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REVIEW ARTICLE

A Review of Pistachio Kernel Composition during Fruit Ripening

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A R T I C L E I N F O

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A B S T R A C T

Pistachios (one of 50 healthy foods) are essential for human health. The ripening stage is of great importance for food processing, as the chemical composition of this fruit is heavily influenced by its maturity level. For instance, as premature pistachio has unique green color, it can be used in desserts, sauces, ice creams, and chocolates, while mature pistachios often used as snacks. Considering that the nutrients in the pistachio kernel are dependent on various factors, especially environmental conditions, determining the amount of these compounds during the ripening stages of the pistachio kernel can considerably contribute to the appropriate harvest time and increase the duration of its storage period. Biochemical compounds such as carbohydrates, fats, and proteins are less affected by growth but may affect pistachio kernel taste and its nutritional value and health. The highest amounts of carbohydrates, fats, and proteins are available at the time of optimal harvesting when the hull is fully ripe. Phenolic compounds and antioxidant activity of pistachio decrease during ripening, and oil and fatty acid levels increase with the ripening period. In the case of the color parameter, the L factor decreases during the ripening period, and the a and b factors increase. Different stages of ripening have a significant effect on pistachio compounds. Nutrients in pistachio kernel are dependent on various factors that their diagnosis in different stages of growth contributes considerably to harvesting at the right time and increasing the storage period of this product.

Introduction

Pistachio (*Pistacia vera* L.) belongs to the family Anacardiaceae. The origin of the plant is the regions of West Asia and Asia Minor. It also grows as a wild plant. Today it is also cultivated commercially in countries including Iran, Turkey, The United States, Syria, Greece, Italy, and Spain (Noguera-Artiaga *et al.*, 2019). Iran's pistachio production was ranked first globally in 2005, while it dropped due to several reasons, including water shortages and low rainfall. It was ranked third in 2020 with a production of 190000 tons after the USA and Turkey (Faostat, 2020). The importance of pistachios is because of their fruit, which has a thin shell and bright green kernels with distinctive flavors (Noguera-Artiaga *et al.*, 2019). Nowadays, consumers have more tendency to use pistachio because of its high fiber content, minerals and micronutrients, monounsaturated fatty acids, and valuable bioactive compounds (Ardakani, 2005; Roozban *et al.*, 2005). In recent decades, kernels of nut treees have been considered due to health effects (Chatrabnous *et al.*, 2018). It is reported that there is a strong relationship between kernels and diets

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containing kernel oil with protection against heart disease, improvement of type 2 diabetes, and prostate and bowel cancer. The health benefits of kernels are associated with their lipid structure and phytochemical profile (Jahanbani *et al.*, 2018). The chemical composition of pistachio kernel may vary depending on the cultivar, latitude and maturation at harvest, moisture content (Davarynejad *et al.*, 2012), growth area, climate, type of cultivation, and ripening (Zarei, 2014). Based on studies on the structure of different cultivars of Iranian pistachios, 100 g of seeds contain 45-72% oil, 15-21.2% protein, 14.9-17.7% carbohydrate, 4 mg sodium, 1048-1142mg potassium, 120-150 mg calcium, 5.8-11.4 mg iron, 1- 1.4 mg copper, 157.5-165 mg magnesium and 494.5/514 mg Phosphorous (Davarynejad *et al.*, 2012). The amount of fiber in soluble and insoluble forms was 0.3% and 10%, respectively. Furthermore, its fat consisted of 5.9% saturated fatty acids, 23.3% monounsaturated fatty acids, and 14.4% polyunsaturated fatty acids. The highest type of fatty acids in Asian pistachios is oleic acid (60.2-64.8%) and linoleic acid (21.95%-26.24%) (Nadimi *et al.*, 2019). Pistachio energy is 567 kcal/100 g. Pistachio is rich in antioxidants (vitamin C and E), fat-soluble vitamins (A, E, and K), and water-soluble (B1, B2, B3, B5, B6, biotin, B9, C). The total tocopherol levels in pistachios were 291 mg g^{-1}, which was 275.4 mg/g gamma-tocopherol and 15.6 mg g^{-1} alpha-tocopherol (Ozdemir and Okay, 2015). Different cultivars of pistachio grow in various regions of Iran, but the physical and chemical properties of some pistachio cultivars during fruit ripening have not yet been accurately evaluated. According to Panahi and Khezri (2011), determining the optimal harvest conditions is one of the most effective horticultural measures to increase the quality of nuts production. Pistachio fruit harvesting should be done in good time after its physiological ripening. The haste or delay in harvest time affects the amount of the crop in the next year because of competition between fruits and buds being formed (Esmaeilpour & Shakerardekani, 2022). Therefore, it is vital to pay attention to determining the harvest time in this area. Detection of pistachio harvest time with apparent changes includes changes in the hull color, splitting, reduction in the binding force of fruit to its peduncle, and cluster peduncle to branch. The first sign of physiological ripening of pistachio and its readiness for harvest is the change in hull color from green to red, depending on the cultivar and region, which occurred in late August or mid-September. In this case, by squeezing pistachio seeds between the point finger and thumb, the hull of most nuts can be easily removed by slippery. Simultaneously, internal changes such as respiration rate, moisture content, and kernel protein decrease, and the amount of fat, sugar, and dry weight increases. Generally, the proper time to harvest the pistachio can be estimated by qualitative indices such as fruit peeling rate, nut splitting percentage, and fat and sugar content in the kernel, which there are usually about 2 to 3 weeks after easy peeling of fruits (Nazoori *et al.*, 2014; Hosseini *et al.*, 2022). Various studies have shown a significant difference in protein, fatty acids, amino acids, sugar, minerals, flavonoids, phenolic compounds, and antioxidant activity of pistachio during ripening (Eslami *et al.*, 2019; Sharifkhah *et al.*, 2020). These parameters may provide useful information for the consumer to recognize a more nutritious fruit (Zarei *et al.*, 2014). Therefore, this review article aimed to investigate the compositions of pistachio kernel during fruit ripening.

