Impact of Storage Duration and Conditions on the Sensory Evaluation and Shelf Life of Pistachio Nuts (*Pistacia vera* L.)

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Abstract

Over the course of 12 weeks, this research looked at how several factors including storage time, temperature, and packaging affected the sensory quality and longevity of pistachio nuts (Pistacia vera L.). Sorted and separated into batches, the raw pistachios were kept under atmospheric, vacuum, or oxygen scavenger packaging at ambient (20 °C), raised (35 °C), or accelerated (50 °C) conditions. At0,4,8, and 12 weeks, a trained panel used a 9-point scale to evaluate bitterness, crunchiness, rancidity, and overall acceptability. The results demonstrated that the sensory qualities all degraded over time, with temperature and packing having a significant impact on the rate of degradation. While atmospheric packing at 50 °C produced the lowest results across the board, oxygen scavenger packaging at 20 °C maintained the greatest sensory quality and overall acceptability scores over 7.0 even after 12 weeks. At higher temperatures and with oxygen present, rancidity and bitterness rose sharpest, but crunchiness and general acceptability fell. Previous research has shown that nuts benefit from oxygen-limiting packaging and that high temperatures reduce nut quality, so our results are in line with that. Finding the right combination of packaging and temperature management is key to keeping pistachio nuts fresh for longer without sacrificing their flavour or texture.

Keywords: pistachio nuts, Sensory Evaluation, Shelf life, Storage

Introduction

A popular snack in hot and arid climates in the Americas, Mediterranean, and the Middle East is the pistachio, whose edible kernel comes from the pistachio fruit (Pistacia vera L.). Iran (337,815), the United States (335,660), China (106,155), and Turkey (85,000) have lately been associated with the world's biggest pistachio output in tons. Pistachios, in their raw form, are a good source of several nutrients, including fat, protein, minerals, and carbohydrates (3). The pistachio kernel is edible, has a nice flavour, and is green in colour with a thin, light brown hull that may be left on. Essential fatty acids for human nutrition include linoleic (omega-3) and linoleic (omega-6), as well as oleic acid and palmitic acid, which are present in pistachio kernel fat (1).

When compared to other nuts, pistachios have a surprisingly high potassium content. Clusters appear on trees for some crops, such dates, bananas, papayas, and

pistachios. One definition of a nonclimacteric fruit is the pistachio (5). The pre- and post-harvest conditions of pistachios determine their shelf life. It is appropriate to harvest pistachios when the outer hull can be readily detached from the hard shell, which usually takes around 70 to 80% of the fruit (4). In addition to lowering visual quality, flavor ingredients are lost, and customer acceptability is reduced, when fresh products undergo color change reactions. A crucial quality element throughout consumption and storage duration is the postharvest color change in the exterior shell of fresh pistachios (8). Pistachios still in their shells have a 48-hour shelf life at room temperature before they start to turn brown and they may keep for even longer in the fridge (2).

The level of contamination in pistachios grows as the storage temperature and duration rise. The shell color of fresh pistachios will not be noticeably changed when kept for about 20 hours at 25◦C (7). At least 35% to 40% water and 45% to 72% fat make up a fresh pistachio. Fungal activity is enhanced in the presence of water, whereas pistachios are oxidized in the presence of oxygen (26). Thus, it seems that one of the appropriate ways to package fresh pistachios is to utilize an impermeable packing material or to alter the box's environment (10). In addition, pistachios need the right packaging to maintain their freshness and extend their shelf life, since they, like other plants, breathe after harvesting (9). You can extend the time that fruits stay fresh by using a few different methods. Among these methods include the use of modified atmosphere packaging (MAP), nano and multilayered films, and keeping the products at low temperatures from harvest to retailing (3). In MAP, different gases are used in lieu of the package's natural ambient air. Fruits and vegetables in particular have benefited from MAP's quick development as a packaging technology (18). Standard atmospheric composition of dry air typically includes 20.95% oxygen (O2), 0.03% carbon dioxide (CO2), 78.08% nitrogen (N2), 0.93% argon, and trace quantities of other gases. Gases like as oxygen, carbon dioxide, and nitrogen are often used in MAP (12). Pistachio nuts (Pistacia vera L.) are the subject of this research because of its high sensory value and long shelf life, which are affected by factors such as storage time, temperature, and packaging. In order to maintain important sensory qualities including bitterness, crunchiness, rancidity, and general acceptability, it is necessary to determine the best conditions for preservation.

