Study set out to evaluate the microbiological status of rabbit meat and the possibility of using irradiation to control foodborne pathogenic bacteria and extend the refrigerated storage life of meat. Rabbit meat samples were γ-irradiated at doses of 0, 1.5 and 3 kGy. The samples were stored at refrigeration temperature, then the effects of irradiation and storage on their microbiological, chemical and sensory properties were studied. Irradiation at 1.5 kGy significantly reduced the counts of Staphylococcus aureus, Listeria monocytogenes, Enterococcus faecalis and enterobacteriaceae but was not enough for complete elimination of Salmonella. However, 3 kGy dose reduced the counts of S. aureus, L. monocytogenes, E. faecalis and enterobacteriaceae by more than 3, 3, 1.4 and 4 log units, respectively, while Salmonella was not detected. On the other hand, irradiation at 1.5 and 3 kGy significantly reduced the counts of aerobic mesophilic bacteria, psychrophilic bacteria and molds and yeasts and prolonged the refrigerated shelf-life of samples to 12 and 21 days, respectively, compared to 6 days for non-irradiated controls. Irradiation of samples significantly increased their amounts of thiobarbituric acid reactive substances (TBARS) but had no significant effects on their total volatile nitrogen (TVN) contents, while storage significantly increased the TBARS and TVN for irradiated and non-irradiated samples. γ-irradiation showed no significant effects on the sensory properties of raw meat. Moreover, fried burgers prepared from irradiated rabbit meat showed high sensory acceptability similar to those prepared from non-irradiated meat.

Keywords: Irradiation; Rabbit meat; Safety and shelf-life; TBARS; TVN; Sensory preference

1. Introduction

Rabbit production for meat is a very important livestock activity in most Mediterranean countries, and the rabbit meat industry is highly developed in many other countries. Rabbits have high fertility rates with rapid rates of growth, a high feed efficiency and early marketing age, high muscle-bone ratios, and require a small land area. This suggests that the rabbit has a practical potential as a livestock species in large scale production (Cambero, de la Hoz, Sanz, & Ordóñez, 1991; Gracey, 1992). Studies have shown that rabbit meat has a high protein content and low levels of sodium, fat and cholesterol, making it a very useful food in human diets (Fernández-Esplá & O’Neill, 1993; Rao, Chen, Sunki, & Johnson, 1978).

There is no doubt that foodborne pathogenic bacteria are the cause of illness and death for many people each year, at great economic cost and human suffering (Borch & Arinder, 2002). Several studies have been conducted on the microbiological quality of red meat, poultry and their products (Anon, 1996; CDC, 1999; Huffman, 2002; IAEA, 1993; WHO, 1986, 1989) but there is some lack of information on the microbiological quality of rabbit meat which may be contaminated with organisms of various kinds including potentially pathogenic bacteria, like many raw foods of animal origin. Two major sources of bacteria causing foodborne diseases in meat and meat products have been identified. The living animal carries pathogenic bacteria, while the processing environment harbours them. Bacteria originating from the animal (may) during slaughter, contaminate the carcass, and subsequently be distributed via cut or raw meat intended for further processing (Borch & Arinder, 2002).
Processing with ionizing radiation is a most versatile treatment for decontamination of food in an increasing number of countries and more-and-more clearances for radiation decontaminated foods have been issued or are expected to be granted in the near future. It is a safe, efficient, environmentally clean and energy efficient process being particularly valuable as an end product decontamination procedure (Farkas, 1998). Because of irradiation’s effectiveness in treating packaged food (thereby minimizing the possibility of cross-contamination prior to consumer use), most food safety officials and scientists view irradiation as an effective Critical Control Point in a Hazard Analysis and Critical Control Points (HACCP) system for meat and poultry processing (Satin, 2002). Therefore, the present work was undertaken to extend our knowledge of the microbiological quality of rabbit meat and its possible improvement through the application of low doses of γ irradiation.

2. Materials and methods

2.1. Preparation of samples

New Zealand white rabbits at live weights of 2.25–2.45 kg were slaughtered and bled in a local abattoir, then the head, viscera, and skin were immediately removed and the meat was separated from the bone. The separated meat was minced. The minced rabbit meat was divided into (100 ± 3 g) samples and aerobically packaged in polyethylene pouches, which were rapidly sealed by heat and transported for irradiation.

