Integrated effect of radiation processing and modified atmosphere packaging (MAP) on shelf life of fresh fig

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Abstract Fresh figs have less shelf life due to the growth of yeasts and molds. The study aimed at extending the shelf life of fresh fig with the help of irradiation and modified atmosphere packaging (MAP). Effects of irradiation and MAP on the quality and shelf life of fresh fig were evaluated. Combined effect of irradiation and MAP on the quality of fresh fig was also studied. To optimize irradiation dose, 1, 2, 3 and 4 kGy doses were given to fresh fig. Firmness and overall acceptability of fresh fig were minimally affected by 1 kGy irradiation dose. Whereas, 2, 3 and 4 kGy had negative effects on firmness and overall acceptability score. Thus, 0.5 and 1 kGy were selected to evaluate the combined effect of irradiation and MAP. Fresh figs were packed in an atmosphere of 5% O₂, 10% CO₂, 85% N₂ and irradiated at 0.5 and 1 kGy doses. These atmospheric packed irradiated samples were stored at 5 °C for 15 days. Physico-chemical parameters, microbial quality and overall acceptability were monitored throughout the storage period at the interval of 5 days. Irradiation treatment did not prevent the firmness of fresh fig. Significant dissimilarities were observed between the irradiated and control fresh fig for all the parameters considered. The results indicated that MAP followed by irradiation doses of 0.5 and 1 kGy showed the best results for improving the quality and shelf-life of fresh fig.

Keywords Fresh fig · Irradiation · Modified atmosphere packaging · Shelf life

Introduction

Fresh fig (*Ficus carica* L.) fruit have an opening, the ostiole, which allows small insects to enter and also causes growth of variety of microorganisms. Fig is a pear-shaped infructescence which is known as syconium (Cantin et al. 2011). It is a good source of minerals, vitamins and dietary fibre and has a pH around neutral (Veberic et al. 2008; Hamanaka et al. 2011). It can be eaten as a delicious fruit and has many medicinal properties (Ishurd et al. 2004). The postharvest shelf life of fresh fig is very less due to delicate epidermal tissue and the growth of yeasts and molds (Hamanaka et al. 2011; Bahar and Lichter 2018).

Modified atmosphere packaging which is commonly known as MAP is used to enhance the shelf life of perishable products. In MAP, perishable products are packed in an atmosphere where the composition of gases is other than that of air. Generally, reduced O₂ and enhanced CO₂ concentration is used to prolong the shelf life of whole and pre-cut fresh produce (Waghmare and Annapure 2013). Hence, MAP effectively extends the post-harvest shelf life of fresh commodities by delaying their enzymatic browning, reducing respiration rate, minimizing metabolic activity and by preserving their visual appearance (Waghmare et al. 2013). A substantial shelf life extension can be achieved by combining MAP with refrigeration. The combined treatment of MAP with low temperature is widely used to maintain the sensory and microbiological quality of fresh commodities during their long term storage (Gonzalez-Buesa et al. 2009; Liamnimitr et al. 2018).

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Recently the application of irradiation on various foods has increased for the reason of its effect on insect disinfestations and improved food security. Ionizing radiation reduces the spoilage and hence enhances the shelf life of many fresh commodities (Kavitha et al. 2015). Irradiation can be treated as an alternative to chemicals for treating fresh produce to improve its shelf life (Peerzada et al. 2016). USDA and FDA approved the use of irradiation treatment for fruits and vegetables up to doses of 1.0 kGy for insect disinfestation and improved food safety (Fan and Mattheis 2001). Irradiation can penetrate the product and remove microorganisms that are present in seeds and vegetables that harbor the pathogens (Latorre et al. 2010). Food can be treated with irradiation either before or after packaging (Wen et al. 2006).

In this work, modified atmosphere packaging (MAP) in combination with irradiation has been used for the preservation of fresh fig. Combine treatment of MAP and irradiation have been successfully studied to improve the post harvest shelf life of few fresh produce for example sliced roma tomatoes (Niemira and Boyd 2013), chinese cabbage (Ahn et al. 2005), grated carrots (Lacroix and Lafortune 2003), potato cubes (Baskaran et al. 2007) and Kimchi (Kim et al. 2008).

Few published reports are present on shelf life extension of fresh figs (Cantin et al. 2011; Hamanaka et al. 2011; Irfan et al. 2013) and dried figs (Sen et al. 2010). According to our literature survey, there are no studies published to extend the shelf life of fresh fig by using combination of MAP and irradiation.

Thus, the current study was conducted with the specific aims of (a) to determine the dose tolerance of fresh fig for irradiation and (b) effects of irradiation, MAP and combination of irradiation with MAP on physicochemical, microbiological and overall acceptability of fresh fig at 5 °C. In physicochemical parameters, headspace gas, weight loss, titratable acidity, total soluble solids, firmness and color were observed. Whereas, in microbiological parameters, mesophilic aerobics and yeast and mold count were checked.

Materials and methods

Fresh fig

Fresh figs (*Ficus carica* L.) of Poona cultivar were obtained from Agriculture Produce Market Committee (APMC), Mumbai. This Poona variety of fresh fig is cultivated in Pune and adjoining areas on a commercial scale in Maharashtra. These fresh figs were kept at 5 °C to equilibrate. Fresh figs were sorted out for uniform size, shape, color and maturity. These figs were washed with water and

then gently and completely surface dried with blotting paper. Fresh figs were checked for initial firmness and TSS (total soluble solids) and the readings are 3.46 N and 13.72%, respectively.