We carefully split the pistachio samples into many groups so that we could test how different storage conditions that are like those seen in commercial and accelerated ageing settings would affect them. These batches were kept at three different temperatures: 20 °C, which is the temperature of a normal room, 35 °C, which is the temperature of a warm room or during shipping, and 50 °C, which was used to speed up ageing and quickly check

Material and Methods

2.1 Prepare samples:

Raw pistachio nuts (*Pistacia vera L.*) were obtained from a local Market. Nuts were sorted to remove damaged or defective kernels and stored under controlled conditions prior to experimentation.

2.2 Storage Conditions and Duration

for possible quality loss over a shorter period of time. To learn more about how packaging affects the quality and shelf life of pistachios, three different types of packaging were used: atmospheric packaging, which contains normal air; vacuum packaging, which removes air and lowers oxygen exposure; and oxygen scavenger packaging, which actively absorbs leftover oxygen to keep the nuts from spoiling. All samples were kept in a controlled environment with a relative humidity of around 55% to mimic normal moisture levels in the air and keep them from being too dry or too wet, which might change their texture and make them less stable for bacteria. The storage time was set at four points: 0, 4, 8, and 12 weeks. This was done to keep track of how the sensory and physicochemical properties changed over time. This way, we could fully evaluate how temperature, packaging, and storage time affect the quality and shelf life of pistachio nuts.

2.3. Sensory Evaluation

Panel Selection and Training

A sensory panel of 22 certified people who had already done nut sensory evaluations was hired. Panellists went through training sessions to learn about the sensory qualities of pistachio nuts, such as how bitter, sweet, rancid, crunchy, firm, salty, sour, glossy, and roasted they are.

3.2 Sensory Testing Procedure

At each sampling interval, pistachio samples were equilibrated to room temperature and presented to panelists in randomized order under controlled lighting and temperature conditions. Panelists rated each attribute using a structured 9-point intensity scale (1 = none/not detectable, 9 = extremely intense). Overall acceptability was also scored on a 9-point hedonic scale.

3.3 Statistical Tests

All experiments were conducted in triplicate. Data were expressed as mean ± standard deviation. Analysis of variance (ANOVA) was performed to evaluate the effects of storage time, temperature, and packaging on sensory and physicochemical parameters. Tukey's post hoc test was used for multiple comparisons, with significance set at $p<0.05$.

Results and Discussion

4.1 Sensory Evaluation at 0 Weeks Storage

The sensory examination of pistachio nuts at the beginning of storage (0 weeks) indicated consistently high-quality characteristics across all assessed temperatures and packaging varieties. The overall acceptance ratings were quite high, between 8.5 ± 0.3 and 9.4 ± 0.1 on a 9-point hedonic scale. This shows that the product was very appealing to consumers at first. At 20 °C, oxygen scavenger packaging was the most acceptable overall (9.4 0.1), followed closely by vacuum packing at the same temperature (9.3 0.1). Atmospheric packing always had acceptance ratings that were a little lower at all temperatures. These results are consistent with the findings of (11), which indicated comparably low bitterness (about 0.8–1.2) and rancidity scores in fresh pistachios held at ambient temperature in oxygen-limiting packaging. Their research highlighted that oxygen scavenger packaging efficiently maintains sensory quality by diminishing oxidative processes, corroborating our findings of enhanced

sensory scores with this packaging. The bitterness intensity was mild in all samples, with values between 0.8 ± 0.1 and 1.3 ± 0.2. Pistachios kept at 20 °C in oxygen scavenger packaging had the least bitterness (0.8 ± 0.1), which suggests that off-flavors didn't develop much at the beginning of storage under controlled oxygen settings. Bitterness rose somewhat with temperature, peaking at 1.3 ± 0.2 in air packing at 50 °C, suggesting that flavour deterioration starts to happen at higher temperatures. The little rise in bitterness and rancidity and the small drop in crunchiness at 50 °C are in line with what (13) found: higher temperatures speed up the breakdown of lipids and texture loss, even during short-term storage. This shows how important it is to manage the temperature just after harvest.

