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ORIGINAL ARTICLE

Effect of the combined action of potassium sorbate and irradiation on the quality-maintenance of strawberries

Amal N. Al-Kuraieef[1] · **Amal H. Alshawi**[1] · **Amnah M. A. Alsuhaibani**[1]

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Abstract A relatively short storage life is considered a major problem for the transportation of strawberries across long distances to markets and for exportation. The aim of this research is to study the combined effects of potassium sorbate and radiation (3 kGy) on the microbial load, shelf life and most of the biochemical constituents such as vitamin C and total soluble solids of strawberries. A potassium sorbate (1%) treatment was combined, in practical application, with irradiation (3 kGy) to extend the shelf life of strawberries. All strawberry samples were stored at 4 ± 1 °C (90–92% RH). Quality assessment of the microbial and biochemical constituents, vitamin C, and TSS during the storage period was performed. The results showed that Gamma irradiation alone at 3 kGy extended the shelf life of strawberries to 21 days. Further extension of the shelf life to 21 days was obtained when irradiation (3 kGy) was combined with potassium sorbate treatment. All treatments caused non-significant decreases in vitamin C content during storage, except for the treatment of strawberries with a solution of potassium sorbate, which caused a significant decrease in the vitamin C content, and a gradual decrease in the vitamin C content occurred with an increase in storage time for all treatments.

✉ Amnah M. A. Alsuhaibani
amalsuhaibani@pnu.edu.sa

Amal N. Al-Kuraieef
analkuraieef@pnu.edu.sa

Amal H. Alshawi
ahalshawi@pnu.edu.sa

[1] Department of Nutrition and Food Science, Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia

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Introduction

Strawberry (*Fragaria* × *ananassa*) in the family Rosaceae is an important and widely consumed fruit all over the world. It has a delicious taste and unique flavour and is consumed in a fresh or processed form. Strawberries have also been found to be rich in antioxidants, flavonols, phenolic compounds and ascorbic acid (Heinonen et al. 1998; Robards et al. 1999). The fruit has a shelf life of 2–3 days at room temperature. The decay and loss of strawberries are generally greater in developing countries as a result of their lack of experience in handling due to the high respiration rate of strawberries, environmental stresses, pathogenic attacks, and the unavailability of climate-controlled storage facilities (Cordenunsi et al. 2005). This relatively short storage life is considered a major problem for the transportation of strawberries to long distance markets and for exportation. To reduce losses and extend the shelf life of fresh strawberries, low temperature storage, controlled-atmosphere packaging and surface treatment with synthetic chemicals are the most widely available management techniques (Geransayeh et al. 2012). Fungi and bacteria are the most common causes of the rotting and deterioration of strawberries. Low temperature storage helps extend their shelf life to some extent, but strawberries have a highly perishable life time, even when stored at 4° since they deteriorate rapidly (Han et al. 2005). The shelf-life of fresh strawberries at cold storage temperatures (2–4 °C) was found to be no more than 6–7 days (Arthur et al. 2007; Bandekar et al. 2003). According to several studies, radiation is considered a safe method of preserving food from microbial deterioration and consequently prolonging its marketing period, improving the safety of ready-to-eat fruits and vegetables, and radiation can be used as a substitute for decontaminating chemical use (Mishra and Kar 2014). Gamma irradiation has been successfully used as an alternative treatment to increase the shelf life of fresh produce (Hallman 2008; Prakash et al. 2000). However, low doses of irradiation (Monk et al. 1995) can be expected to only double the maximum storage life of strawberries by destroying radiation-sensitive fungi and delaying the appearance of radiation-resistant fungi (Horak et al. 2006; Hsu et al. 2010). Doses higher than 3 kGy are required to control deterioration due to radiation-resistant fungi and can result in undesirable flavours and softening of the fruits' tissues (Shurong et al. 2005). Considering that a compound must kill 99.999% of a certain microorganism population to be accepted as a sanitizing agent, when using gamma radiation, a 5 log reduction is desirable (Saltmarsh 2015). Certain permitted antimicrobial food additives have been shown to enhance the shelf life of many foods (Carocho et al. 2014; FAO 2013). It is of interest to combine the effects of a low irradiation dose with certain food preservatives to avoid the development of undesirable flavours and softening from pectinolysis due to high-dose irradiation. The main objective of this study was to evaluate the combined effects of potassium sorbate and irradiation (3 kGy) on the microbial load (bacterial, yeasts and moulds), shelf life, and some biochemical constituents such as vitamin C and total soluble solids of strawberries after different storage periods.