Packaging

The plastic packages made up of polypropylene (PP) material were used in this study. These PP film bags were supplied by Dhvani Poly Prints Private Limited, India. The dimensions of PP bag were 25 µm thick, 20 cm length × 15 cm width. Oxygen and carbon dioxide transmission rate of PP bags were 4.9×10^{-9} and 1.3×10^{-7} mL m⁻²s⁻¹Pa⁻¹ respectively at 23 °C.

Experimental design

Experiment 1, optimization of irradiation dose Four fresh figs were packed in each PP bag and four sets were prepared. These four sets of packets were subjected to gamma irradiation by a cobalt-60, Food Package Irradiator (AECL, Canada; activity 1.97PBq; dose rate 2.4 kGy/h) at Food Technology Division, Bhabha Atomic Research Centre, Mumbai, India. 1, 2, 3 and 4 kGy doses were given to the fresh figs packets.

Experiment 2, low dose irradiation combined with MAP Total fresh figs were divided into two sets. One set of the total fig was packed in an atmosphere of 5% O₂, 10% CO₂ and 85% N₂. The modified atmosphere packaging unit was used for creating the atmosphere inside the package. The unit consists of Reepack packaging machinery supplies and PBI Dansensor, MAP Mix 9001 ME, Ringsted, Denmark. The other half set of total figs were packed in air. A dose of 0.5 kGy was given to one part of packets and dose of 1 kGy was given to another part. Therefore, the samples were named as T₀ (control), T₁ (MAP), T₂ (0.5 kGy irradiated), T₃ (1 kGy irradiated), T₄ (0.5 kGy irradiated + MAP) and T₅ (1 kGy irradiated + MAP). All these fresh fig packed samples were stored at 5 °C for 15 days. Analysis of these packets were done at the interval of 5 days. From each batch three replicate packets were taken for analysis on each storage day.

Irradiation processing and dosimetry

Two parts from packets packed in MAP and two parts from air packets were irradiated by a cobalt-60 Food Package Irradiator at Food Technology Division, Bhabha Atomic Research Centre, Mumbai, India. The dose rate of this irradiator is 2.4 kGy/h. One hundred and twenty packets of four figs were irradiated for every dose. Dosimetry was carried out using Fricke dosimeter, which is a Reference

Standard dosimeter. To determine the absorbed dose, dosimeters were kept with the samples during irradiation. The dosimeters were kept in all the three vertical planes of the box i.e. front, middle and rear vertical planes. Maximum absorbed dose was observed at front and rear vertical planes, whereas at the middle vertical plane minimum dose was observed. Hence the minimum absorbed dose was considered as the absorbed dose for the samples. The absorbed doses for the fresh fig samples were 0.5, 1, 2, 3 and 4 kGy.

Physicochemical study

Headspace gas analysis

Four fresh figs weighed approximately 150 g were placed into packaging material. Packets were stored for 15 days. Packages were removed from storage, just before being gas measured. Oxygen and carbon dioxide concentration within the package were measured by gas analyzer (PBI Dansensor, Checkmate 9900, Ringsted, Denmark). The gas analyzer equipment has a highly stable zirconium sensor which is used to detect oxygen concentration and an infrared detector to detect carbon dioxide concentration. This equipment directly detects the changes in gas composition inside a sealed package. Furthermore, the needle of gas analyzer was introduced into the packets to determine the gas composition. After nearly 30 s, screen displays the O₂ and CO₂ percentage which is believed to be generated because of respiration of fresh fig. The measurements were performed in triplicates.

Weight loss

The net weight of each package was monitored by weighing the package on the day of examination. A laboratory level weighing balance (Anamed electronic balance, India) was used for measurement. The accuracy of this weighing balance was 0.0001 g. Weight loss values are expressed as % of weight loss per initial fruit weight. Three measurements were taken for every sample.

Titrateable acidity

Titrateable acidity (TA) was expressed as % citric acid. Samples were taken from each packet for analysis. Fresh figs were squashed crushed with the help of a mortar and pestle to remove extract the juice. The 5 g of extracted fresh fig fruit juice was blended with 50 mL of distilled water. This mixture is then titrated against 0.1 N NaOH using phenolphthalein as an indicator. The titration was carried out with 0.1 N NaOH where phenolphthalein was used as an indicator. The appearance of pink color

indicated the end point. The titration was performed in triplicate for each sample. Three measurements were taken for every sample.

Total soluble solids (TSS)

Total soluble solids of the fig fruit juice was measured with a handheld refractometer (R. S. Scientific, Delhi, India). TSS readings were expressed as in percentage.

Firmness

Texture of fresh fig was measured by TA-XT2i texture analyzer (Stable Micro System, Ltd. in Godalming, Surrey, UK) with a 50 kg load cell. 5 mm diameter cylindrical probe was used to determine the firmness of fresh fig. Fresh fig was positioned on the square metal plate and probe was inserted inside fresh fig sample. Firmness was measured at the surface of fresh fig. The test speed was 0.5 mm/s, pretest speed 10 mm/s, probe reversing speed 10 mm/s and trigger force was 15 g and the distance travelled by the probe inside the sample was 5 mm. Firmness was expressed in N force by measuring the peak value of graph. Three measurements were taken for every sample.

Color

The surface color of fresh fig fruit was determined using a Hunter Lab Colourimeter (LabScan XE, Hunter Lab Colourimeter, DP-9000 D25A, Reston, USA). The results were expressed in terms of L^* , a^* and b^* values, where L^* represents lightness, a^* represents chromaticity on a green (–) to red (+) axis and b^* represents chromaticity on a blue (–) to yellow (+) axis. Results were expressed as an average of 3 replicates.