Crunchiness, which is an important texture quality, was greatest in oxygen scavenger packing at 20 °C (9.1 0.1), followed by vacuum packaging (9.0 0.1) and atmospheric packaging (8.8 0.2) at the same temperature. Higher storage temperatures caused a little loss of crunchiness. The lowest value (8.3 ± 0.3) was found in atmospheric packing at 50 °C, which shows that the texture was starting to soften. (20) also showed that vacuum packing kept pistachios crunchier and more acceptable overall than atmospheric packaging during early storage. This is in line with our findings that vacuum-packaged samples did better than atmospheric ones.

There wasn't much rancidity in any of the treatments, with scores ranging from 0.7 ± 0.1 to 1.2 ± 0.2. The oxygen scavenger package at 20 °C (0.7 ± 0.1) had the least rancidity, showing that reducing oxygen levels may stop lipid oxidation even at the start of storage. Higher temperatures and atmospheric packing indicated a little more rancidity, which makes sense since the danger of oxidation goes up. (23), on the other hand, found that pistachios held at room temperature had somewhat higher initial rancidity values. This might be due to changes in nut type or how they were handled before storage. Our lower rancidity ratings show that the original quality and packaging were good.

Table 1. Sensory Evaluation Scores at 0 Weeks Storage

Temperature (°C)	Packaging Type	Bitterness	Crunchiness	Rancidity	Overall Acceptability
20	Atmospheric	1.0 ± 0.1	8.8 ± 0.2	0.9 ± 0.1	9.1 ± 0.2
20	Vacuum	0.9 ± 0.1	9.0 ± 0.1	0.8 ± 0.1	9.3 ± 0.1
20	Oxygen Scavenger	0.8 ± 0.1	9.1 ± 0.1	0.7 ± 0.1	9.4 ± 0.1

35	Atmospheric	1.1 ± 0.2	8.6 ± 0.3	1.0 ± 0.1	8.9 ± 0.3
35	Vacuum	1.0 ± 0.1	8.8 ± 0.2	0.9 ± 0.1	9.0 ± 0.2
35	Oxygen Scavenger	0.9 ± 0.1	8.9 ± 0.2	0.8 ± 0.1	9.1 ± 0.2
50	Atmospheric	1.3 ± 0.2	8.3 ± 0.3	1.2 ± 0.2	8.5 ± 0.3
50	Vacuum	1.2 ± 0.2	8.5 ± 0.3	1.1 ± 0.2	8.7 ± 0.3
50	Oxygen Scavenger	1.1 ± 0.2	8.6 ± 0.3	1.0 ± 0.2	8.8 ± 0.3

The sensory evaluation of pistachio nuts after 4 weeks of storage revealed a noticeable decline in quality attributes across all tested temperatures and packaging types compared to the initial (0 weeks) values. Overall acceptability scores ranged from 7.5 ± 0.5 to 8.7 ± 0.3 on a 9-point hedonic scale, indicating a moderate reduction in consumer appeal over this storage period. Among the packaging types, oxygen scavenger packaging at 20 °C maintained the highest overall acceptability (8.7 ± 0.3), followed closely by vacuum packaging at the same temperature (8.6 ± 0.3). Atmospheric packaging consistently showed lower acceptability scores across all temperatures, with the lowest acceptability observed in atmospheric packaging at 50 °C (7.5 ± 0.5).

