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ORIGINAL ARTICLE

Investigating the Role of Orchard Management in Pistachio (*Pistacia vera* L.) Stained Shell: A Questionnaire Study

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KEYWORDS

Manure channel;
Orchard management;
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ABSTRACT

A white and unstained shell enhances the marketability of pistachios, while shells with yellow or dark stains are less desirable. Furthermore, studies suggest a direct correlation between shell stains and contamination with aflatoxin which significantly decreases pistachio exports and reduces farmers' earnings from pistachios. Current study aimed to investigate the impact of orchard characteristics and management on pistachio shell staining in Anar and Rafsanjan counties in Kerman province. Data were collected in the fall of 2023 from 286 pistachio orchards in these two counties and analyzed using analysis of variance and SPSS26 software. The results revealed that both quantitative and qualitative water stress on trees, as well as heavy soil texture, increase the likelihood of pistachio shell staining. During summer, preventing the temperature from exceeding 40°C on the surface of the pistachio nuts on the tree can reduce the likelihood of shell staining. Furthermore, the results indicated that the use of calcium-rich fertilizers such as chicken manure, annual application of nitrogen fertilizers, using potassium fertilizers, and pruning excessive spurs in cultivars like Akbari, can decrease the percentage of pistachios with stained shells. Minimizing root damage during nutrition and soil improvement operations also reduces the likelihood of producing pistachios with stained shells. For instance, it is advisable to use manual labor instead of machinery for digging manure channel.

Introduction

Pistachio trees produce valuable commodities that are mainly traded as dry nuts (Hosseini *et al*., 2022; Nazoori *et al*., 2022a, b). The selling price of dried pistachio nuts is a critical factor influencing the profitability of producing this product. Various factors impact the selling price of pistachios in both domestic and international markets. Market supply and demand, currency exchange rates, economic and trade regulations, and other variables contribute to these fluctuations, but most importantly, the quality of the pistachios offered to the market plays a vital role in determining the price. Several qualitative factors influence the pricing of pistachios, such as the cultivar of pistachio, whether it is split or non-split, the number of nuts per ounce indicating the fineness or coarseness of the pistachio, and the overall appearance of the pistachio. The appearance of the pistachio itself encompasses various components, including the splitting degree of the shell, the number of super lux quality nuts, the uniformity of the nuts,

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and ultimately, the color of the shell. A white and unstained shell enhances the marketability of pistachios, while shells with yellow or dark stains are less desirable (Abdolahi-Ezzatabadi, 2011). Furthermore, studies suggest a direct correlation between shell stains and contamination with aflatoxin (Pearson, 1996; Mahbobinejhad *et al.*, 2019; Arjomand-Kermani and Alipour, 2021;), which significantly impacts farmers' earnings from pistachios (Abdolahi-Ezzatabadi, 2010). Therefore, identifying the causes of shell staining and implementing proper management practices to reduce them are crucial for enhancing marketability, increasing selling prices, and ultimately boosting farmers' income.

Stained pistachios can be categorized into different groups. In nuts that exhibit cracks on their soft hull prior to harvesting (known as pistachio hull cracking in the orchard), often display dark yellow to brown spots. The larger the area of the stain, the longer the nuts has likely remained on the tree after hull cracking. Some pistachio nuts whose hulls have not split in the orchard may show gray and black spots on the shell. These stains could result from delayed harvesting or from heat and pressure due to the accumulation of fresh pistachios before peeling and drying (Arjomand-Kermani and Alipour, 2021). Pistachio shell staining is a multifaceted phenomenon that can also be attributed to contamination by certain fungi (Siegel, 2023).

The most valuable pistachios are those with split shells and no staining. Even though the percentage of pistachios with shell staining in the orchard may be low, this small percentage can significantly impact the quality of all export shipments, potentially leading to reduced selling prices or even rejected export consignments. In this regard, Siegel (2023) illustrates the following scenario: For instance, in a load weighing 7200 kilograms, having one percent of pistachios with stained shells equates to 72 kilograms of affected pistachios. Assuming each pistachio seed weighs one gram, this translates to 72,000 shell-stained pistachio seeds in the shipment. The presence of this quantity of stained pistachio seeds diminishes the value of the cargo, and given the high likelihood of contamination, it may lead to rejected export shipments due to non-compliance with export standards. Hence, striving to produce pistachios without shell staining holds paramount importance.