Sensory evaluation

Sensory evaluation of fresh fig was done by a 15 member trained panel by modifying the procedure of Carvalho and Clemente (2004). Members of the panel were carefully selected and trained to find out difference in specific quality characteristics. Members were trained for rating test to evaluate the fig samples. Members were trained till they were able to distinguish the samples. Panellists provided sensory scores independently for fig samples. Aroma and visual appearance were evaluated as per Deza et al. (2003). Decay was evaluated by modifying the procedure of Loaiza and Cantwell (1997). Taste and the overall acceptance ratings were based on a nine point hedonic scale (Banerjee et al. 2016). Three measurements were taken for every sample.

Microbial studies

Microbial load for fresh figs were evaluated as per the standard plate count method. Total plate count agar and potato dextrose agar (HiMedia Laboratories, India) were used to determine the mesophilic aerobics and yeast and molds count, respectively. Sample was diluted with 90 mL of sterile NaCl solution. Solution was homogenized with sterilized kitchen blender homogenizer for 10 min and was then further diluted to get serial dilutions. Serially diluted samples were plated onto total plate count agar, potato dextrose agar. 1 mL of each dilution was transferred to sterile petri plate and 15–20 mL of sterile agar media at temperature 40–45 °C was poured, mixed well and allowed to set. For mesophilic aerobics plates were incubated at 37 °C for 72 h and for yeast and mold count plates were incubated at 25 °C for 5 days. At the end of the incubation period the colony forming unit (cfu) were counted and multiplied by appropriate dilution factor to obtain total plate count and yeast and mold count. All the experiments were performed in triplicates.

Statistical analysis

All data were expressed as means $\pm$ standard errors of triplicate measurements and analysed by SPSS for Windows (ver. 16.0). Two-way analysis of variance (ANOVA): Post Hoc multiple comparison were carried out to test significant differences. Statistical comparisons between variables (control, chemical treated and MAP samples) were performed with Least Square Differential method (LSD). Differences were considered significant at $P < 0.05$.

Results and discussion

Dose response

Firmness and overall acceptability score of fresh fig irradiated for 1, 2, 3 and 4 kGy and stored for 15 days at 5 °C are shown in Table 1. A significant difference is observed in the firmness of irradiated and non-irradiated fresh fig samples. In the firmness a significant difference is observed between the irradiated and non-irradiated fresh fig samples. The results presented in Table 1 indicate, that irradiation is not effective in maintaining the firmness of fresh fig. However, overall sensory acceptance for 1 kGy irradiation dose was significantly higher as compared to all other samples after 10 days of storage. 1 kGy irradiation dose was effectively maintaining the overall acceptability of fresh fig.

During the study it has been observed that the firmness of fresh fig decreases with the increase in irradiation dose. This fruit softening by irradiation may result from pectin degradation caused by direct action of radiation and damaging of the wall cells (Stefanova et al. 2010; Zhao et al. 1996). 2, 3 and 4 kGy samples showed significantly higher loss of firmness than control and 1 kGy samples during storage of 20 days. Decrease in firmness with an increase in irradiation dose were also observed in kiwifruit (Kim and Yook 2009), peach (McDonald et al. 2012) and ‘Gala’ apple (Fan and Mattheis 2001).

1 kGy irradiated fruits were acceptable throughout the storage period. Fresh figs irradiated at 2, 3 and 4 kGy were not accepted by the taste panelist. Results indicate that the irradiation treatment after 1 kGy affects the sensorial attributes of fresh figs. Sensory attributes will be affected if the constituents normally associated with these attributes

Table 1 Effect of irradiation (1, 2, 3 and 4 kGy) on firmness and overall sensory acceptance (means of three replicates $\pm$ standard deviation) of fresh figs during storage at 5 °C

Parameters	Days	Control	1 kGy	2 kGy	3 kGy	4 kGy
Firmness	0	3.46 $\pm$ 0.05 ^{aA}	3.04 $\pm$ 0.07 ^{bA}	2.68 $\pm$ 0.04 ^{cA}	2.21 $\pm$ 0.02 ^{dA}	1.85 $\pm$ 0.03 ^{eA}
	5	2.95 $\pm$ 0.02 ^{aB}	2.86 $\pm$ 0.03 ^{bB}	2.44 $\pm$ 0.01 ^{cB}	1.9 $\pm$ 0.05 ^{dB}	1.63 $\pm$ 0.04 ^{eB}
	10	2.63 $\pm$ 0.1 ^{aC}	2.40 $\pm$ 0.01 ^{bC}	2.13 $\pm$ 0.06 ^{cC}	1.55 $\pm$ 0.03 ^{dC}	1.29 $\pm$ 0.02 ^{eC}
	15	2.32 $\pm$ 0.05 ^{aD}	2.15 $\pm$ 0.01 ^{bD}	1.92 $\pm$ 0.03 ^{cD}	1.31 $\pm$ 0.04 ^{dD}	0.72 $\pm$ 0.01 ^{eD}
Overall sensory	0	8.2 $\pm$ 0 ^{aA}	7.7 $\pm$ 0.1 ^{bA}	6.3 $\pm$ 0.2 ^{cA}	5.5 $\pm$ 0 ^{dA}	5.0 $\pm$ 0.3 ^{eA}
Acceptance	5	7.8 $\pm$ 0.1 ^{aB}	7.5 $\pm$ 0.2 ^{aA}	5.6 $\pm$ 0.1 ^{bB}	5.1 $\pm$ 0.2 ^{cB}	4.4 $\pm$ 0 ^{dB}
	10	5.3 $\pm$ 0.4 ^{aC}	7.4 $\pm$ 0.2 ^{bA}	4.9 $\pm$ 0 ^{cC}	4.4 $\pm$ 0.1 ^{dC}	4.0 $\pm$ 0.2 ^{eC}
	15	4.1 $\pm$ 0.2 ^{aD}	7.0 $\pm$ 0 ^{bB}	4.1 $\pm$ 0.1 ^{cD}	4.1 $\pm$ 0.1 ^{cD}	3.6 $\pm$ 0 ^{dD}

Different small letters following the values in same row are significantly different ($P < 0.05$). Different capital letters following the values in same column are significantly different ($P < 0.05$)

which can effectively compete for the primary radicals and then follow a reaction pathway that leads to a stable product with different sensorial characteristics. The panelists detected sourness in 2, 3 and 4 kGy samples. This may be because of the deterioration of food sensory properties due to high dose of irradiation (Stefanova et al. 2010).