Investigation of pistachio compounds

The summary of studies conducted on changes in pistachio compounds during ripening was shown in Table 1.

Moisture content

Moisture content in pistachios was 4.9g/100g (Alasalvar and Shahidi, 2009). Panahi and Khezri (2011) investigated the effect of harvest time on the quality of pistachio cultivars. Ahmad Aghaei, Kalleh Ghoochi, Ohadi, and Badami-Zarand cultivars were

utilized to investigate qualitative indices. Kernel samples were collected for eight weeks (24 hours a day for seven days) from August 23 to October 11. Based on the results, moisture content decreased during harvest weeks. The highest moisture content was observed in the Ahmad Aghaie cultivar, from 39.8% on August 23 to 35.7% on October 11. The lowest moisture levels were related to the Kale-Ghoochi cultivar, which at the beginning and end of the harvest were 34.2% and 29.6%, respectively. In a study by Chahed *et al.* (2006), the moisture content decreased during ripening.

Table 1. Summary of studies conducted on changes in pistachio compounds during ripening.

The subject of research	Result	Reference
Physicochemical characteristics of pistachios in different harvesting stages	The oil efficiency increased with the increase of the maturation period in the samples. Phenolic compounds and antioxidant activity of pistachios decreased with the increase of the maturation period and these two parameters showed a linear correlation.	Kelebek *et al.* (2020)
The effect of early harvesting on seed quality and physiological characteristics of pistachio during 5 harvest stages (July 27, August 6, August 16, August 27, and September 6)	The highest content of potassium, calcium, magnesium, and protein was observed in the first stage of harvesting (July 27) and decreased during ripening.	Esmaeilpour *et al.* (2018)
The effect of harvesting time on the quality of pistachio cultivars (Ahmad Aghaei, Kale Ghochi, Ohadi, and Badami-Zarand varieties)	The moisture content decreased during the harvest weeks. Total fat content showed a peak in mid-September. Although the amount of total crude fat increased with brain ripening, it was not statistically significant	Panahi and khezri (2011)
Total phenol	The levels of total phenol in the methanolic extract of unripe pistachios were 185.2 mg higher than the ripe sample's 150.9 mg. The acidic methanolic extract of unripe pistachios was lower with the amount of 23.2 mg, which increased to 202.1 mg in the ripening stage.	Ballistreri *et al.* (2009)
Evaluation of pistachio characteristics during ripening	Moisture content decreased with ripening	Chahed *et al.* (2006)
The effect of harvesting in 5 periods (August 26, September 2, September 9, September 16, September 23) with an interval of one week on Turkish pistachio cultivars	The delay in harvesting significantly reduced the amount of total chlorophyll and the green color of the kernel changed to yellowish green. The chlorophylls a and b content in pistachios with green kernels is reported to be 150 mg kg^{-1} and the ratio of chlorophyll a to b was about 3.	Kunter *et al.* (1995)
The effect of harvesting time on the quality characteristics of pistachio fruit during freezing temperature storage	The nutritive value of the brain improved during ripening. The amount of fat (57.6%) and protein (23.5%) was higher in the fourth stage (September 5) of harvesting. The carbohydrates content (14.22%) was higher in the fifth stage of harvest (September 19). During ripening, the amount of nitrogen in the brain (83.3%) and soft skin (1.41%) had an upward trend, unlike the amount of calcium in the kernel (149 mg/kg) and soft skin (73 mg kg^{-1}). Unsaturated fatty acids, especially oleic acid, reached the maximum value (58.04%) with the development of the kernel, while saturated fatty acids had a downward trend (11.49%) with the progress of maturity.	Nazoori *et al.* (2016)
The best time to harvest pistachios based on physiological and biochemical indicators	The highest amount of protein (20.5%) and chlorophyll was recorded in pistachios harvested in the first stage	Nazoori *et al.* (2013)
The compounds content during puberty	Different stages of maturity in both Ahmad Aghaei and Ohadi pistachio cultivars had a significant effect on the amount of chlorophyll, and the highest amount of chlorophyll was observed 115 days after full flowering. Chlorophyll content decreased during ripening	Shekhari and Rezanjad (2011)