Various factors contribute to the color of pistachio shells offered in the market. Harvest timing is one such factor; delayed harvesting leads to darker shell colors, staining, and reduced marketability. Hence, determining, diagnosing, and timely harvesting of pistachios from trees are essential for increasing marketability (Nazoori *et al.*, 2015). Another factor affecting shell staining is delays in processing the product; prolonged periods between harvesting and hulling increase the likelihood of staining on the shells (Esmaeilpour and Shakerardekani, 2022). Storage conditions for green-hulled pistachios can also intensify shell staining, with storage temperature playing a crucial role in determining staining intensity (Sadeghi *et al.*, 2005; Crisosto and Ferguson, 2020; Thompson *et al.*, 2013). Post-hulling processing stages, including washing, separating pistachios, drying methods, and exposure to sunlight, further affect shell whiteness or staining (Esmaeilpour and Shakerardekani, 2022).

While existing research has primarily focused on harvesting and post-harvest stages as factors affecting shell staining in pistachios, orchard management practices can also influence the degree and intensity of shell staining. Previous research has explored case studies on the impact of orchard management on the quality of pistachio production, specifically focusing on shell staining. For instance, Siegel (2023) investigated the role of the navel orangeworm, *Amyelois transitella* (Lepidoptera: Pyralidae), in creating stains on pistachio shells in California, USA, revealing a significant relationship. Kallsen and Maranto (2020) examined how pistachio cultivar influences the percentage of split nuts. Furthermore, Porter and Rawnsley's (2021) study in Australia found

no significant link between dark stains on pistachio shells and fungal pathogens. They also noted that there was no correlation between green hull appearance and shell stains, with delayed harvesting being the only factor leading to increased dark stains. Pearson *et al*. (1994) highlighted early splitting as a cause of shell staining, while Zhang and Ranford (2021) established a significant relationship between pre-harvest temperatures and pistachio quality metrics such as split percentage, nut size, and nuts with damaged shells.

Despite existing research findings, a comprehensive investigation into the impact of various orchard management factors on pistachio shell staining has not been conducted. Therefore, this study represents the first attempt to address this gap in the literature.

Materials and Methods

In order to examine the impact of orchard management on pistachio shell staining, data from 286 pistachio orchards in Rafsanjan and Anar counties in Kerman province were utilized. Information was gathered through questionnaires distributed to orchard owners, covering orchard characteristics, types of management practices implemented, and crop quantity and quality. Various aspects of management practices such as irrigation, nutrition, and pest and disease control were queried.

Orchard characteristics were recorded, starting with soil texture classification into light, medium, or heavy by farmers. Water salinity was assessed as a water quality indicator based on electrical conductivity (EC) measurements on water samples from study wells. Annual water consumption per hectare was calculated by obtaining information on the number and timing of irrigation rounds from orchardists. Flow rates of irrigation wells were measured using the flume method if water was flowing in the pipe. Flow rates in irrigation channels were determined using a float body to calculate the average water velocity and cross-sectional area, resulting in the calculation of annual water consumption per hectare in cubic meters.

Different irrigation management patterns were identified by questioning farmers about their irrigation methods, including the type of system used, water quality, consumption levels, timing, deficit irrigation practices, water distribution, strip area, row width, and more.

Nutritional management patterns were evaluated by inquiring about the fertilization methods employed by farmers, such as chemical fertilizers only, animal fertilizers only, combined use of chemical and animal fertilizers, and foliar spraying. Different application methods of a single fertilizer type, such as foliar spraying or channel fertilization, were also considered.

Pest control management patterns were assessed by investigating the pest control methods used by farmers, including pesticide types (insecticides, herbicides), timing of application, quantities used, and other control methods (agricultural, biological, physical). Factors like cost and crop yield were also considered for each pest control method.

To evaluate the quantity and quality of pistachio crops produced, performance per hectare of dried pistachios was assessed, along with variables like cultivar, splitting percentage, nuts per ounce, and shell appearance (white or stained). A binary value of one was assigned for white shells and zero for stained shells. The impact of orchard management practices on shell appearance was analyzed using mean comparison methods with SPSS26 software.

Results

Table 1 presents the statistical characteristics of the quantity and quality of products from pistachio orchards studied between 2021 and 2023.

Table 1. Statistical characteristics of the quantity and quality of the product produced in pistachio orchards studied from 2021 to 2023.

Variable name	Minimum	Mean	Maximum
Product yield in 2021 (kg ha^{-1})	0	596.39	4000
Product yield in 2022 (kg ha^{-1})	0	81.11	1200
Product yield in 2023 (kg ha^{-1})	0	854.20	6000
Percentage of non-splitting	4.17	30.63	100
Percentage of blankness	5	23.22	50
Number of nuts per ounce	21	26.97	35
Percentage of pistachio orchards producing pistachios with white and unstained shells	-	84.88	-

The data in Table 1 illustrates a significant variability in both the quantity and quality of products across the pistachio orchards studied. For instance, the yield per hectare in 2023 ranged from zero to 6000 kilograms per hectare. Furthermore, the percentage of non-split products varied from 4 to 100 percent. Notably, nearly 85 percent of the studied pistachio orchards produced pistachios with white and unstained shells, while 15 percent yielded pistachios with stained shells.