However, very little sourness was detected in 1 kGy samples. Thus, 1 kGy can be considered as the highest tolerable irradiation dose for fresh figs. Hence, 0.5 and 1 kGy were selected for further studies based on firmness and overall acceptability score.

Gas composition

Changes in O₂ and CO₂ concentration inside the PP bags for all the samples at 5 °C are shown in Fig. 1. From the Fig. 1 it has been observed that the O₂ concentration decreases while the CO₂ concentration increases during the storage period due to the respiratory activity of the fresh figs. O₂ concentration decreased more sharply (T₀) in control samples compared to relatively gradual decrease in

irradiated samples (T₂ and T₃), indicating that control samples have a higher rate of respiration. Contrary to the O₂ concentration, the CO₂ concentration showed an increase during the storage period. Respiration rate was inhibited by gamma irradiation and the respiration rate decreased with an increase in irradiation dose. The use of irradiation and different initial gas concentrations in the packages significantly affected the headspace O₂ and CO₂ concentration during the storage ($P < 0.05$). A significant difference was observed between control (T₀), 0.5 kGy (T₂) and 1 kGy (T₃) irradiated samples packed in air ($P < 0.05$). Whereas, very less or no significant difference was found in irradiated + MAP (T₄ and T₅) and MAP packed samples (T₁). Irradiation lowers the rate of CO₂ concentration increase and the rate of O₂ decrease. However, irradiation has very less effect on the irradiated samples packed in MAP atmosphere. It was also observed that the CO₂ concentration of the samples packed in MAP atmosphere were similar to the samples packed in air on day 10 and 15.

Weight loss

The weight loss percentage of fresh fig packed in PP bags is shown in Fig. 2a. Changes in the weight of fresh fig are an important index because it leads to the economical loss. Throughout storage, weight loss increased in all the samples during 15 days of storage at 5 °C. Among all the samples, significant weight loss was observed on 15th day ($P < 0.05$). However, no difference in weight loss was found between 1 kGy irradiated sample (T₃) and 0.5 kGy irradiated fresh fig packed in MAP sample (T₄) throughout the storage period. Weight loss with 3–10% shows symptoms of freshness loss of fresh produce (Ben-Yehoshua 1987). In this case, weight loss of the entire irradiated fresh fig was below 3% throughout the storage period of 15 days. However, control (T₀) and MAP (T₁) samples have weight loss of 3.39 and 3.12% on 15th day. The weight loss of T₅ was minimum, followed by T₄, T₂, T₁ and T₀. Increases in weight loss over storage time were also recorded in coriander (Waghmare and Annapure 2015) fresh-cut papaya (Waghmare and Annapure 2013) and litchi cv. Mauritius (Somboonkaew and Terry 2010).

TA

Changes in TA of fresh figs during storage are shown in Fig. 2b. The initial TA of fresh figs samples on day 0 was 0.61%. The TA values for all the samples showed a declining trend significantly ($P < 0.05$) during storage at 5 °C. The changes of TA values during the storage period may be associated with utilization of organic acid as respiratory substrates and as carbon skeleton for the

Fig. 1 Changes in **a** % oxygen and **b** % carbon dioxide (means of three replicates $\pm$ standard deviation) of fresh fig packaged with modified atmosphere packaging alone or in combination with irradiation and stored 5 °C. $\blacklozenge$, Control (T₀); $\bullet$, MAP (T₁); $\blacktriangle$, 0.5 kGy (T₂); $\blacksquare$, 1 kGy (T₃); $\times$, 0.5 kGy + MAP (T₄); $+$, 1 kGy + MAP (T₅)

Fig. 2 Changes in **a** %weight loss **b** %TA and **c** TSS (means of three replicates $\pm$ standard deviation) of fresh fig packaged with modified atmosphere packaging alone or in combination with irradiation and stored 5 °C. $\bullet$, Control (T₀); $\bullet$, MAP (T₁); $\blacktriangle$, 0.5 kGy (T₂); $\blacksquare$, 1 kGy (T₃); $\ast$, 0.5 kGy + MAP (T₄); $\square$, 1 kGy + MAP (T₅)

production of new compounds during ripening (Wani et al. 2008). Irradiation treatment lowered TA of all the irradiated samples. The low TA may be related to irradiation injury to fresh figs (Fan and Mattheis 2001). One kGy irradiated samples (T₃) had lower TA than 0.5 kGy irradiated samples (T₂). Slower TA changes occurred in control (T₀) and stand-alone MAP (T₁) samples. The lower TA values were observed for the T₃ samples followed by T₅, T₂, T₄, T₀ and T₁ samples. Slower TA changes occurred in the sample subjected to irradiation treatment and packaged in MAP composition (T₄ and T₅) than irradiated samples alone (T₂ and T₃), indicating combination treatment minimizes loss of TA.