Materials and methods

Strawberries

Fresh harvested strawberries were collected from a local market in Riyadh, Saudi Arabia.

Potassium sorbate dip

Fresh and healthy strawberries were dipped in a solution containing 1% W/V potassium sorbate solution (PSS) for 1 min. Control strawberries were dipped for 1 min in distilled water. The strawberries were then allowed to drain for 10 min.

Strawberry packaging

Strawberries were packed in plastic baskets (50 strawberries in each basket) and wrapped with non-perforated plasticized polyvinyl chloride (PVC) film, which is a stretch film with high transparency, 12-micron thickness, self clinging, and the following rates of permeability: $CO_2 > 100$ cm^3/m^2/24 h; O_2 1800 cm^3/m^2/24 h; and water vapour 700 g/m^2/24 h.

Irradiation and storage

Samples of undipped and dipped strawberries were exposed to 3 kGy from cobalt 60 in a Gammacell 220 at King Abdul Aziz City for Science and Technology (KACST) in Riyadh (Model Gammacell 220 from MDS; Nordion Initial Canada Activity source (Co-60) was 24.000). All strawberry samples were stored at 4 ± 1 °C (90–92% RH).

Enumeration of microorganisms

Apparently fresh and healthy strawberries (25 g) were added to 225 ml of sterile saline solution (0.85% NaC1) and subjected to stomaching (10 min) with a Stomacher 400 (Seward Medical, London) to produce a 1:10 dilution. Further dilutions were also made. Total aerobic bacterial counts were counted on plate count agar medium (APHA 1985). Yeast and mould counts were determined with Czapek's yeast extract agar medium (Pitt and Hocking 1985). The surface spread plates were incubated at 30 °C for 2 days.

Inspection

Strawberries were visually inspected at 0, 7, 14 and 21 days of storage, and any fungus infected fruits were recorded and subsequently removed. Infected fruits were readily distinguishable by mould discoloration of the infected tissue and/or by softness resulting from watery rots. The percentage of infection was calculated and recorded (Zheng et al. 2007).

Total soluble solids (TSS)

To determine the total soluble solids, five fruits were randomly taken from each treatment and blended in an electrical blender. Then, the homogenates were filtered through a double layer of cheese cloth to obtain a clear juice of the homogenate. The total soluble solids was analysed with the help of a handheld digital refractometer, and evaluations were carried out four times during the study (AOAC 2012).

Ascorbic acid content

The ascorbic acid content was determined by using 2,6 dichlorophenol indophenols titration method as described by AOAC (2012).

Statistical analysis

The experimental data were subjected to analysis of variance for the completely randomized block design that was used. Averages and least significant differences were calculated using the SAS system version 9.1.3. (Cary, NC). An AP value of < 0.05 was considered significant (Ott 1984).

Results

Inspection and microbial counts

During storage at 4 °C, inspection of strawberries showed gradual increases in rotting at different rates, where the greatest increase (by 26.5 ± 1.7) was observed in strawberries without any treatment (control) at 21 days of storage, where the strawberries were mouldy and rotted. Strawberries dipped in potassium sorbate were rotted by 23.3 ± 0.9 at 21 days. The strawberries that received only irradiation were putrefied by 20.6 ± 0.9 at 21 days of storage. The lowest rotted level was found after combined treatments of potassium sorbate with irradiation (3 kGy) by 8.1 ± 0.7 at 21 days of storage (Table 1).

The untreated control strawberries had the highest total count percentage of microflora (bacteria, yeast, and moulds) after the seventh day until the end of the storage period (21 days). Strawberries dipped in a solution of potassium sorbate (1% W/V) for 1 min had reduced total bacterial counts, yeasts and moulds (6.3×10^5, 5.4×10^5 and 7.1×10^4), whereas irradiation alone at 3 kGy reduced these counts by 5.1×10^3, 2.7×10^3 and 5.7×10^3, respectively, at 21 days of storage compared to those of control strawberries. Combined treatments of potassium sorbate with irradiation (3 kGy) reduced the total bacterial counts, yeasts and moulds by 2.8×10^3, 2.9×10^2 and 1.9×10^2, respectively, at 21 days of storage (Table 2).

