Quality and stability evaluation of chicken meat treated with gamma irradiation and turmeric powder

Muhammad Sajid Arshad\textsuperscript{a}, Zaid Amjad \textsuperscript{a}, Muhammad Yasin\textsuperscript{b}, Farhan Saeed \textsuperscript{a}, Ali Imran\textsuperscript{a}, Muhammad Sohaib\textsuperscript{c}, Faqir Muhammad Anjum\textsuperscript{d}, and Shahzad Hussain\textsuperscript{e}

\textsuperscript{a}Department of Food Science, Nutrition and Home Economics, Government College University, Faisalabad, Pakistan; \textsuperscript{b}Food Science Division, Nuclear Institute for Food and Agriculture, Peshawar, Pakistan; \textsuperscript{c}Department of Food Science and Human Nutrition, University of Veterinary and Animal Sciences, Lahore, Pakistan; \textsuperscript{d}Vice Chancellor Secretariat, University of the Gambia, Banjul, The Gambia; \textsuperscript{e}College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia

\textbf{ABSTRACT}
This study was carried out to evaluate the impact of gamma irradiation and turmeric powder (TP) on microbial quality (total aerobic bacteria and coliforms), physicochemical quality (pH, Hunter’s parameter, oxidative and microbial stabilities, haem pigment), stability, and antioxidant status of chicken meat. Accordingly, two doses (1 kGy and 2 kGy) of gamma irradiation alone and in combination with 3% TP along with the control (0 kGy) were applied. Aerobic and vacuum packaging were used for storage of chicken meat on the 0, 7th, and 14th days of storage at refrigeration temperature (4°C). The microbiological results showed that the contamination level decreased as the dose of gamma irradiation was increased for both total bacteria and coliforms, whereas no contamination was documented in the group treated with 2 kGy+TP for both aerobic and vacuum packaging. The results further showed that pH, haem pigment, and Hunter’s colour were also significantly influenced with respect to different groups. The peroxide value (POV), thio-barbituric acid reactive substances (TBARS), and total volatile basic nitrogen (TVBN) differed significantly in chicken meat with different treatments and storage intervals. Higher POV and TBARS were noticed in chicken meat treated with 2 kGy under aerobic packaging after 14 days of storage, and TVBN was higher in the control on the 14th day under aerobic packaging. Total phenolics and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity were also higher in chicken meat treated with 2 kGy+TP on 0 day of storage. Furthermore, higher sensory attribute scores for attributes like appearance, taste, texture, flavour, and overall acceptability were found in the 2 kGy-treated group. It is concluded that chicken meat treated with 2 kGy+TP was considered better for microbial and physicochemical quality, antioxidant activity as well as sensorial properties of chicken meat.

\textbf{ARTICLE HISTORY}
Received 11 September 2018
Revised 8 January 2019
Accepted 21 January 2019

\textbf{KEYWORDS}
Gamma irradiation; turmeric powder; chicken meat; antioxidant activity; sensory evaluation

\textbf{Introduction}

Chicken meat is important worldwide due to the accessibility of nutrients like vitamins, essential amino acids, long-chain polyunsaturated fatty acids (PUFAs), and minerals. Meat and meat products can be contaminated from external sources during handling, bleeding, and processing. The contaminants on the knives will soon spread on various parts of the meat. Raw meat can be contaminated with different microorganisms, such as \textit{Salmonella} spp, \textit{Escherichia coli}, \textit{Listeria monocytogenes}, \textit{Streptococcus}, and \textit{Micrococcus}, and hence the control of meat pathogens is a vital safety issue.\textsuperscript{[11]}

\textbf{CONTACT} Muhammad Sajid Arshad \textsuperscript{a} sajid_ft@yahoo.com Department of Food Science, Nutrition and Home Economics, Government College University, Faisalabad, Pakistan

© 2019 Muhammad Sajid Arshad, Zaid Amjad, Muhammad Yasin, Farhan Saeed, Ali Imran, Muhammad Sohaib, Faqir Muhammad Anjum and Shahzad Hussain. Published with license by Taylor & Francis Group, LLC.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
Ionizing radiation technology shows potential as most of the problems that arise particularly by microbial spoilage and by the use of various chemical substances that pose potential health risks can be efficiently reduced by it, hence reducing the risks of food-borne disease outbreaks. Food irradiation eliminates or reduces the microbial population from food that are harmful for human health. It is a physical process involving the treatment of foods with ionizing radiation. The Food and Drug Administration (FDA) approved the forms of ionizing energies that can be used for food processing, including gamma rays (from 137-Cesium or 60-Cobalt), X-rays, and electron beams. Food preservation through radiation technology provides consumers with healthy and nutritious foods with improved safety, increased storage life, and quality and ease of transport.

The advantages of γ-radiation are basically its lethality, wide penetration power, and high energy content, as they act at the cellular level. It has uniform, deep, and instantaneous penetration ability. Cooked meat treated with the radiation process gives a strong flavour compared to cooked samples that are not treated with the radiation process. The recommended doses of gamma irradiation for chicken meat are up to 7 kGy for different types of meat. Salmonella spp. and other pathogens are easily decontaminated by the use of these doses. These recommended doses are sufficient for enhancing the shelf life of meat and meat products.

Irradiation produces some free radicals due to the radiolysis of water. These free radicals cause oxidation in the meat due to the fact that it is necessary to use native bioactive compounds along with the radiations. Turmeric, commonly known as “haldi” in the Indian subcontinent, contains a number of phyto-constituents, namely fat, protein, moisture, carbohydrates, and minerals in 5.1, 6.3, 13.1, 69.4, and 3.5%, respectively. Turmeric owes its characteristic yellow colour to three major pigments: curcumin (71.5%), demethoxy-curcumin (19.4%), and bis-demethoxycurcumin (9.1%). From the safety point of view, the FAO/WHO expert on food additives jointly authorized curcumin, the yellow colouring agent of turmeric, for this purpose. It represents about 3–5% of curcuminoids in the rhizomes of turmeric and is regarded as one of the strong phenolic antioxidants. It also benefits the nutrition of poultry, which include improvement in the parameters of broiler’s performance and the secretion of endogenous digestive enzymes and the activation of immune responses.