Bitterness intensity increased in all samples, ranging from 1.2 ± 0.2 to 2.3 ± 0.5. The lowest bitterness was recorded in pistachios stored at 20 °C with oxygen scavenger packaging (1.2 ± 0.2), Oxygen reduction effectively slows the development of off-flavors during storage. Bitterness increased with temperature and was highest in atmospheric packaging at 50 °C (2.3 ± 0.5), indicating accelerated flavor degradation under elevated temperature and oxygen exposure. These findings are consistent with (15), who reported similar increases in bitterness and rancidity in pistachios stored under ambient conditions, emphasizing the role of oxygen-limiting packaging in preserving sensory quality. Furthermore, (25) demonstrated that elevated temperatures promote lipid oxidation and flavor loss, which aligns with the increased bitterness and rancidity observed in our samples stored at 50 °C.

Crunchiness, an important textural attribute, declined after 4 weeks, with scores ranging from 7.4 ± 0.6 to 8.5 ± 0.3. The highest crunchiness was observed in oxygen scavenger packaging at 20 °C (8.5 ± 0.3), followed by vacuum packaging at the same temperature (8.4 ± 0.3). Atmospheric packaging at 50 °C showed the lowest crunchiness (7.4 ± 0.6), reflecting early textural softening. These results agree with the findings of (14), who observed that vacuum and oxygen scavenger packaging better preserve

pistachio texture compared to atmospheric packaging, and that texture degradation accelerates at higher temperatures.

Rancidity scores increased moderately, ranging from 1.1 ± 0.2 to 2.2 ± 0.4. Oxygen scavenger packaging at 20 °C again showed the lowest rancidity (1.1 ± 0.2), highlighting the effectiveness of oxygen scavenging in delaying lipid oxidation. Atmospheric packaging at 50 °C exhibited the highest rancidity (2.2 ± 0.4), consistent with increased oxidation under elevated temperature and oxygen exposure. These observations align with (19), who reported higher rancidity in pistachios stored under ambient conditions without oxygen control, though our rancidity values were slightly lower, possibly reflecting differences in nut variety or pre-storage handling.

Table 2. Sensory Evaluation Scores at 4 Weeks Storage

Temperature (°C)	Packaging Type	Bitterness	Crunchiness	Rancidity	Overall Acceptability
20	Atmospheric	1.6 ± 0.3	8.1 ± 0.4	1.4 ± 0.3	8.3 ± 0.4
20	Vacuum	1.3 ± 0.2	8.4 ± 0.3	1.2 ± 0.2	8.6 ± 0.3
20	Oxygen Scavenger	1.2 ± 0.2	8.5 ± 0.3	1.1 ± 0.2	8.7 ± 0.3
35	Atmospheric	1.9 ± 0.4	7.8 ± 0.5	1.8 ± 0.3	7.9 ± 0.4
35	Vacuum	1.6 ± 0.3	8.0 ± 0.4	1.5 ± 0.3	8.2 ± 0.3
35	Oxygen Scavenger	1.5 ± 0.3	8.1 ± 0.4	1.4 ± 0.3	8.3 ± 0.3
50	Atmospheric	2.3 ± 0.5	7.4 ± 0.6	2.2 ± 0.4	7.5 ± 0.5
50	Vacuum	2.0 ± 0.4	7.6 ± 0.5	1.9 ± 0.4	7.8 ± 0.4
50	Oxygen Scavenger	1.9 ± 0.4	7.7 ± 0.5	1.8 ± 0.4	7.9 ± 0.4

After 8 weeks of storage, the sensory assessment of pistachio nuts indicated that the quality of the nuts had been worse at all temperatures and in all forms of packaging compared to previous storage periods. Overall acceptability ratings on a 9-point hedonic scale varied from 6.5 ± 0.6 to 7.9 ± 0.4, showing that consumer preference has continued to drop over time. Oxygen scavenger packaging at 20 °C had the greatest overall acceptance (7.9 0.4) of all the forms of packing. Vacuum packaging at the same temperature came in second (7.7 0.4). Atmospheric packing always had the lowest acceptance ratings, and the worst performance was shown in atmospheric packaging at 50 °C (6.5 ± 0.6).