2.2. Irradiation and storage

Packaged rabbit meat samples (100 ± 3 g) were subjected to γ irradiation at doses of 0, 1.5 and 3 kGy using an experimental Co-60 source, with a dose rate of 9.23 kGy/h, located at the National Center for Radiation Research and Technology, Nasr city, Cairo, Egypt. Irradiation was carried out at room temperature, while dosimetry was conducted with ferrous sulfate/cupric sulfate dosimeters (IAEA, 1977). After irradiation, all samples were refrigeration stored at 4 ± 1 °C (except samples required for zero time analysis) until withdrawal for periodical sampling and analysis at 3 days intervals. Meat samples were rejected at the appearance of mold growth on the surface of the meat and/or the off-odors were detected, based on sensory evaluation, and their data discarded from the results after statistical analysis. All analyses were performed using three samples (pouches) per treatment.

2.3. Microbiological analyses

At the time of withdrawal from refrigerated storage, 10 g aliquots of the minced rabbit meat were removed aseptically from each of the pouches to prepare the initial 1/10 dilution which was used for the preparation of other serial dilutions in 0.1% peptone water. Colony forming units for total aerobic mesophilic and psychrophilic bacteria were determined by plating on plate count agar medium and incubation at 30 °C for 3 days and 7 °C for 7 days, respectively (APHA, 1992). Enterobacteriaceae were counted on violet red bile glucose agar medium after incubation for 20–24 h at 37 °C (Roberts, Hooper, & Greenwood, 1995). Total molds and yeasts were enumerated on malt agar medium after incubation at 25 °C for 3–5 days (APHA, 1992). Staphylococcus aureus was counted using Baird–Parker RPF medium after incubation at 35 °C for 24–48 h (Oxoid, 1998), and confirmed by the coagulase test as described by Collins, Lyne, and Grange (1989). Enumeration of Listeria monocytogenes was carried out on Listeria selective medium after incubation at 35 °C for 24–48 h (Oxoid, 1998). Cultures were examined for typical colonies after 24 and 48 h incubation, while colonies presumptively identified as L. monocytogenes were confirmed by biochemical testing according to Bille and Doyle (1991). Enterococcus faecalis was counted on kanamycin aesculin azide agar medium after incubation at 35 °C for 16–24 h and confirmation was carried out by the catalase test and utilization of glucose (Oxoid, 1998). The detection of Salmonella was carried out using the most probable number technique. After enrichment at 37 °C for 24 h in selenite broth, the cultures were streaked on Brilliant green agar and incubated at 37 °C for 24 h, then colonies were biochemically examined in triple sugar iron agar and lysine decarboxylase broth (ISO, 1978).

2.4. Chemical analyses

2.4.1. Proximate composition

AOAC (1995) official methods were used for the determination of moisture, total protein and ash contents, while total lipids were determined after extraction according to Bligh and Dyer (1959).

2.4.2. Oxidation measurements

Thiobarbituric acid reactive substances (TBARS) were determined in the minced meat as described by Lawlor, Sheehy, Kerry, Buckly, and Morrissey (2000) and the results were expressed as mg of malonaldehyde per kg of meat from the standard curve.

2.4.3. Total volatile nitrogen

Total volatile nitrogen (TVN) was determined as described by Mwansyemela (1973).

2.5. Sensory evaluation

Two experiments were conducted for sensory evaluation where the minced rabbit meat was evaluated both
as raw meat and as fried burgers. Samples of raw irradiated and non-irradiated meat were daily examined for appearance and odor to determine the shelf-life of the samples. For safety reasons, sensory evaluation of the fried burgers was carried out on day zero only. Irradiated and non-irradiated minced rabbit meat (40 g aliquots) were formed into burgers, ~0.7 cm thick and ~8 cm diameter as described by Fernández-Esplán and O’Neill (1993). The formed burgers were pan-fried and sensory evaluated in randomized order for their taste and odor as well as texture and juiciness. Juiciness was defined as the degree to which moisture was released from the sample after seven chews between the molars (Rocha-Garaz & Zayas, 1996). In all sensory tests, the panelists consisted of 10 non-expert members from our laboratory, and scores were obtained by rating the quality attributes using the following scale: 9 – excellent, 8 – very good, 7 – good, 6 – below good/above fair, 5 – fair, 4 – below fair/above poor, 3 – poor, 2 – very poor and 1 – extremely poor. Ratings of 5 and above indicated an acceptable sample, while ratings of 5 and 4 indicated that the samples were of marginal quality and ratings of 3 and below indicated unacceptable samples (Wierbicki, 1985).

