nut is generally very low in Kaleh-Ghoochi, indicating that calcium nitrate treatments are particularly effective for improving the quality of Akbari pistachios (Fig. 3c).

Internal shell staining

According to the results in Table 1, internal shell staining in dried fruits was affected by the simple effect of treatment and the interaction effects of cultivar and treatment. The occurrence of internal shell staining was decreased with the application of calcium nitrate treatments in Akbari as compared to control samples. The highest rate of internal shell staining was observed in control samples, whereas the lowest rate occurred in calcium nitrate enriched with lecithin. Notably, in Kaleh-Ghoochi, calcium nitrate enriched with lecithin, calcium nitrate, and control samples exhibit similar effects on the rate of internal shell staining. However, the mean for calcium nitrate enriched with lecithin is lower than that of the calcium nitrate and control samples (Fig. 4a).

External shell staining

As shown in Table 1, external shell staining was influenced by the simple effects of treatment and the interaction effects of cultivar and treatment ($P \leq 0.05$). The application of calcium nitrate treatments, especially calcium nitrate, significantly reduces external shell staining in Akbari as compared to control samples. Notably, in Kaleh-Ghoochi, calcium nitrate enriched with lecithin, calcium nitrate, and control samples exhibit similar effects on external shell staining. However, the mean of the calcium nitrate treatments is slightly lower than the control samples (Fig. 4).

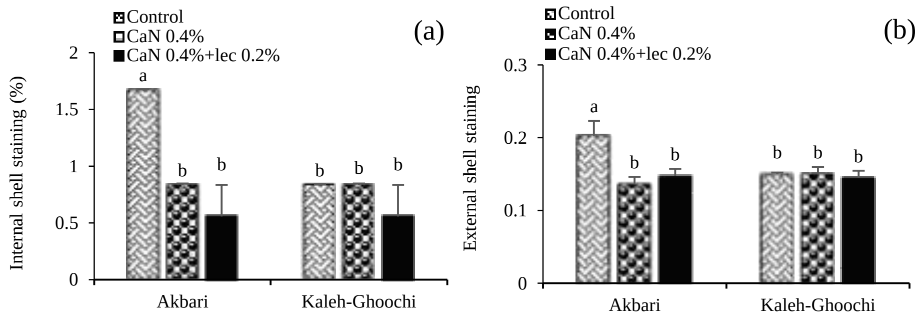

Fig. 4. Internal shell staining (a) and external shell staining (b) of pistachio fruit treated with CaN and CaN + lec. The same letters indicate no significant difference in the 5% probability level for Duncan's multiple range tests. Vertical bars represent the SE.

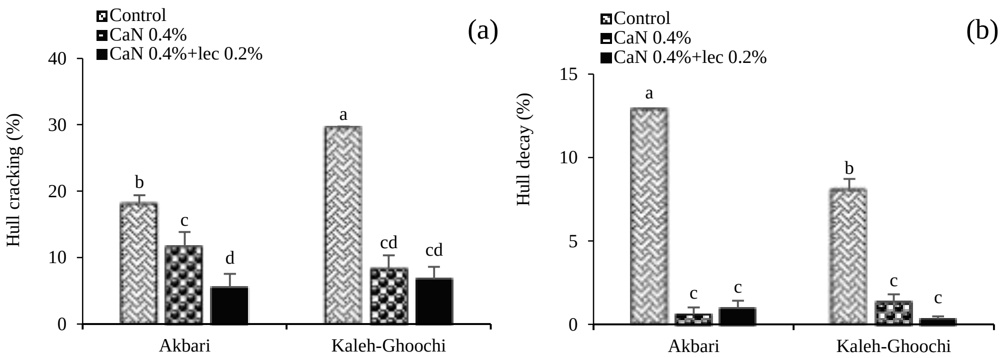

Fig. 5. Hull cracking (a) and hull decay (b) of pistachio fruit treated with CaN and CaN + lec. The same letters indicate no significant difference in the 5% probability level for Duncan's multiple range test. Vertical bars represent the SE.