Lipids and fats

The amount of fat in pistachios is 45 to 72 percent of the total weight of pistachios, which may vary depending on the pistachio cultivar (Shakerardekani *et al*, 2015). Most of their fats are essential fatty acids, including oleic and linoleic acids. It is known that unsaturated fatty acids prevent cardiovascular diseases by preventing the accumulation of erythrosine in the blood (Okay, 2002). Pistachio consumption is reported to alter the microbial composition of the human gut and lead to an increase in the number of beneficial bacteria producing butyrate (D'Evoli *et al.*, 2015). Research has been conducted on the effect of different origins and cultivars on the number of fatty acids in pistachio, considering the importance of unsaturated fatty acids in the oil of seeds. Panahi and Khezri (2011) evaluated the effect of harvest time on the quality of pistachio cultivars. Ahmad Aghaei, Kalleh Ghochi, Ohadi, and Badami-Zarand cultivars were utilized to investigate qualitative indices. Kernel samples were collected for eight weeks (24 hours a day for seven days) from August 23 to October 11. There was a peak in total fat content in mid-September. Although total crude fat content increased with the ripening of kernel, it was not statistically significant. The percentage of the fat varied among different cultivars. The highest content was observed in the Kale-Ghoochi cultivar. Nazoori and Kalantari (2016) investigated the effect of harvest time on the quality characteristics of pistachio fruit during storage at freezing temperatures. The results of this study showed that the nutritional value of the kernel improved during ripening. The amount of fat (57.6%) was higher in the fourth harvest stage. Kelebek *et al.* (2020) examined some physicochemical properties of pistachio at different harvest stages. Oil efficiency increased with increasing maturity period in samples.

Proteins

The data from the analysis of amino acids showed that the pistachio kernel contains about 25% amino acid. Pistachio kernel with a protein content of 19-31% is a good source of proteins. Most amino acids in pistachios include glutamic acid, aspartic acid, and essential amino acids such as lysine and leucine (Mollaei and Nazoori, 2019). Many factors such as cultivar, rootstock and type of pollen, pests, diseases, environmental conditions, and geographical location affect its amount (Vahdati *et al.*, 2021; Norozi *et al.*, 2019). Glutamic acid, asparagine, alanine, methionine, citrulline, and arginine are the most abundant amino acids in pistachios (Bailey& Stein, 2020). In pistachio fruit protein, arginine amino acid is a precursor to nitric oxide. Nitric oxide is a factor in regulating blood pressure and preventing the blockage of veins. The presence of biotic and abiotic stresses reduces protein levels (Alipour *et al.*, 2018). Studies on the protein in pistachio nuts reveal that its amount decreases during maturity (Okay, 2002). Nazoori and Kalantari (2016) investigated the effect of harvest time on the quality characteristics of pistachio fruit in five stages (July 24, August 5, August 17, August 27, and September 10) based on physiological parameters such as peeling percentage (separation of the hull from the kernel) and discoloration of pistachio skin from green to red during storage at freezing temperature. The results of this study showed that the nutritional value of the kernel improved during ripening. Protein (23.5%) was higher in the fourth stage (August 27).

Carbohydrates

Carbohydrates are other nutrients found in pistachio nuts. Pistachio contains 29 grams per 100 grams of carbohydrate (Mollaei and Nazoori, 2019). Sucrose is the major soluble sugar in pistachios. Other sugars, including glucose and fructose, account for 5-7% of the total kernel (Labavitch *et al.*, 1982). Unlike protein, the total sugar content of the kernel increases until the fruit ripens and reaches its highest level in late September (Labavitch *et al.*, 1982). Nazoori and Kalantari (2016) investigated the effect of harvest time on qualitative characteristics of pistachio fruit in

five different stages of ripening (July 25, August 5, August 17, August 27, and September 10) during storage at freezing temperature. The level of carbohydrates (14.22%) was higher in the fifth stage of harvest (September 10).