2.6. Statistical analysis

The results were statistically analyzed by randomized complete block design (two factors) using a microcomputer programme for the design, management and analysis of agronomic research experiments (MSTAT-C), while the differences among means ($p < 0.05$) were determined by the least significant difference (Nissen, 1993).

3. Results and discussion

3.1. Microbiological properties

3.1.1. Microbial flora

As with all raw meats, non-irradiated rabbit meat samples were found to be contaminated with relatively high initial counts of aerobic mesophilic bacteria, psychrophilic bacteria, enterobacteriaceae and molds and yeasts as their mean log_{10} counts reached 6.021, 5.888, 4.785 and 4.886 cfu/g, respectively (Fig. 1). This reflects possible cross contamination during slaughter which has a significant effect on the bacterial status of carcasses (Borch & Arinder, 2002). It has been stated that many foods, particularly of animal origin, are heavily contaminated with organisms of various kinds (WHO, 1986, 1989). Meat can become contaminated during processing through contact with the skin of animals, which is an excellent depository for all kinds of microorganisms; feet and intestinal contents of the animal;

![Graphs](image-url)
floor, equipment and personnel and bleeding of the animal, which is considered to be the first step that can spread contamination from animal to animal (Satin, 2002).

Treating rabbit meat samples with γ irradiation induced significant decreases ($p < 0.05$) in these counts with the concomitant benefit of extending refrigerated storage life (Fig. 1). Irradiation at 1.5 kGy reduced the counts of aerobic mesophilic bacteria, psychrophilic bacteria, enterobacteriaceae, and molds and yeasts by 94%, 96.4%, 97.8% and 84%, respectively, while irradiation at 3 kGy reduced the counts of mesophilic bacteria, psychrophilic bacteria and molds and yeasts by 99.3%, 99.7% and 94%, respectively, and reduced the count of enterobacteriaceae to below the level of detection. During storage, these microorganisms significantly increased ($p < 0.05$) in all samples, with higher rates of increase in non-irradiated samples. Enterobacteriaceae were not detected during storage in samples that received 3 kGy dose, indicating that such a dose was effective in keeping the count of enterobacteriaceae below the detection level. The effectiveness of irradiation in delaying spoilage of foods was reviewed by Olson (1998), while Stekelenburg (1990) demonstrated that in low sodium meat products, enterobacteriaceae could effectively be inactivated in refrigerated or frozen products by irradiation with a dose of 1 or 2 kGy, respectively, provided the initial number of these bacteria was below $10^3$–$10^4$/g.

3.1.2. Bacteria of public health significance

Among foodborne pathogens, $S$. aureas, $L$. monocytogenes and $E$. faecalis were found in the rabbit meat samples and their initial mean log counts reached 3.982, 3.813 and 4.262 cfu/g, respectively (Fig. 2), in addition to the presence of Salmonella (Table 1). The importance of veterinary sources of foodborne illness has been reviewed by Johnston (1990) and it is well documented that $S$. aureus, $L$. sp. and Salmonella sp. are pathogens that can be detected in the slaughter house and the possibilities of cross contamination are high (Autio, Sater, Fredriksson-Ahomaa, Rahkio, Lundén, & Korkeala, 2000; Borch & Arinder, 2002; Fenlon, Wilson, & Donachie, 1996; Samarco, Ripabelli, Ruberto, Iannitti, & Grasso, 1997). Moreover, the most important pathogens cannot be eliminated from most farms, nor is it possible to eliminate them by primary processing, particularly from those foods which are sold raw (Farkas, 1998).

Subjecting rabbit meat samples to 1.5 kGy significantly decreased ($p < 0.05$) the counts of $S$. aureus, $L$. monocytogenes and $E$. faecalis by 93%, 95% and 74%, respectively, and was not sufficient for complete elimination of Salmonella. The observed counts showed significant increases ($p < 0.05$) during subsequent refrigerated storage in all samples but with higher rates in