Total soluble solids (TSS)

There was a significant difference in the content of total solids that occurred gradually during the storage period and that appeared after 21 days of storage. Fruits subjected to different treatments and storage periods were found to be significantly different regarding their TSS contents. The TSS content in strawberry samples (control) was decreased by 2.25 ± 2.91, while strawberries dipped in potassium sorbate had a TSS value of 5.13 ± 0.99 at 21 days of storage. The TSS content after 21 days of storage was decreased by 8.37 ± 0.32 after treatments using irradiation (3 kGy). After 21 days, strawberries treated with both potassium sorbate and irradiation had a TSS difference that was not significant compared to the values at baseline of 8.58 ± 0.39 and that were significantly increased compared to those of the control strawberry samples (Table 3).

Ascorbic acid content

The data recorded in Table 4 show the ascorbic acid (vitamin C) content (mg/100 g FW) in strawberries. All treatments caused a decrease of the ascorbic acid content that was not significant after 7 days of storage. The amount of ascorbic acid was significantly decreased at 14 and 21 days of storage in control strawberries and in strawberries dipped in solutions of potassium sorbate. Dipping strawberries in a solution of potassium sorbate followed by irradiation could somewhat maintain the ascorbic acid values (52.01 ± 4.45 and 53.77 ± 4.77 mg/100 g) compared to those of fresh strawberries at baseline.

A maximum decrease was found in the control (14.08 ± 1.95 mg/100 g), followed by in strawberries treated with a potassium sorbate solution (20.09 ± 1.99 mg/100 g), while a minimum decrease was observed after treatment with a solution of potassium sorbate and irradiation (53.77 ± 4.77 mg/100 g) at 21 days storage.

Discussion

The limiting factor affecting the shelf life of strawberries, even with refrigerated storage, was mould growth on the surface of the fruits and/or soft rot. The shelf life (based on a 20% incidence of mouldy and rotted fruit) of untreated strawberries (control) was 7 days at 4 °C (90–92% RH), as

Table 1 Inspection of rotted strawberry fruits after different treatments and storage periods

Storage period (days)	Treatments			
	Control	PSS	3 kGy	PSS + 3 kGy
0	0.0^d	0.0^d	0.0^d	0.0^c
7	9.0 ± 0.5^c	6.9 ± 0.7^c	4.3 ± 0.4^c	0.0^c
14	22.2 ± 2.1^b	14.6 ± 1.3^b	9.5 ± 0.5^b	3.2 ± 0.4^b
21	26.5 ± 1.7^a	23.3 ± 1.9^a	20.6 ± 1.2^a	8.1 ± 0.7^a

PSS potassium sorbate solution

Mean values ± SD in each column having different letters (a, b, c, d) are significantly different at $P < 0.05$

Table 2 Microbiological content after different treatments of strawberry fruits at different storage periods

Storage period (days)	Total bacterial count				Total yeast				Total mould			
	Control	PSS	3 kGy	PSS + 3 kGy	Control	PSS	3 kGy	PSS + 3 kGy	Control	PSS	3 kGy	PSS + 3 kGy
0	3.2×10^2	2.1×10^2	6.3×10	4.2×10	2.1×10^3	1.6×10^2	3.5×10	2.3×10	9.2×10^2	5.1×10^2	1.8×10	< 10
7	6.3×10^3	3.6×10^2	7.5×10	6.6×10	5.2×10^3	2.9×10^2	6.7×10	6.1×10	4.9×10^3	5.7×10^2	3.4×10	< 10
14	7.6×10^4	3.1×10^3	3.2×10^2	4.2×10^2	6.4×10^4	2.1×10^3	2.0×10^2	2.2×10^2	2.6×10^4	2.1×10^3	1.3×10^2	5.3×10
21	8.2×10^6	6.3×10^5	5.1×10^3	2.8×10^3	9.3×10^5	5.4×10^5	2.7×10^3	2.9×10^2	4.3×10^6	7.1×10^4	5.7×10^3	1.9×10^2