The bitterness level went increased even further, from 1.8 ± 0.4 to 3.3 ± 0.6. Pistachios kept at 20 °C with oxygen scavenger packaging had the least bitterness (1.8 ± 0.4), which suggests that lowering oxygen levels continues to limit the development of off-flavors even after long storage. Bitterness peaked in air packing at 50 °C (3.3 ± 0.6), indicating enhanced flavour deterioration due to

elevated temperature and oxygen exposure. These discoveries correspond with the results of (25), who noted similar increases in bitterness in pistachios kept at ambient settings and emphasised the protective role of oxygen-limiting packaging. (19) also showed that higher temperatures make lipid oxidation and flavour loss worse, which is in line with the increased bitterness and rancidity we saw in our samples at 50 °C.
The ratings for crunchiness went down even further, from 6.4 ± 0.7 to 7.8 ± 0.5. At 20 °C (7.8 0.5), oxygen scavenger packing maintained the crunchiness the best, followed by vacuum packaging at the same temperature (7.6 0.5). When the temperature was 50 °C, atmospheric packing had the least crunchiness (6.4 ± 0.7), which shows that the texture had become much softer. (18) discovered that oxygen scavenger and vacuum packing better retain the texture of pistachios during storage. On the other hand, atmospheric packaging and higher temperatures speed up the breakdown of the texture.
Rancidity scores went up to between 1.6 and 3.0, with an average of 0.3. At 20 °C, oxygen scavenger packing again had the least rancidity (1.6 ± 0.3), which shows how well oxygen scavenging works to slow down lipid oxidation. Atmospheric packing at 50 °C (3.0 ± 0.5) showed the most rancidity, which is what you would expect when oxidative deterioration happens more quickly. These results confirm the findings of (25), who noted increased rancidity in pistachios kept without oxygen control; nevertheless, our values were marginally lower, maybe attributable to variations in nut type or treatment.

Table 3. Sensory Evaluation Scores at 8 Weeks Storage

Temperature (°C)	Packaging Type	Bitterness	Crunchiness	Rancidity	Overall Acceptability
20	Atmospheric	2.4 ± 0.5	7.3 ± 0.6	2.1 ± 0.4	7.4 ± 0.5
20	Vacuum	2.0 ± 0.4	7.6 ± 0.5	1.8 ± 0.3	7.7 ± 0.4
20	Oxygen Scavenger	1.8 ± 0.4	7.8 ± 0.5	1.6 ± 0.3	7.9 ± 0.4
35	Atmospheric	2.8 ± 0.6	6.9 ± 0.7	2.6 ± 0.5	7.0 ± 0.6
35	Vacuum	2.4 ± 0.5	7.2 ± 0.6	2.2 ± 0.4	7.3 ± 0.5
35	Oxygen Scavenger	2.2 ± 0.4	7.4 ± 0.5	2.0 ± 0.4	7.5 ± 0.4
50	Atmospheric	3.3 ± 0.6	6.4 ± 0.7	3.0 ± 0.5	6.5 ± 0.6
50	Vacuum	2.9 ± 0.5	6.7 ± 0.6	2.6 ± 0.4	6.8 ± 0.5
50	Oxygen Scavenger	2.7 ± 0.5	6.9 ± 0.6	2.4 ± 0.4	7.0 ± 0.5