Ash

The ash content of pistachio is 3-3.2 g/100 g (Alasalvar and Shahidi, 2009). Esmaeilpour and Shakerardekani (2018) examined the effect of early harvesting on nut quality and characteristics of pistachio physiology in five harvest stages (July 27, August 6, August 16, August 27, and September 6). The highest amounts of potassium, calcium, magnesium, and nitrogen were observed at the first harvest stage (July 27). Nazoori and Kalantari (2016) investigated the effect of harvest time on the quality characteristics of pistachio fruit during storage at freezing temperatures. The results of this study showed that during ripening, the amount of kernel nitrogen (83.3%) had an upward trend, unlike the amount of kernel calcium (149 mg kg^{-1}).

Fiber

Pistachio fiber is a good source of dietary fiber with 10% fiber content. 80% of pistachio fibers are insoluble (Dreher, 2012). Kashaninejad *et al*. (2011) reported the amount of ripe pistachio fiber in Ohadi and Kerman cultivars (1.93% and 1.03%, respectively). According to Bullo *et al.*, (2015), the amount of raw and roasted pistachio fiber was 10.3 and 9.9 g, respectively.

Chlorophyll

Chlorophylls are pigments responsible for the green color of fruits and vegetables that are rapidly degraded during the process and change the color of the food. The major chlorophyll in plants consists of chlorophyll a and b, with a ratio of 3 to 1. The thermal stability of chlorophyll a is less than chlorophyll b. The stability of chlorophylls is reduced for a long time at temperatures above 100°C or about 100°C. Total chlorophyll a and b in green pistachios is 150 mg/kg (Shakerardekani and Mohamadi, 2019). Plant pigments play a vital role in health. Color is the crucial parameter for the evaluation of pistachio nuts. Chlorophyll (a and b), and lutein are the most significant pigment in raw pistachios. Chlorophylls are unstable against heat and can decompose into pheophorbide and pheophytin (Heaton and Marangoni, 1996). Kunter *et al.* (1994) evaluated the different harvest times (August 26, September 2, September 9, September 16, and September 23) with a week interval on Turkish pistachio cultivars for green color and high kernel quality of pistachio nut. They reported that delays in harvest time significantly reduced the total chlorophyll amount and the green color of the kernel was changed to tan green. The number of chlorophylls a and b in pistachios with green kernel was 150 mg/kg, and the ratio of chlorophyll a to b was about 3. The amount of Turkish pistachio chlorophyll was 25 mg/kg. One way to have a green kernel is to harvest it before maturity. Studies reveal that pistachio produces better green kernels in areas with cooler air temperatures during the summer day and night (Shekari and Rezanejad, 2012). Esmaeilpour and Shakerardekani (2018) investigated the effect of early harvesting on the quality and physiological characteristics of pistachio grain. The highest chlorophyll content was observed at the first stage of harvest. Nazoori *et al.* (2014) examined the best harvest time of pistachio based on physiological and biochemical indices in three stages of ripening (40, 70, and 100% of wet skin peeling). The highest amount of chlorophyll (6mg) was recorded in pistachios harvested in the first stage (40% of wet skin peeling). According to Shekari and Rezanejad (2012), different stages of maturity in both Ahmad Aghaei and Ohadi pistachio cultivars had a significant effect on chlorophyll levels. The highest amount of chlorophyll was observed 115 days after full bloom. Chlorophyll content decreased during ripening.

Fatty acids

Kelebek *et al.* (2020) investigated some physicochemical properties of pistachio at different harvest stages. In terms of fatty acids, oleic acid had the highest concentration in all samples, followed by linoleic and palmitic acid. Pistachio fatty acids increased with increasing maturity period. Satil *et al*. (2003) have found that the composition of pistachio fatty acids is different in different regions of Turkey. High temperature in the pistachio cultivation area reduces the production of saturated fatty acids. Pistachios that grow in areas with temperatures above 25°C have lower saturated fatty acids than those with lower temperatures. Furthermore, in the study conducted by Abdolshahi *et al.* (2013) on the amount of fat and the composition of fatty acids in pistachio cultivars, it was shown that the amount of essential fatty acids of poly-unsaturated linoleic and linolenic in Damghan pistachio cultivars were higher than others in Iran and the world. In addition, the Akbari of Damghan and Rafsanjan cultivars had significant differences in the number of fatty acids (Abdolshahi *et al.*, 2015). Nazoori and Kalantari (2016) investigated the effect of harvest time on the quality characteristics of pistachio fruit during storage at freezing temperatures. Their results showed that unsaturated fatty acids, especially oleic acid, reached the maximum amount (58.04%) with kernel development, while saturated fatty acids had a downward trend (11.49%) with maturity.