![Fig. 2. Effects of γ irradiation and refrigerated storage (4 ± 1 °C) on the counts of Staphylococcus aureus, Listeria monocytogenes and Enterococcus faecalis in rabbit meat.](image-url)
the controls. Irradiation dose of 3 kGy appeared to be sufficient to keep the counts of *S. aureus*, *L. monocytogenes* and *Salmonella* below the detection levels and significantly decreased (*p* < 0.05) the initial count of *E. faecalis* by 96.3% which then showed significant increases (*p* < 0.05) during storage. Radiation treatment of foods to destroy pathogenic, non-sporeforming, foodborne bacteria has been well documented ( Olson, 1998; Thayer, Josephson, Brynjolfson, & Giddings, 1996), while the radioresistance of enterococci was previously reported by Huhtanen (1990) and Badr (1998). From these results, an irradiation dose of 3 kGy is sufficient to improve the microbiological safety of rabbit meat. Moreover, the effectiveness of such a dose in eliminating enterobacteriaceae further increases the safety of the meat as this group of bacteria includes, in addition to *Salmonella, Shigella*, enterotoxigenic *Escherichia coli* and *Klebsiella* sp. A dose range as low as 1–3 kGy could be expected to reduce any *Salmonella* by an overall average 2–3 logs (Beuchat, Doyle, & Brackett, 1993) and be more than adequate to control *E. coli O157:H7* and other more radiation sensitive non-sporeforming pathogens on chilled meat cuts or in ground beef (Clavero, Monk, Beuchat, Doyle, & Brackett, 1994; Thayer & Boyd, 1993).

### 3.2. Chemical properties

#### 3.2.1. Proximate composition

Table 2 represents the proximate chemical composition of non-irradiated and irradiated rabbit meat samples. Non-irradiated rabbit meat contained 72.2% moisture, while the percentages of crude protein, total lipids and ash (calculated on dry weight basis) were 80.27%, 13.18% and 6.54%, respectively. The proximate chemical composition of rabbit meat samples showed no significant changes (*p* < 0.05) due to irradiation.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Proximate chemical composition of non-irradiated and irradiated rabbit meat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Components</td>
<td>Percentages (mean ± SD)/irradiation dose (kGy)</td>
</tr>
<tr>
<td>Moisture</td>
<td>70.202 ± 0.293b</td>
</tr>
<tr>
<td>Crude protein</td>
<td>80.271 ± 0.730b</td>
</tr>
<tr>
<td>Total lipids</td>
<td>13.185 ± 0.754b</td>
</tr>
<tr>
<td>Ash</td>
<td>6.544 ± 0.133b</td>
</tr>
</tbody>
</table>

LSD value (*p* < 0.05) = 0.2378 for moisture, 0.3041 for protein, 0.2378 for lipids and 0.2378 for ash.

Means with the same letter (b) within a row for each component are not differ significantly (*p* < 0.05).

*Calculated on dry weight bases.

3.2.2. Thiobarbituric acid reactive substances

Irradiated rabbit meat produced significantly higher (*p* < 0.05) TBARS than non-irradiated samples and the amounts of TBARS showed positive correlations with the applied dose and storage time (Table 3). These results agree with the findings of Kim, Nam, and Ahn (2002) and Lobovics, Gaal, Somogyi, and Farkas (1992). The fat content and fatty acid composition are important in determining the extent of lipid oxidation during storage (Ahn, Lutz, & Sim, 1996; Ahn, Olson, Jo, Chen, Wu, & Lee, 1998). It has been suggested that the lipids of rabbit meat would be more susceptible to the development of rancidity than other meats due to its high content of polyunsaturated fatty acids, thus lipid oxidation may have an important influence on the stability of products containing rabbit meat (Fernández-Esplá & O’Neill, 1993; Lee & Ahn, 1977; Sinclair & O’Dea, 1987).

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Effects of irradiation and refrigerated storage (4 ± 1 °C) on thiobarbituric acid reactive substances in rabbit meat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage (days)</td>
<td>TBARS (mean ± SD mg malonaldehyde/kg meat)/irradiation dose (kGy)</td>
</tr>
<tr>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>0</td>
<td>0.287 ± 0.015b</td>
</tr>
<tr>
<td>3</td>
<td>0.477 ± 0.021b</td>
</tr>
<tr>
<td>6</td>
<td>0.697 ± 0.015p</td>
</tr>
<tr>
<td>9</td>
<td>R</td>
</tr>
<tr>
<td>12</td>
<td>2.347 ± 0.015s</td>
</tr>
<tr>
<td>15</td>
<td>R</td>
</tr>
<tr>
<td>18</td>
<td>R</td>
</tr>
<tr>
<td>21</td>
<td>R</td>
</tr>
</tbody>
</table>

LSD value (*p* < 0.05) = 0.05197.

Means with a different letter are different significantly (*p* < 0.05). R, rejected.