Hull cracking

The results of the variance analysis table showed that hull cracking was influenced by the effect of treatment and the interaction effect of cultivar and treatment at a significance level of 1% (Table 1). In Figure 5a, it is evident that calcium nitrate and calcium nitrate enriched with lecithin effectively reduced hull cracking in as comparison to the control samples in Akbari. It is noteworthy that a similar effect was observed in Kaleh-Ghoochi, where calcium nitrate treatments reduced hull cracking. In both cultivars, it is evident that calcium nitrate enriched with lecithin had a more favorable effect than calcium nitrate, although there was no statistically significant difference between the two treatments.

Hull decay

As shown in Table 1, the simple effects of cultivar, treatment, and their interaction significantly influenced hull decay in pistachios at a significance level of 1%. The application of calcium nitrate treatments significantly reduces hull decay in Akbari as compared to the control samples. Specifically, calcium nitrate exhibits a more pronounced positive effect. Notably, a similar effect is observed in Kaleh-Ghoochi, with the distinction that calcium nitrate enriched with lecithin has a greater impact than calcium nitrate in reducing hull decay (Fig. 5b).

Fruit abscission

As Table 1 indicated, the simple effects of cultivar and treatment affected fruit abscission at a significance level of 1%. Calcium nitrate enriched with lecithin demonstrated a lower percentage of fruit abscission than control samples, although it did not exhibit a significant difference with calcium nitrate (Fig. 6a). Additionally, Kaleh-Ghoochi demonstrates a higher percentage of fruit abscission as compared to Akbari (Fig. 6b).

Pistachio nut ounce

Based on the analysis of variance table, the effects of cultivar, treatment, and their interaction on pistachio nut ounce were statistically significant ($P \leq 0.05$) (Table 1). The results suggest that in Akbari, calcium nitrate treatments, especially calcium nitrate enriched with lecithin, result in a decrease in pistachio nut ounce as compared to the control samples. Additionally, in Kaleh-Ghoochi, no significant difference was observed between calcium nitrate enriched with lecithin, calcium nitrate and control samples (Fig. 6c).

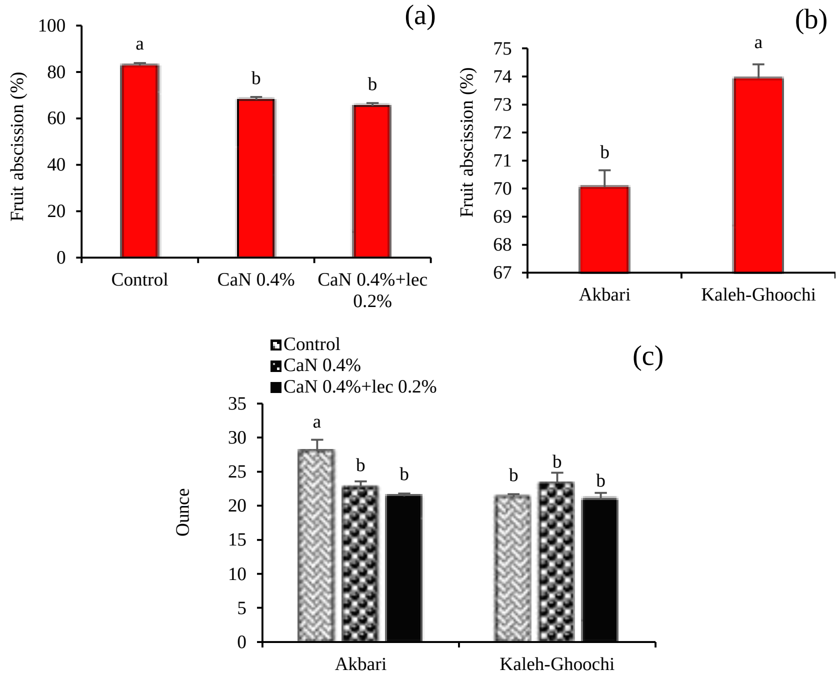

Fig. 6. Fruit abscission (a, b) and pistachio nut ounce (c) of pistachio fruit treated with CaN and CaN + lec. The same letters indicate no significant difference in the 5% probability level for Duncan's multiple range test. Vertical bars represent the SE.