Phenolic compounds

Pistachio phenolic compounds include anthocyanins, flavonoids, lignans, phenolic acids, proanthocyanins, acetylenes, and hydrolyze tannins. Pistachio contains a total phenol content of about 16608 mg kg^{-1}. Phenolic compounds have antioxidant and disinfectant properties that help improve endothelial function and reduce LDL oxidation. Phenolic antioxidants are more effective in kernels rich in monounsaturated fatty acids than kernels rich in poly-unsaturated fatty acids (Dreher, 2012).

Kelebek *et al.* (2020) examined phenolic compounds and some physicochemical properties of pistachio at different harvest stages. 13 phenolic compounds with 136 and 210 mg/kg were identified in this study. Catechin, daidzin, and genistin were the most commonly identified phenolic compounds. Phenolic compounds and oxidant activity of pistachio decreased with increasing maturity period, and these two parameters showed linear correlation. According to the Zarei *et al.* (2014) study, there was a significant decrease in the levels of phenolic compounds associated with ripening for all cultivars. The highest amount of phenolic compounds was related to the Kale-Ghoochi cultivar, and the lowest amount belonged to the Ohadi cultivar. These researchers believed that the main reason for reducing the levels of phenolic compounds was the oxidation of phenolic compounds by polyphenol oxidase. According to Ballistreri *et al.* study (2009), total phenol levels of methanolic extract of premature pistachio were 185.2 mg more than the ripe sample of 150.9mg. The phenolic extract of premature pistachio was 23.2 mg, which increased by 202.1 mg at the ripening stage. This increase can be due to anthocyanins. These pigments are located exclusively in pistachio peel, and their surfaces increase with ripening. Ripening leads to an increase in phenolic compounds associated with anthocyanin biosynthesis. The most common compounds in the ripe sample were anthocyanins (cyanidin-3-galactoside and cyanidin-3-glucoside). The total of two anthocyanins in the ripe sample (63.7 mg) was ten times higher than that of premature samples.

Sensory evaluation

Kader *et al*. (1982) reported the 'Kerman' pistachio cultivar were rated higher in firmness and sweetness, and lower in crispness, bitterness, and rancidity than those of the 'Red Aleppo', 'Trabonella', and 'Bronte' pistachio cultivars. Sensory evaluation procedures can be useful in determining

flavor quality in such studies and the evaluation of new cultivars and advanced breeding lines. Nazoori and Kalantari (2016) investigated the effect of harvest time on qualitative characteristics of pistachio fruit in five different stages of ripening (July 25, August 5, August 17, August 27, and September 10) during storage at freezing temperature. Keeping pistachios harvested at 18 °C showed that in overall acceptance, the best score was related to pistachios harvested in the fourth stage (August 27) from harvest.

Conclusions

Changes in physical and chemical properties of pistachio vary from unmatured fruit to ripening at different stages of growth, recovery, and maturing. Cultivar type and date of harvest are crucial factors determining physical properties, chemical composition, and antioxidant activity in pistachio. Different ripening stages affect the quality of pistachio seeds. Early harvesting causes no splitting and no maturity. In late harvesting, the nuts become vulnerable to cracking shells, insect attacks, and birds. The maximum levels of carbohydrates, fats, and proteins are present at the optimum harvest time when the hull is fully mature. Pistachio fruit harvesting should be done in good time after its physiological ripening. Factors such as cultivar, stock, climatic conditions of the region, soil texture, feeding, and irrigation affect fruit ripening time. With a brief look at the advantages and disadvantages of different harvest times, it is found that early harvesting is preferred in terms of quality and health indicators and the high nutritional value of the crop. However, the efficiency of early harvesting in crop yield (weight of 100 seeds and production per hectare) and maturity (percentage of premature nuts) is lower than traditional harvest time. Evaluation of each factor's effect on fruit harvesting time needs to be investigated to determine and recommend the appropriate time for fruit harvesting of each pistachio cultivar in each region. In general, determination of the change of compounds during ripening can help determine fruit quality, develop the fruit processing industry, and select superior genotypes of pistachio for cultivation in commercial cultivation.

Conflict of interest

The authors declare that they do not have any conflict of interest.

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