Table 2 compares the water, soil, and orchard characteristics between two groups of pistachio orchards producing white and stained products.

Table 2. Role of water, soil, and orchard characteristics in the development of white or stained shells on pistachios.

Variable name	Stained shell	White shell with no stains	F statistic value	Significance level of F statistic
Allocated water ownership price per hectare (million Rials)	6164.61	9391.34	5.06	0.028
Orchard soil texture heavy (Yes=1, No=0)	0.4615	0.1644	6.17	0.015
Orchard soil texture medium (Yes=1, No=0)	0.1538	0.4658	4.54	0.036
Row orientation (North-South=1, East-West=0)	0.7692	0.4521	4.57	0.035
Pistachio cultivar (Fandoghi=1, Others=0)	0.4615	0.2055	4.01	0.048

The findings in Table 2 reveal that the cost of water ownership allocated to one hectare for orchards producing white and unstained products is more than 1.5 times higher than that for orchards producing stained products. The cost of water ownership per hectare is influenced by factors such as the amount of water allocated to one hectare of orchard, well water flow rate, water quality, and well maintenance throughout the year. These factors collectively reflect the ability to provide adequate, high-quality, and timely water supply to the trees. This underscores the significance of providing sufficient water according to the trees' needs in terms of quantity, quality, and timing to produce pistachios with desirable characteristics and avoid water-related stress. The study by Sedaghati *et al.* (2008) demonstrated that a prolonged irrigation cycle (45 days) and water reduction from mid-April to mid-May resulted in a significant increase (up to two times) in the occurrence of early splitting in pistachios compared to the control treatment (regular irrigation). Additionally, Pearson *et al.* (1994) identified early splitting as a contributing factor to shell staining in pistachios. Therefore, maintaining regular irrigation in pistachio orchards is a key method to minimize shell staining, which aligns with the findings of the present study.

Additionally, Table 2 indicates that a higher percentage of pistachio orchards producing stained products have heavy soil texture, while orchards producing white and unstained products typically have medium soil texture. This suggests that soil texture plays a role in the production of pistachios with different shell appearances. Orchards with heavy soil texture tend to produce stained pistachios, whereas medium soil texture is optimal for pistachio cultivation. Excessive water stress in light soil and

waterlogging in heavy soil can disrupt nutrient absorption, leading to shell staining. Although heavy soil reduces soil dryness, it hinders nutrient uptake due to stagnant conditions, while these issues are less prevalent in soils with medium texture.

The penultimate row in Table 2 reveals that nearly 80 percent of orchards producing stained products have tree rows oriented north-south. This orientation impacts sunlight exposure and subsequently affects the temperature of the soft hull of the pistachio, especially during harvest time. This highlights the importance of using shading covers or materials like kaolin in pistachio orchards. Furthermore, the last row of Table 2 highlights that the Fandoghi pistachio cultivar has a higher likelihood of shell staining compared to the Kaleh-Ghouchi, Akbari, and Ahmadaghaei cultivars. This increased susceptibility in Fandoghi cultivar is attributed to its lower leaf area, leading to greater sunlight exposure on the nuts and subsequent warming of the surface hull, increasing the risk of shell staining. In This context, Kallsen and Maranto (2020) investigated how pistachio cultivar influences the percentage of split nuts.

In Table 3, the influence of pistachio orchard nutrition on the whitening or staining of the shell is demonstrated.

As depicted in Table 3, a higher percentage of pistachio orchards producing white and unstained products have utilized cow fertilizer as manure channel. This indicates that the higher water retention capacity of organic matter, such as manure, can help reduce water stress and decrease the likelihood of nut staining. Therefore, employing cow fertilizer as manure channel enhances the quality of pistachio products and results in a whiter shell appearance. The application of cow fertilizer as manure channel enhances soil aeration, a factor consistent with the findings in Table 2 regarding the impact of soil texture on the color quality of pistachio shells. Furthermore, the data in Table 3 indicates that the utilization of chicken manure, compared to its absence, and an increased application of this fertilizer contribute to improved product quality and shell whitening. The final two rows of Table 3 also demonstrate that annual nitrogen fertilizer application, as opposed to intervals between applications, and the use of potassium fertilizer, as opposed to its absence, decrease the likelihood of staining in pistachio shells. Overall, the results in Table 3 underscore the significant role of pistachio orchard nutrition in enhancing product quality and achieving a whiter shell appearance.