TSS

During storage, the TSS increased in both irradiated and non-irradiated unirradiated fresh figs as shown in Fig. (2-c). This indicates the solubilization and synthesis of carbohydrates. TSS is related with the ripening of fruits (Antunes et al. 2003). In this study, the initial TSS of fresh fig was 13.72%. TSS of T₄ and T₅ samples was

significantly lower than those of T₂ and T₃ samples throughout the entire storage period. TSS in T₂ samples increased at a rate not significantly different ($P > 0.05$) from T₃ over the first 10 days. On the 15th, day significant difference was observed between T₂ and T₃ samples. Similarly, significant difference was found between T₄ and T₅ samples on the 15th day. The increase in TSS of stand-alone MAP sample (T₁) and irradiated + MAP (T₄ and T₅) was slower which could be attributed to lower respiratory activity and retardation in metabolic activity of the samples.

Firmness

Texture of fresh fig was monitored throughout the study. In this study, the decrease in the firmness of fresh figs was observed in all the three different treatments MAP, irradiation and combined treatments 0.5 kGy irradiated fruits (T₂) required 3.21 N of force to penetrate whereas 1 kGy (T₃) required 3.04 N of force. T₃ samples showed significantly higher loss of firmness during storage of 15 days. Irradiated fruits packed in MAP (T₄ and T₅) had higher firmness when compared to irradiated fruit packed in air (T₂ and T₃). Fresh figs packed under modified atmosphere and irradiated at 0.5 kGy dose presented the best firmness among the irradiated samples. However, fresh figs packed under modified atmosphere alone (T₁) showed the best firmness throughout the storage period. These results were in agreement with those from papaya fruit (Waghmare and Annapure 2013) and Red delicious apples (Hussain et al. 2012) in which firmness decreases with an increase in storage time.

Color

Changes in color parameters (L^* , a^* , b^*) of fig stored at temperature of 5 °C for 15 days are shown in Table 2. L^* , a^* and b^* value of 1 kGy irradiated fruits was lower than 0.5 kGy followed by non-irradiated fruits. L^* value, lightness of the sample, significantly decreased ($P < 0.05$) (darkness increased) for all the samples during its shelf life. L^* value of irradiated (T₂ and T₃) fruits were lower than irradiated + MAP (T₄ and T₅) and non-irradiated (T₀ and T₁) samples during the shelf life. This showed that irradiation does not preserve the natural color of the fresh fig during the storage. This might be due to the production of chemical compound such as hydrated electrons, hydroxyl radicals or hydrogen atoms which may oxidize anthocyanin colour compounds. A similar effect was observed in mushrooms, where gamma irradiation (0.5 and 1 kGy) treated samples showed a decrease of L^* value with increase in irradiation dose and L^* value also decrease with

Table 2 Changes in firmness and color parameters (means of three replicates $\pm$ standard deviation) of fresh fig packaged with modified atmosphere packaging alone or in combination with irradiation and stored 5 °C