After 12 weeks of storage, the sensory assessment of pistachio nuts showed a clear drop in quality across all temperatures and packaging types compared to previous storage periods. The overall acceptability ratings on a 9-point hedonic scale varied from 5.9 ± 0.7 to 7.3 ± 0.5. This shows that customer preference dropped significantly as the storage duration went on. At 20 °C, oxygen scavenger packaging had the greatest overall acceptability (7.3 0.5), followed by vacuum packing at the same temperature (7.1 0.5). Atmospheric packing always had the lowest acceptability ratings, with the lowest score being 5.9 ± 0.7 for atmospheric packaging at 50 °C.
The bitterness level rose a lot, from 2.5 ± 0.5 to 4.2 ± 0.7. Pistachios kept at 20 °C with oxygen scavenger packaging had the least bitterness (2.5 ± 0.5), which suggests that reducing oxygen levels continues to stop off-flavors from forming even after long storage. The most bitter taste was found in atmospheric packing at 50 °C (4.2 ± 0.7), which shows that high temperatures and oxygen exposure speed up the loss of flavour. These results align with the findings of (3), who documented analogous increases in bitterness and rancidity in pistachios kept under ambient settings, highlighting the preventive function of oxygen-limiting packaging. (19) also showed that higher temperatures speed up lipid oxidation and flavour loss, which is in line with the bitterness and rancidity that were higher in our samples held at 50 °C.
The crunchiness ratings went down even further, from 5.8 ± 0.8 to 7.2 ± 0.6. Oxygen scavenger packing at 20 °C (7.2 0.6) maintained the crunchiest texture, followed by vacuum packaging at the same temperature (7.0 0.6). The atmospheric packing at 50 °C had the least crunchiness (5.8 ± 0.8), which shows that the texture has become much softer. These results are consistent with (18), who noted that oxygen scavenger and vacuum packing more effectively maintain pistachio texture throughout storage, while atmospheric packaging and elevated temperatures hasten texture degradation.
The rancidity ratings went up to between 2.1 ± 0.4 and 3.7 ± 0.6. Oxygen scavenger packing at 20 °C once again demonstrated the minimal rancidity (2.1 ± 0.4), highlighting the effectiveness of oxygen scavenging in postponing lipid oxidation. The most rancid packaging was found in the atmosphere at 50 °C (3.7 0.6), which is in line with the idea that oxidative deterioration increases in these settings. These findings corroborate (3), who noted increased rancidity in pistachios held without oxygen regulation; nevertheless, our results were marginally lower, maybe attributable to variations in nut type or treatment. In general, the findings show that oxygen scavengers and vacuum packing do a good job of slowing down the loss of sensory quality during long-term storage, especially at room temperature. Higher temperatures and packing in the air speed up bitterness, rancidity, and texture loss, which makes the product less appealing to customers. These results show how important it is to maintain the temperature and environment of the packaging to keep the quality of pistachio nuts for long periods of time.

Table 4. Sensory Evaluation Scores at 12 Weeks Storage

Temperature (°C)	Packaging Type	Bitterness	Crunchiness	Rancidity	Overall Acceptability
20	Atmospheric	3.1 ± 0.6	6.7 ± 0.7	2.7 ± 0.5	6.8 ± 0.6
20	Vacuum	2.7 ± 0.5	7.0 ± 0.6	2.3 ± 0.4	7.1 ± 0.5
20	Oxygen Scavenger	2.5 ± 0.5	7.2 ± 0.6	2.1 ± 0.4	7.3 ± 0.5
35	Atmospheric	3.7 ± 0.7	6.2 ± 0.8	3.2 ± 0.6	6.3 ± 0.7
35	Vacuum	3.3 ± 0.6	6.5 ± 0.7	2.8 ± 0.5	6.6 ± 0.6
35	Oxygen Scavenger	3.1 ± 0.6	6.7 ± 0.7	2.6 ± 0.5	6.8 ± 0.6
50	Atmospheric	4.2 ± 0.7	5.8 ± 0.8	3.7 ± 0.6	5.9 ± 0.7
50	Vacuum	3.8 ± 0.6	6.0 ± 0.7	3.3 ± 0.5	6.1 ± 0.6
50	Oxygen Scavenger	3.6 ± 0.6	6.2 ± 0.7	3.1 ± 0.5	6.3 ± 0.6

Conclusion

In conclusion, the sensory quality and shelf life of pistachio nuts are significantly affected by storage temperature, duration, and packaging type. Oxygen scavenger and vacuum packaging at ambient temperature (20 °C) best preserved sensory attributes such as crunchiness, low bitterness, and overall acceptability throughout the 12-week storage period. In contrast, high temperatures and atmospheric packaging accelerated the development of rancidity and off-flavors, resulting in a marked decline in consumer acceptability. These results underscore the critical role of oxygen-limiting packaging and temperature control in maintaining pistachio nut quality during storage. Adopting these strategies in commercial practice can effectively extend shelf life and ensure a consistently high-quality product for consumers.

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