Table 4 presents the impact of pruning and the presence of endocarp lesion disorder on white or stained pistachio shells.

Table 3. Role of pistachio orchard nutrition in the development of white or stained shells on pistachios.

Variable name	Stained shell	White shell with no stains	F statistic value	Significance level of F statistic
Cow fertilizer consumption as manure channel (Yes=1, No=0)	0.4167	0.7455	5.18	0.026
Chicken fertilizer consumption (Yes=1, No=0)	0.3846	0.7534	7.58	0.007
Amount of chicken fertilizer consumption (tons per hectare per year)	1.17	6.86	8.75	0.004
Annual nitrogen fertilizer consumption (Yes=1, No=0)	0.6154	0.8750	5.42	0.023
Potash fertilizer consumption (Yes=1, No=0)	0.4615	0.7397	4.15	0.045

Table 4. Role of pruning and presence of endocarp lesion disorder in the development of white or stained shells on pistachios.

Variable Name	Stained shell	White shell with no stains	F statistic value	Significance level of F statistic
Extent of spur pruning (High=1, Low=0)	0.0769	0.3562	4.09	0.046
Presence of endocarp lesion disorder in the orchard (Yes=1, No=0)	0.4615	0.1644	6.17	0.015

As illustrated in Table 4, extensive pruning of spurs results in white and unstained pistachio shells. The removal of excess spurs from trees enhances the nutrient uptake by the remaining spurs and pistachio clusters, leading to improved quality and a whiter shell appearance. Additionally, in pistachio orchards where shell staining occurs, there is an increased likelihood of endocarp lesion disorder in May. This issue arises from calcium absorption challenges from the soil and an elevated magnesium-to-calcium ratio in the leaves. Factors such as waterlogging and reduced evaporation have been identified as hindrances to calcium absorption in May (Hashemi Rad *et al.*, 2006; Sadr *et al.*, 2019; Mohamadi-MohamadAbadi, 2022; Abdolahi-Ezzatabadi *et al.*, 2022), aligning with the findings in Table 2 regarding the role of soil texture in shell staining. In essence, any factor impeding nutrient absorption, particularly calcium, from the soil leads to shell staining in pistachios. Conversely, the utilization of fertilizers rich in calcium content, such as chicken manure, mitigates the likelihood of shell staining in pistachios.

Table 5 delves into the impact of tillage operations on the whitening or staining of pistachio shells.

Table 5. Role of tillage operations in the development of stained shells on pistachios.

Variable name	Stained shell	White shell with no stains	F statistic value	Significance level of F statistic
Number of plow application per year	0.5000	0.1370	5.78	0.018
Number of laborers used for digging manure channel (day-person per hectare per year)	0.0000	5.91	8.37	0.005
Amount of tractor use in digging manure channel (hours per hectare per year)	6.50	0.7143	11.22	0.001
Number of times tree sides are shoveled per year	0.4231	0.9897	7.09	0.009
Number of laborers used for shoveling (day-person per hectare per year)	7.15	21.49	6.94	0.010

As depicted in Table 5, pistachio orchards that yield stained crops undergo plowing every other year using a plow, whereas orchards producing white and unstained fruit are plowed once every seven years with a plow. This implies that the continuous use of the plow and the removal of roots in pistachio trees lead to challenges in nutrient absorption, resulting in pistachio products with stained shells. This observation is further supported by subsequent rows in Table 5. The manual digging of manure channel results in white and unstained products, whereas using a tractor for digging leads to the production of products with stains. The use of a tractor for digging manure channel creates deeper channels and removes more tree roots. Additionally, manual labor prevents the removal of main tree roots during the digging process. As demonstrated in Table 3, utilizing cow fertilizer as manure channel has advantages over surface application, but caution should be exercised during the digging of manure channel to avoid continuous root removal. In essence, the process of digging manure channel presents both benefits and drawbacks that necessitate careful consideration to mitigate the disadvantages while capitalizing on the advantages. From an economic standpoint, it is advisable to prioritize manual labor over tractors for digging manure channel whenever feasible.

The final two rows of Table 5 highlight that manual shoveling around pistachio trees also diminishes the likelihood of staining on the pistachio shell. In pistachio orchards where shoveling occurs approximately once a year, the resulting product is white and unstained. Conversely, in orchards yielding stained products, shoveling is conducted roughly every two years. Furthermore, the number of workers engaged in shoveling around trees in orchards producing white and unstained products is three times greater than in orchards yielding stained products. In

essence, both the frequency and quality of shoveling have proven to be effective in achieving this outcome.