PSS potassium sorbate solution

shown in Table 1. IAEA (1994) found that the shelf life of strawberries was only 7 days at 4 °C. Dipping strawberries in a solution of potassium sorbate delayed mould growth and extended the shelf life by approximately 7 days compared to the shelf-life of the control strawberries. Irradiation alone at 3 kGy almost doubled the shelf life of strawberries. Further extension of the shelf life to 21 days was obtained when irradiation (3 kGy) was combined with the antimicrobial agent, resulting in 15 additional days of shelf life compared to that of the control samples. The combined effects of treatment with chemical preservatives and ionizing radiation for mould inhibition and shelf life extension of some foods has been previously reported by Erkan et al. (2008) and Saltmarsh (2015). The obtained results shown in Table 2 agreed with those of previous studies. Dipping of strawberries in a solution of potassium sorbate for 1 min greatly reduced all microbial counts. The inhibitory effect of these preservatives against microorganisms has been demonstrated by Kumar and Sagarand (2008) and Wisal et al. (2013). It is well known that sorbate is promising as an effective agent against most yeasts and moulds but that its inhibitory effect against bacteria is lower (Zhang et al. 2006). The reduction in the microbial load of strawberries by irradiation alone has also been demonstrated by Zhang et al. (2003) and Majeed et al. (2014). The results of the total soluble solids analysis were explained by Pelayo et al. (2003) and Kumar and Devi (2011), who observed an increase in total soluble solids during osmo-dehydration of pineapple slices. According to other authors, TSS of blackberries do not change during storage, suggesting that sugar gain as a result of fruit ripening is balanced with respired sugar (Wu et al. 2010). The soluble solids contents in irradiated kiwifruit were higher than those of non-irradiated fruit during the initial storage period; however, a lower rate of increase was verified during the storage period (Kim et al. 2007). These results shown in Table 4 indicate that the losses of water soluble vitamins, especially thiamine and ascorbic acid, were affected by the food temperature during the storage (Chung and Yook 2003). Similar observations were reported by Lopez et al. (2005) and Maraei and Elsawy (2017). The non-significant decrease in vitamin C levels in strawberries when submitted to 1.0–2.0 kGy doses during 2 and 11 days of storage at 5 °C could be attributed to the activity of ascorbate oxidase that promotes ascorbic acid to dehydroascorbic acid. On the other hand, the ascorbic acid content fluctuated during the storage period in Camarosa strawberries. However, the total ascorbic acid content increased at the end of 9 days of storage, indicating the synthesis of ascorbic acid during storage, as reported by Cordenunsi et al. (2005). These outcomes are in agreement with the conclusions of Kumar and Devi (2011), who observed a decreased ascorbic acid content in osmovac-dehydrated mango slices.

Table 3 Total soluble solids content (mg/100 g) of strawberry fruits after different treatments and storage periods

Storage period (days)	Treatments			
	Control	PSS	3 kGy	PSS + 3 kGy
0	9.06 ± 0.95[a]	8.95 ± 0.43[a]	8.75 ± 0.38[a]	9.00 ± 0.35[a]
7	8.87 ± 0.64[b]	8.83 ± 0.56[a]	8.63 ± 0.47[a]	8.93 ± 0.41[a]
14	3.65 ± 0.13[c]	8.23 ± 0.64[ab]	8.56 ± 0.40[a]	8.65 ± 0.48[ab]
21	2.25 ± 0.11[d]	5.13 ± 0.59[c]	8.37 ± 0.32[ab]	8.58 ± 0.39[ab]

PSS potassium sorbate solution

Mean values ± SD in each column having different letters (a, b, c, d) are significantly different at $P < 0.05$

Table 4 Ascorbic acid content (mg/100 g) of strawberry fruits after different treatments and storage periods

Storage period (days)	Treatments			
	Control	PSS	3 kGy	PSS + 3 kGy
0	56.31 ± 5.24[a]	54.76 ± 5.11[a]	55.32 ± 5.35[a]	55.90 ± 6.03[a]
7	51.09 ± 4.99[ab]	51.06 ± 4.78[ab]	54.11 ± 5.09[a]	54.83 ± 5.89[a]
14	22.03 ± 1.54[c]	48.20 ± 4.33[c]	53.61 ± 4.99[ab]	54.02 ± 5.23[a]
21	14.08 ± 1.95[d]	20.09 ± 1.99[d]	52.01 ± 4.45[ab]	53.77 ± 4.77[ab]

PSS potassium sorbate solution

Mean values ± SD in each column having different letters (a, b, c, d) are statistically significant at $P < 0.05$

Conclusion

This study showed that gamma irradiation alone at 3 kGy extended the shelf life of strawberries to 21 days. Further extension of the shelf life to 21 days with minimum microbiological activity and maintenance of total solids and ascorbic acid was obtained when irradiation (3 kGy) was combined with potassium sorbate.

Recommendations

These results suggest that gamma ray exposure combined with potassium sorbate treatment is a useful method for maintaining strawberry fruit quality and extending its postharvest life. Further research should be conducted on different doses of gamma rays with other potassium sorbate concentrations or the use of other preservatives.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this paper.

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