Parameters	Days	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅
Firmness (N)	0	3.46 $\pm$ 0.03 ^{aA}	3.46 $\pm$ 0.01 ^{aA}	3.21 $\pm$ 0.02 ^{bA}	3.04 $\pm$ 0.01 ^{cA}	3.21 $\pm$ 0.02 ^{dA}	3.04 $\pm$ 0.01 ^{eA}
	5	2.95 $\pm$ 0.06 ^{aB}	3.31 $\pm$ 0.02 ^{bB}	2.90 $\pm$ 0.01 ^{cB}	2.86 $\pm$ 0.05 ^{cB}	2.93 $\pm$ 0.04 ^{cB}	2.92 $\pm$ 0.05 ^{cB}
	10	2.63 $\pm$ 0.02 ^{aC}	2.86 $\pm$ 0.01 ^{bC}	2.52 $\pm$ 0.02 ^{cC}	2.40 $\pm$ 0.03 ^{dC}	2.59 $\pm$ 0.04 ^{cC}	2.50 $\pm$ 0.03 ^{fC}
	15	2.32 $\pm$ 0.03 ^{aD}	2.54 $\pm$ 0.04 ^{bD}	2.25 $\pm$ 0.03 ^{cD}	2.15 $\pm$ 0.08 ^{cD}	2.30 $\pm$ 0.1 ^{dD}	2.23 $\pm$ 0.02 ^{eD}
<i>L</i> * value	0	41.2 $\pm$ 0.16 ^{aA}	41.2 $\pm$ 0.16 ^{aA}	39.35 $\pm$ 0.16 ^{bA}	37.11 $\pm$ 0.14 ^{cA}	39.35 $\pm$ 0.16 ^{dA}	37.11 $\pm$ 0.14 ^{eA}
	5	38.51 $\pm$ 0.08 ^{aB}	40.23 $\pm$ 0.16 ^{bB}	37.14 $\pm$ 0.14 ^{cB}	35.38 $\pm$ 0.12 ^{dB}	37.77 $\pm$ 0.09 ^{eB}	36.15 $\pm$ 0.14 ^{fB}
	10	36.74 $\pm$ 0.2 ^{aC}	38.82 $\pm$ 0.11 ^{bC}	35.73 $\pm$ 0.22 ^{cC}	34.04 $\pm$ 0.05 ^{dC}	36.5 $\pm$ 0.17 ^{cC}	35.34 $\pm$ 0.15 ^{fC}
	15	35.08 $\pm$ 0.12 ^{aD}	36.73 $\pm$ 0.3 ^{bD}	34.4 $\pm$ 0.13 ^{cD}	33.29 $\pm$ 0.10 ^{dD}	35.36 $\pm$ 0.15 ^{eD}	35.12 $\pm$ 0.18 ^{fD}
<i>a</i> * value	0	12.72 $\pm$ 0.10 ^{aA}	12.72 $\pm$ 0.10 ^{aA}	11.44 $\pm$ 0.14 ^{bA}	10.36 $\pm$ 0.08 ^{cA}	11.44 $\pm$ 0.14 ^{dA}	10.36 $\pm$ 0.08 ^{eA}
	5	9.83 $\pm$ 0.12 ^{aB}	11.14 $\pm$ 0.14 ^{bB}	10.65 $\pm$ 0.16 ^{cB}	8.76 $\pm$ 0.13 ^{dB}	11.03 $\pm$ 0.2 ^{eB}	9.34 $\pm$ 0.13 ^{fB}
	10	7.14 $\pm$ 0.23 ^{aC}	9.71 $\pm$ 0.15 ^{bC}	8.30 $\pm$ 0.12 ^{cC}	7.24 $\pm$ 0.11 ^{dC}	9.48 $\pm$ 0.16 ^{cC}	8.64 $\pm$ 0.17 ^{fC}
	15	5.03 $\pm$ 0.13 ^{aD}	7.84 $\pm$ 0.09 ^{bD}	7.17 $\pm$ 0.18 ^{cD}	6.37 $\pm$ 0.05 ^{dD}	8.49 $\pm$ 0.12 ^{eD}	7.76 $\pm$ 0.15 ^{fD}
<i>b</i> * value	0	12.07 $\pm$ 0.8 ^{aA}	12.07 $\pm$ 0.8 ^{aA}	11.35 $\pm$ 0.12 ^{aA}	10.24 $\pm$ 0.2 ^{bA}	11.35 $\pm$ 0.6 ^{cA}	10.24 $\pm$ 0.2 ^{dA}
	5	10.84 $\pm$ 0.22 ^{aB}	11.65 $\pm$ 0.05 ^{bB}	10.44 $\pm$ 0.05 ^{cB}	9.37 $\pm$ 0.03 ^{dB}	11.28 $\pm$ 0.15 ^{eA}	9.63 $\pm$ 0.24 ^{fB}
	10	8.79 $\pm$ 0.11 ^{aC}	9.92 $\pm$ 0.18 ^{bC}	8.25 $\pm$ 0.21 ^{cC}	7.67 $\pm$ 0.14 ^{dC}	9.53 $\pm$ 0.08 ^{eB}	8.24 $\pm$ 0.19 ^{fC}
	15	7.24 $\pm$ 0.23 ^{aD}	8.16 $\pm$ 0.14 ^{bD}	6.87 $\pm$ 0.12 ^{cD}	5.83 $\pm$ 0.11 ^{dD}	7.71 $\pm$ 0.13 ^{eB}	6.74 $\pm$ 0.11 ^{fD}

T₀, control; T₁, MAP; T₂, 0.5 kGy; T₃, 1 kGy; T₄, 0.5 kGy + MAP; T₅, 1 kGy + MAP. Different small and capital letters following the values in same row and column, respectively, are significantly different ($P < 0.05$)

storage time in control samples (Fernandes et al. 2012). *a** values, indicated redness when positive or greenness when negative. Initially *a** value of fresh fig for 0.5, 1 kGy and non-irradiated samples were 11.44, 10.36 and 12.72, respectively. The *b** value, yellowness when positive or blueness when negative, showed no trend during storage period. These results of *L** value are in agreement with the results obtained by Fernandes et al. (2012) for mushrooms.

Sensory evaluation

Visual appearance, aroma, decay, taste and overall acceptability scores for irradiated and non-irradiated fresh fig are shown in Table 3. Visual appearance and taste were considered as the most important attributes by the panelists in deciding the shelf-life of fresh fig. All the treatment showed decrease in quality during storage period in all the parameters considered. In visual appearance, the rating of all the irradiated (T₂ and T₃) combined treated (T₄ and T₅) and MAP (T₁) samples were acceptable at the end of storage period. While for treated samples, the visual color rating was not acceptable on the 10th day. Degradation in aroma increased in all the samples. T₀ samples were detected with off-odor after 5th day of storage. However, no off-odor was detected in remaining samples. No significant difference in aroma was observed between the treatments. The taste scores of fresh fig decreased with

storage time. Very little sourness was detected in 0.5 and 1 kGy samples. 0.5 kGy irradiated samples and control received 8.2 overall sensory acceptance score on day 0, whereas 1 kGy samples received 7.7 score. Thus 0.5 kGy was comparable with control samples on day 0. Combination treatment (T₄ and T₅) received the highest overall acceptability score than irradiation (T₂ and T₃) treatment on day 5 and 10. No significant difference was observed between irradiated samples packed in MAP (T₄ and T₅) and irradiated samples (T₂ and T₃) on day 10 and 15.

Microbial studies

Important differences in microbial counts of mesophilic aerobics and yeasts and mould were observed for fresh figs in control, irradiated and MAP samples during storage at 5 °C. Increase in microbial load was found in all the samples throughout the shelf life (Table 4). Control samples showed the highest microbial growth among all the samples. Irradiation treatment and MAP tends to reduce microbial load in both mesophilic aerobics and yeasts and mould. 1 kGy irradiated fresh figs packed under MAP conditions showed the lowest microbial population (T₅), followed by 0.5 kGy + MAP (T₄), 1 kGy (T₃), 0.5 kGy (T₂) and stand-alone MAP (T₁) samples. Microbial counts of mesophilic aerobics were 4.71, 4.17, 3.86, 3.42 3.17 and 2.56 log CFU/g for T₀, T₁, T₂, T₃, T₄ and T₅ respectively.