DISCUSSION

Calcium deficiency in fruit can lead to various physiological disorders (Sen et al., 2010). It is employed to avert disorders both pre- and post-harvest (Dunnd & Able, 2006). The formation and strength of the pistachio endocarp significantly depend on the availability of calcium ions (Sadr et al., 2020). Research conducted by Sadr et al. (2019, 2020) demonstrates that applying calcium spray to pistachio fruit effectively enhances the structural integrity of the endocarp. Consequently, improvement in endocarp integrity leads to a reduction in endocarp lesion disorder. In this study, the incidence of endocarp lesion disorder decreases with the implementation of calcium treatments. Similarly, research by Sajadian (2016) demonstrates that applying calcium treatments during the rapid growth of the endocarp decreases the occurrence of endocarp lesions. Additionally, the findings of Pourahmadi et al. (2019) and Sajadian and Hokmabadi (2011) indicate that calcium treatments enhance calcium uptake in pistachio fruits and reduce the incidence of endocarp lesion disorder, which is in line with the results of our study.

Calcium nitrate and calcium nitrate enriched with lecithin in Akbari, have resulted in a reduction in the occurrence of blank nuts. However, in Kaleh-Ghoochi, only calcium nitrate enriched with lecithin demonstrates a reduction in blank nuts. The findings align with the research by Pourahmadi et al. (2019). According to Ferguson and Haviland (2016), blanking occurs during the fruit set stage and persists until the kernel is fully formed. The primary cause of blank is associated with inadequate differentiation and damage to various components of the embryo sac, leading to embryo miscarriage during the growing season (Mohammadi et al., 2017; Pourahmadi et al., 2019). Calcium, as a key regulator, influences various physiological processes in plants (Hashimoto et al., 2012). Furthermore, the application of calcium mitigates the occurrence of blank nuts by safeguarding the embryo sac (Desouky et al., 2009).

Microscopic observations indicate that pistachio deformities arise due to the destruction of parenchymal cells in the endocarp (Pourahmadi et al., 2019). Calcium, as a vital nutrient, plays a crucial role in cellular functions and membrane stabilization (Sinha et al., 2019). Notably, Fageria (2016) emphasizes that calcium is essential for cell division, elongation, and the structural integrity of plant cell walls and other organelles. Furthermore, calcium significantly influences auxin activity, which contributes to improving fruit shape (Tiwari et al., 2012). It appears that calcium contributes to tissue reconstruction, resulting in a decrease in the percentage of deformed nuts in pistachio fruit (Mohammadi et al., 2017).

In this study, it is evident that calcium nitrate treatments effectively mitigate early-split nuts. The exogenous application of calcium may reduce pistachio fruit cracking by increasing the calcium content in the skin of the fruit and maintaining the structural integrity of plant cell walls (Mohammadi et al., 2017). The increase in early-split nuts could be attributed to irrigation and nutritional stresses within the orchard (Khezri et al., 2010). If the occurrence of early-split nuts is indeed associated with nutritional stresses, calcium nitrate may potentially alleviate the occurrence of early-split nuts (Pourahmadi et al., 2019). On the other hand, ROS can cause damage to membranes, lipids, proteins, and cellular structures (Karray-Bouraoui et al., 2011). Considering that early-split nuts affect the skin of the fruit, it appears that ROS and ethylene contribute to the occurrence of early-split nuts in pistachio trees. The application of calcium nitrate as an anti-ethylene agent reduces the incidence of early-split nuts by increasing calcium levels (Pourahmadi et al., 2019). Similarly, the application of calcium compounds has been shown to decrease early-split nuts and enhance overall yield in pistachios (Mohammadi et al., 2017).

The appearance of fruit serves as a fundamental indicator of post-harvest quality, directly influencing the marketability of the produce. From a horticultural perspective, the external application of essential elements, such as calcium, contributes to improving the quality of fruit (Madani et al., 2014). Calcium plays a crucial role in reinforcing the cell wall structure of fruit and enhancing the integrity of the plasma membrane. By maintaining the structure and functionality of the cell wall, calcium stabilizes the membrane and facilitates signal transmission. The application of calcium leads to improved quality attributes and an increase in bioactive compounds within the fruit. Specifically, calcium ions form cross-links with pectin in the cell wall, thereby protecting cell wall from degradation by polygalacturonate enzymes (Sinha et al., 2019; Fattah et al., 2023). In our research, calcium nitrate improved the visual quality of nuts and reduced shell staining in Akbari. In line with these research findings, the application of calcium chelates via foliar spray, one week before full bloom and again four weeks after full bloom, reduces browning and enhances aril quality (Tadayon, 2021). Applying calcium as a pre-harvest treatment can either reduce internal browning or completely prevent internal browning in pineapples (Herath et al., 2003).