Discussion

This study investigated the impact of orchard characteristics and management practices on the staining of pistachio shells. The findings revealed that a crucial factor in producing high-quality white pistachios is ensuring the trees receive sufficient water in terms of quantity, quality, and timely supply to prevent water stress. Moreover, the heavy texture of orchard soil hinders water and nutrient absorption by trees, increasing the likelihood of staining on pistachio shells in such soils. Conversely, orchards with medium (loamy) soil texture produce pistachios with white shells. Hosseini *et al.* (2022) also highlighted the importance of water quality, appropriate irrigation timing, and relatively light soil texture in reducing blankness, increasing splitting percentage, and enhancing nut size in pistachios.

Furthermore, the orientation of tree rows was found to have a significant impact on shell staining. North-south row orientations, which receive more sunlight and lead to higher temperatures on pistachio soft hulls, increase the likelihood of shell staining. This underscores the importance of using shading covers or materials like kaolin in pistachio orchards. Another study (Sadeghi *et al.*, 2005) indicated that dark stains appear more on shells when harvested pistachio mass temperature exceeds 40 °C. However, creating airflow with mesh baskets can reduce temperature and mitigate stain occurrence on pistachio shells. The study results also indicated that cultivars like Fandoghi, with lower leaf and branch density in the canopy, are at higher risk of shell staining due to increased surface temperature exposure to sunlight compared to other commercial cultivars (Ahmadaghaei, Akbari, and Kaleh-Ghouchi).

Analysis of nutrition management in pistachio orchards revealed that using cow fertilizer as the manure channel reduces shell staining likelihood by improving soil aeration and facilitating nutrient absorption. Using chicken fertilizer, especially compared to not using it or using higher amounts, also reduces shell staining occurrence. The presence of endocarp lesion symptoms in orchards showed a positive relationship with shell staining, indicating that calcium deficiency and imbalanced magnesium-to-calcium ratios contribute to endocarp lesion disorder (Hashemi Rad *et al.*, 2006) and increased shell stain severity. Given that chicken manure is rich in calcium, its use reduces the likelihood of shell staining.

In terms of nutrition management, annual nitrogen fertilizer application reduces shell staining likelihood compared to less frequent use. Regular nitrogen application is crucial as nitrogen can be easily washed out of the soil. Additionally, the use of potash fertilizers has been shown to decrease shell staining occurrence, highlighting the importance of potassium in producing high-quality pistachios.

Regarding pruning management, the study findings suggest that severe pruning of spurs decreases the occurrence of shell stains on pistachios. By removing excess spurs, particularly in Akbari cultivar, adequate nutrients can reach the remaining branches, resulting in denser and higher-quality pistachio clusters.

The investigation into soil tillage operations in pistachio orchards revealed that practices leading to a reduction in shell-stained pistachios involve modifying the soil with minimal damage to tree roots. Given that pistachio trees often face water stress and are irrigated with saline water, establishing their root network can be challenging. Any operation that cuts or damages roots diminishes both the quantity and quality of the crop produced. For instance, constructing manure channel with minimal root damage using manual labor decreases the occurrence of shell stains in pistachios. Conversely, using a tractor for digging manure channel or repeatedly employing heavy machinery for land plowing, both of which involve root cutting to some extent, increases the percentage of pistachios with shell stains. Opting

to manually plow the soil around trees with a hand shovel can reduce the likelihood of shell stain occurrence.

Based on the research findings, the following recommendations are proposed:

- To achieve white and unstained shell pistachio products, it is essential to prevent any water stress and avoid irrigation with low-quality water.

- In heavy-textured soils, enhancing soil conditions by incorporating organic materials and sand can yield pistachio products without shell stains.

- During summer, strategies such as using shading covers, applying kaolin, adjusting tree row orientation to minimize direct sunlight exposure, selecting cultivars with denser branches and leaves like Ahmadaghaee and Akbari, and preventing nut surface temperatures from exceeding 40 °C can reduce the likelihood of shell stain occurrence.

- Utilizing calcium-rich fertilizers such as chicken manure can decrease the percentage of pistachios with shell stains.

- Applying nitrogen fertilizers annually and using potash fertilizers can help reduce the occurrence of shell stains.

- Removing excess spurs in cultivars like Akbari can lower the risk of increased pistachios with stained shells.

- Employing soil tillage methods that minimize damage to tree roots is crucial. For instance, opting for manual labor instead of a tractor for digging manure channel is preferable.

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Conflict of interests

All authors declare that they have no conflict of interest.

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