Table 3 Changes in sensory attributes (means of three replicates $\pm$ standard deviation) of fresh fig packaged with modified atmosphere packaging alone or in combination with irradiation and stored 5 °C

Parameters	Days	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅
Visual appearance	0	5.0 $\pm$ 0 ^{aA}	5.0 $\pm$ 0 ^{aA}	5.0 $\pm$ 0 ^{aA}	4.6 $\pm$ 0.1 ^{bA}	5.0 $\pm$ 0 ^{cA}	4.6 $\pm$ 0.1 ^{dA}
	5	4.1 $\pm$ 0.1 ^{aB}	4.5 $\pm$ 0.2 ^{bB}	4.4 $\pm$ 0.1 ^{bB}	4.2 $\pm$ 0.2 ^{bA}	4.6 $\pm$ 0.2 ^{bA}	4.3 $\pm$ 0.2 ^{bA}
	10	2.6 $\pm$ 0.1 ^{aC}	3.7 $\pm$ 0.3 ^{bC}	4.1 $\pm$ 0.1 ^{bC}	4.0 $\pm$ 0.2 ^{bB}	4.2 $\pm$ 0.3 ^{bA}	4.2 $\pm$ 0.1 ^{bA}
	15	1.8 $\pm$ 0.3 ^{aD}	3.2 $\pm$ 0.1 ^{bD}	3.8 $\pm$ 0.2 ^{cC}	3.9 $\pm$ 0.1 ^{CB}	4.0 $\pm$ 0.1 ^{cA}	4.1 $\pm$ 0.1 ^{cA}
Aroma	0	5.0 $\pm$ 0 ^{aA}	5.0 $\pm$ 0 ^{aA}	5.0 $\pm$ 0 ^{aA}	5.0 $\pm$ 0 ^{aA}	5.0 $\pm$ 0 ^{aA}	5.0 $\pm$ 0 ^{aA}
	5	4.3 $\pm$ 0.1 ^{aB}	4.5 $\pm$ 0.2 ^{aB}	4.4 $\pm$ 0.3 ^{aB}	4.5 $\pm$ 0.1 ^{aB}	4.5 $\pm$ 0.2 ^{aB}	4.6 $\pm$ 0.1 ^{aB}
	10	3.5 $\pm$ 0.2 ^{aC}	4.2 $\pm$ 0.1 ^{bB}	4.1 $\pm$ 0.1 ^{bB}	4.2 $\pm$ 0.2 ^{bB}	4.3 $\pm$ 0.1 ^{bB}	4.1 $\pm$ 0.1 ^{bC}
	15	2.4 $\pm$ 0.2 ^{aD}	3.8 $\pm$ 0.1 ^{bC}	3.9 $\pm$ 0.2 ^{bB}	4.0 $\pm$ 0.3 ^{bB}	4.1 $\pm$ 0.2 ^{bB}	4.1 $\pm$ 0.1 ^{bC}
Decay	0	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}
	5	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}
	10	2.2 $\pm$ 0.2 ^{aB}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}
	15	3.1 $\pm$ 0.3 ^{aC}	1.4 $\pm$ 0.2 ^{aB}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}	1.0 $\pm$ 0 ^{aA}
Taste	0	9.0 $\pm$ 0 ^{aA}	9.0 $\pm$ 0 ^{aA}	8.5 $\pm$ 0.1 ^{bA}	8.3 $\pm$ 0.1 ^{bA}	8.5 $\pm$ 0.2 ^{bA}	8.3 $\pm$ 0.1 ^{bA}
	5	7.6 $\pm$ 0.2 ^{aB}	8.2 $\pm$ 0.1 ^{bB}	7.8 $\pm$ 0.2 ^{cB}	7.5 $\pm$ 0.2 ^{cB}	8.0 $\pm$ 0.1 ^{dB}	7.7 $\pm$ 0.1 ^{eB}
	10		7.0 $\pm$ 0.1 ^{aC}	7.0 $\pm$ 0.3 ^{aC}	6.8 $\pm$ 0.2 ^{aC}	7.4 $\pm$ 0.2 ^{bC}	7.1 $\pm$ 0.1 ^{bC}
	15			6.6 $\pm$ 0.1 ^{aC}	6.5 $\pm$ 0.2 ^{aC}	7.0 $\pm$ 0.3 ^{aC}	6.9 $\pm$ 0.2 ^{aC}
Overall sensory	0	8.2 $\pm$ 0 ^{aA}	8.2 $\pm$ 0 ^{aA}	8.2 $\pm$ 0 ^{aA}	7.7 $\pm$ 0.1 ^{bA}	8.2 $\pm$ 0 ^{cA}	7.7 $\pm$ 0.1 ^{dA}
Acceptance	5	7.8 $\pm$ 0.2 ^{aB}	8.0 $\pm$ 0.2 ^{aA}	7.6 $\pm$ 0.2 ^{aB}	7.5 $\pm$ 0.2 ^{aA}	8.0 $\pm$ 0.1 ^{bB}	7.6 $\pm$ 0.1 ^{cA}
	10	5.3 $\pm$ 0.3 ^{aC}	6.9 $\pm$ 0.3 ^{bB}	7.1 $\pm$ 0.3 ^{bB}	7.0 $\pm$ 0.2 ^{bA}	7.7 $\pm$ 0.2 ^{bB}	7.5 $\pm$ 0.1 ^{bA}
	15	4.1 $\pm$ 0.2 ^{aD}	5.7 $\pm$ 0.1 ^{bC}	7.0 $\pm$ 0.4 ^{cB}	6.8 $\pm$ 0.2 ^{cA}	7.1 $\pm$ 0.3 ^{cC}	7.0 $\pm$ 0 ^{cB}