The importance of calcium in influencing fruit growth and maturation, including cell wall characteristics, is widely acknowledged (Wu et al., 2022). It is evident that applying calcium nitrate and calcium nitrate enriched with lecithin effectively reduces hull cracking and blackening compared to the control fruits in both cultivars. Calcium interacts with proteins, influencing their structure and functions within plant cells (Fattah et al., 2023). Pre-harvest calcium treatment enhances fruit quality by strengthening cell walls (Sinha et al., 2019; Fattah et al., 2023). Calcium is employed both pre- and post-harvest to slow down ripening and improve the quality of various fruits (Dunnd & Able, 2006). Applying calcium nitrate to pomegranate trees decreases the incidence of fruit cracking and sunburn, while enhancing fruit firmness (Al-Saif et al., 2022).

In this study, the percentage of fruit abscission decreased significantly with the application of various calcium nitrate treatments. This finding aligns with previous research, which has demonstrated that an enhanced nitrogen supply helps prevent fruit abscission and increases fruit yield in trees (Arias et al., 2005). Under environmental stress conditions, plants respond by generating ROS and ethylene. These substances serve as intracellular signals, activating the plant's defense mechanisms against stress (Xia et al., 2015). Interestingly, an increase in fruit abscission is positively correlated with ethylene levels, and the presence of ethylene reduces the overall percentage of fruit set. However, calcium acts as an anti-ethylene agent during the abscission process, effectively mitigating stress-induced fruit drop (Pourahmadi et al., 2019).

In the context of pistachio trees, numerous valuable studies conducted over the past decade have consistently highlighted nutritional deficiencies, particularly in potassium, zinc, and possibly calcium (Malakouti, 2005). Pourahmadi et al. (2019) reported that using calcium nitrate as a treatment resulted in reduced fruit drop. This reduction in fruit drop can potentially lead to smaller fruit size. When fruit drop decreases, resources distributed among a larger number of fruits, resulting in smaller individual fruit sizes but an increased pistachio nut ounce. Calcium nitrate treatments led to both increased fruit set and a higher pistachio nut ounce compared to control samples in Akbari (Pourahmadi et al., 2019). In pistachio trees, calcium deficiency can lead to endocarp lesion, which in turn causes fruit abscission (Sajadian & Hokmabadi, 2011). Researchers have found that applying calcium treatments during the rapid growth phase of the endocarp can reduce the occurrence of endocarp lesion disorder. Therefore, addressing calcium deficiency can help mitigate fruit abscission (Pourahmadi et al., 2019; Sadr et al., 2020).

CONCLUSION

Calcium deficiency in pistachio fruit leads to various physiological disorders. Managing disorders is crucial for quality fruit production. Applying calcium during the initial growth stage ensures efficient calcium absorption. Notably, findings suggest that calcium nitrate treatments, especially when enriched with lecithin, effectively mitigate physiological disorders by reducing stress conditions. In this study, the application of calcium nitrate and calcium nitrate enriched with lecithin resulted in reduced fruit abscission and endocarp lesions. These treatments have reduced defects (external shell staining, deformed nut, blank nut, internal shell staining, early-split nut, hull decay, and hull cracking) in Akbari, that result in improvement of the appearance of the nuts. In Kaleh-Ghoochi, similar positive effects are observed, although some differences exist. Kaleh-Ghoochi exhibits a lower fruit abscission percentage and fewer defects compared to Akbari. These findings suggest that calcium plays a significant role in enhancing the yield, quality, and marketability of pistachio fruits. However, it is also possible that calcium nitrate treatments have negative effects. For instance, a decrease in the percentage of fruit abscission results in an increase in the percentage of fruit formation but a reduction in the size of each fruit. In conclusion, based on the findings of this study, the use of these treatments has the potential for addressing physiological disorders in pistachios, benefiting economic and marketing aspects.

Conflict of interest
The authors have no conflict of interest to report.

Acknowledgments
We express our thanks to the Vali-e-Asr University of Rafsanjan for providing financial resources and equipment necessary for this research.

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