#### 3.2.3. Total volatile nitrogen

Irradiation of rabbit meat samples had no significant effects (*p* < 0.05) on their TVN content. However, Table 4

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Influence of γ irradiation and refrigerated storage (4 ± 1 °C) on the total volatile nitrogen in rabbit meat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage (days)</td>
<td>TVN (mean ± SD mg/100 g dry matter)/irradiation dose (kGy)</td>
</tr>
<tr>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>0</td>
<td>29.422 ± 0.029a</td>
</tr>
<tr>
<td>3</td>
<td>39.634 ± 0.035a</td>
</tr>
<tr>
<td>6</td>
<td>51.153 ± 0.067a</td>
</tr>
<tr>
<td>9</td>
<td>R</td>
</tr>
<tr>
<td>12</td>
<td>52.937 ± 0.057a</td>
</tr>
<tr>
<td>15</td>
<td>R</td>
</tr>
<tr>
<td>18</td>
<td>R</td>
</tr>
<tr>
<td>21</td>
<td>R</td>
</tr>
</tbody>
</table>

LSD value (*p* < 0.05) = 0.4317.

Means with a different letter are different significantly (*p* < 0.05). R, rejected.
refrigerated storage significantly increased \((p < 0.05)\) their TVN contents (Table 4). These results agree with previous observations (Badr, 1998). The TVN is related to protein breakdown (Egan, Kirk, & Sawyer, 1981) and the observed increases may be attributed to the formation of ammonia or other basic compounds due to microbial activity (Banwart, 1981). Increasing the applied dose decreased the rate of TVN formation during storage by reducing the initial levels of the common spoilage bacteria.

### 3.3. Sensory properties

\(\gamma\) irradiation of rabbit meat at the doses used in the present study had no significant effects \((p < 0.05)\) on the initial sensory attributes of the raw meat samples (Fig. 3). Panelists gave similar preference scores for both irradiated and non-irradiated samples which indicated that all were highly acceptable as judged by appearance and odor. Moreover, irradiated and non-irradiated samples gave similar acceptable scores for the sensory attributes during refrigerated storage until the rejection (Fig. 3). On day 7 of refrigerated storage, non-irradiated samples were scored as poor samples and rejected due to the appearance of mold growth, slime formation and off-odors. Small spots of mold growth started to appear on the surface of samples and off-odors detected on day 13 and 22 of refrigerated storage for samples irradiated at 1.5 and 3 kGy, respectively. Thus, based on sensory evaluation, these doses could prolong the edible refrigerated storage life of rabbit meat to 12 and 21 days, respectively, compared to 6 days for non-irradiated controls.

In the present study, sensory evaluation was also used to determine the effects of irradiating raw rabbit meat on the sensory quality of meat after cooking. As shown in Table 5, samples of fried burgers prepared from both irradiated and non-irradiated fresh rabbit meat had similar high scores for odor, taste, texture and juiciness indicating that irradiation of rabbit meat at these doses does not significantly affect \((p < 0.05)\) the sensory quality of the cooked meat. The results in general, are in good agreement with those of Kim et al. (2002) who found that irradiated meats produced new volatiles not found in non-irradiated meats (turkey, pork and beef) and the amounts of total volatiles and TBARS were higher than in non-irradiated samples. However, there were no significant differences in sensory scores between irradiated and non-irradiated meats. Thus the effects of irradiation on lipid oxidation, odor and sensory characteristics of meat from different animal species appears to be similar.

### 4. Conclusion

In conclusion, irradiation dose of 3 kGy can be effective to control bacterial pathogens in rabbit meat, through its effectiveness in destroying \(S.\) aureus, \(L.\) monocytogenes, Salmonella, enterobacteriaceae, and in significantly reducing \(E.\) faecalis, with extending their refrigerated shelf-life without any significant effects on the sensory quality of the meat.

<table>
<thead>
<tr>
<th>Sensory attributes</th>
<th>Scores (mean ± SD)/irradiation dose (kGy)</th>
<th>0.0</th>
<th>1.5</th>
<th>3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odor</td>
<td>(8.0 ± 0.50^a) (7.8 ± 0.47^a) (7.8 ± 0.67^a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taste</td>
<td>(7.3 ± 0.29^a) (7.3 ± 0.76^a) (6.9 ± 0.82^a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture and Juiciness</td>
<td>(7.8 ± 0.58^a) (7.8 ± 0.55^a) (7.8 ± 0.29^a)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LSD value \((p < 0.05)\) = 1.219 for odor, 1.696 for taste, and 0.8047 for texture and juiciness.

Means with the same letter (a) within a row for each property are not differ significantly \((p < 0.05)\).

Fig. 3. Sensory attributes of raw irradiated and non-irradiated rabbit meat during refrigerated storage (4 ± 1 °C).
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