T₀, control; T₁, MAP; T₂, 0.5 kGy; T₃, 1 kGy; T₄, 0.5 kGy + MAP; T₅, 1 kGy + MAP. Different small and capital letters following the values in same row and column, respectively, are significantly different ($P < 0.05$)

Table 4 Changes in mesophilic aerobics and yeast and moulds counts (means of three replicates $\pm$ standard deviation) of fresh fig packaged with modified atmosphere packaging alone or in combination with irradiation and stored 5 °C

Parameters	Days	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅
Mesophilic	0	2.60 $\pm$ 0.05 ^{aA}	2.60 $\pm$ 0.03 ^{aA}	1.95 $\pm$ 0.04 ^{bA}	1.40 $\pm$ 0.02 ^{cA}	1.95 $\pm$ 0.04 ^{dA}	1.40 $\pm$ 0.02 ^{eA}
Aerobics	5	3.16 $\pm$ 0.01 ^{aB}	2.85 $\pm$ 0.0 ^{bB}	2.57 $\pm$ 0.02 ^{cB}	1.99 $\pm$ 0.06 ^{dB}	2.24 $\pm$ 0.01 ^{eB}	1.75 $\pm$ 0.03 ^{fB}
(Log CFU/gm)	10	3.84 $\pm$ 0.02 ^{aC}	3.47 $\pm$ 0.02 ^{bC}	3.05 $\pm$ 0.04 ^{cC}	2.68 $\pm$ 0.02 ^{dC}	2.86 $\pm$ 0.03 ^{eC}	2.14 $\pm$ 0.01 ^{fC}
	15	4.71 $\pm$ 0.04 ^{aD}	4.17 $\pm$ 0.11 ^{bD}	3.86 $\pm$ 0.01 ^{cD}	3.42 $\pm$ 0.01 ^{dD}	3.17 $\pm$ 0.02 ^{eD}	2.56 $\pm$ 0.05 ^{fD}
Yeasts and	0	1.44 $\pm$ 0.06 ^{aA}	1.44 $\pm$ 0.04 ^{aA}	1.02 $\pm$ 0.02 ^{bA}	0.70 $\pm$ 0.01 ^{cA}	1.02 $\pm$ 0.02 ^{dA}	0.70 $\pm$ 0.07 ^{eA}
Moulds	5	2.56 $\pm$ 0.02 ^{aB}	1.83 $\pm$ 0.04 ^{bB}	1.54 $\pm$ 0.05 ^{cB}	1.11 $\pm$ 0.02 ^{dB}	1.35 $\pm$ 0.03 ^{eB}	0.97 $\pm$ 0.04 ^{fB}
(Log CFU/gm)	10	3.23 $\pm$ 0.03 ^{aC}	2.66 $\pm$ 0.08 ^{bC}	2.07 $\pm$ 0.03 ^{cC}	1.52 $\pm$ 0.07 ^{dC}	1.86 $\pm$ 0.11 ^{eC}	1.36 $\pm$ 0.05 ^{fC}
	15	4.31 $\pm$ 0.05 ^{aD}	3.47 $\pm$ 0.01 ^{bD}	2.73 $\pm$ 0.04 ^{cD}	2.28 $\pm$ 0.07 ^{dD}	2.22 $\pm$ 0.01 ^{eD}	1.81 $\pm$ 0.02 ^{fD}

T₀, control; T₁, MAP; T₂, 0.5 kGy; T₃, 1 kGy; T₄, 0.5 kGy + MAP; T₅, 1 kGy + MAP. Different small letters following the values in same row are significantly different ($P < 0.05$). Different capital letters following the values in same column are significantly different ($P < 0.05$)

Thus, it could be conclude that MAP alone does not reduce the microbial load, while the irradiation treatment effectively reduced the microbial load. These results indicate that the combined treatment of MAP and irradiation was more effective than any single treatment for inhibiting the

growth of mesophilic aerobics and yeast and mould. Similarly, Ahn et al. (2005) reported that combined effect of irradiation and MAP is more useful for inhibiting the growth of the aerobic and coliform bacteria than single treatment in Chinese cabbage.

Conclusion

The work clearly revealed the combined effect of irradiation (0.5 and 1 kGy) with MAP (5% O₂, 10% CO₂ and 85% N₂) which has significantly affected the in-package gas atmosphere. The study conducted show the gradual decrease in the loss of color and weight of fresh figs, the delayed change in TA, TSS and reduction in microbial count of fresh figs at 5 °C MAP. Taking this into consideration, it can be concluded that the combination treatment was found to be more effective in maintaining the firmness of fresh figs than irradiation treatment and irradiation treatment was found to be advantageous in enhancing the efficiency of modified atmosphere packaging than the MAP. Hence, it can be well stated that the MAP alone is less effective than combined treatment of irradiation with MAP. Also, the irradiation combined with MAP treatment very well preserves the quality of fresh figs. Furthermore, Irradiation of 0.5 kGy alone with MAP combination was found to be superior in maintaining the firmness, overall acceptability, color and delayed change in TA of fresh figs than 1 kGy alone with MAP combination. However, 1 kGy and combination was found to be much better in preventing weight loss, TSS and microbial count reduction. Consequently, it can be concluded that irradiation dose up to 1 kGy shows the best potential for extension of the shelf life of fresh figs up to 15 days at 5 °C. Thus, MAP with low-dose irradiation was found appropriate technology for extending shelf life of fresh fig.

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