These plant extracts contend with synthetic drugs. Most medicinal plants have no residual effects. As the world becomes more advanced, animals and humans have started developing new diseases through the irrational use of antimicrobial and antibiotic growth promoters. This has led to increased numbers of works being carried out on medicinal plants. Hence, the evaluation of the fact on how different doses of gamma irradiation, combined with aerobic and vacuum packaging, influence the microbiological, physicochemical, and antioxidant parameters, along with the sensory attributes of chicken meat during storage, was the basic aim of this study.

**Materials and methods**

**Materials**

The chicken meat samples were purchased from a local market of Peshawar, Pakistan, from a freshly slaughtered chilled carcass and irradiated with gamma radiation at Nuclear Institute of Food and Agriculture (NIFA), Peshawar, 25000, Pakistan. The analyses were performed both at Institute of Home and Food Sciences, Government College University, Faisalabad and at NIFA, Peshawar. Chicken meat samples were aerobically packed using ziplock bags and a vacuum sealer used for vacuum packaging, and then these samples were stored at 4°C prior to use. All the chemicals and reagents being used in this study were purchased from well-known companies, including Sigma Aldrich (Tokyo) and Merck (Merck KGaA and Darmstadt, Germany). Three replicates were used in all parameters except in sensory, where there were seven trained panellists.
Gamma irradiation

Gamma irradiation was performed at NIFA, Peshawar, which is under the Pakistan Atomic Energy Commission. There were in total six groups with aerobic and vacuum packaging. Two doses (1 kGy and 2 kGy) of gamma irradiation were used alone and with a combination of 3% turmeric powder (TP) with the control (0 kGy).

Microbial quality

The microbial counts of the total viable bacteria (TVC) and the total coliforms in accordance with the guidelines of Association of Official Agricultural Chemists (AOAC) (2005) were performed and expressed as log CFU/g (CFU per gram). The samples of meat were placed in each enrichment broth, and then at the most favourable conditions, the samples were incubated.

Haem pigments

The haem pigments, for example, myoglobin (Mb), metmyoglobin (MMb), and oxy-myoglobin (MbO2) relative concentrations, were determined according to the method described by Krzywicki.[22]

Hunter’s colour

The surface colour values of the chicken samples treated and untreated with gamma irradiation with and without 3% TP were determined via a Hunter colorimeter, with the help of measurements that were standardized with respect to a white calibration plate (L = 89.2, a = 0.921, and b = 0.783). The CIE L* (lightness), CIE a* (redness), and CIE b* (yellowness) colour values, by using an average from nine random readings, were obtained on the surface of each sample for statistical analysis.

2-thio-arbituric acid reactive substances (TBARS) value

Using the method of TBARS explained earlier,[23] with a few modifications, the extent of lipid oxidation was measured. The concentration of malonaldehyde was calculated using the following equation, where the values of TBARS are expressed as milligram (mg) malondialdehyde per kilogram (kg) meat:

\[
\text{mg malondialdehydes per kg meat} = \frac{(\text{Sample absorbance} - \text{blank}) \times \text{Total sample vol.}}{0.000156 \times 1000}
\]

Peroxide value (POV)

POV was determined according to the method of the International Dairy Federation (IDF).[24]

Antioxidant potential

DPPH free radical scavenging activity

The irradiated and non-irradiated chicken meat samples with and without 3% TP were subjected to analysis of the DPPH radical scavenging activity according to the procedure outlined in.[25] The inhibition of free radicals by DPPH in percent (%) was calculated using the following equation:

\[
\text{Inhibition(\%)} = 100 \times \left( \frac{A_{\text{blank}} - A_{\text{sample}}}{A_{\text{blank}}} \right)
\]
**Total phenolic contents (TPCs)**

The TPCs in chicken meat treated and untreated with and without gamma irradiation with 3% TP were determined by following the method described in.\(^{26}\)

**TVBN**

The TVBN values of the irradiated and non-irradiated chicken meat samples with and without 3% TP were measured. The TVBN value was calculated using the following equation:

\[
\text{TVBN value (mg/100 mL)} = 100 \times N, \quad \text{where} \quad 14 = \text{molecular weight of nitrogen,} \quad a = \text{normality of} \quad H_2SO_4, \quad \text{and} \quad b = \text{volume of} \quad H_2SO_4 \quad \text{titration value.}
\]

**Sensory evaluation**

Sensory evaluation of chicken turmeric patties treatments was carried out by a trained taste panel, employing a nine-point hedonic scale (9 = extremely liked; 1 = extremely disliked) by following the guidelines in.\(^{27}\) During the time of sensory evaluation, the panellists were given mineral water, unsalted crackers, and expectorant cups to neutralize and rinse their taste receptors for rational assessment. In total, 10 panellists were selected on the basis of their expertise in sensory evaluation.

**Statistical analysis**

The data obtained for different parameters were analysed statistically using the Statistical Package, Statistic 8.1. Levels of significance (\(p \leq 0.05\)) were determined (analysis of variance, ANOVA) using three-factor factorial under completely randomized design (CRD) by following the principles outlined in.\(^{28}\) The means were compared using least significant difference (LSD). Three replicates were used for all parameters, except for sensory and Hunter’s colour. In Hunter’s colour, there were nine random readings, and 10 trained panellists were selected for the sensory scores.

**Results and discussion**

**Microbial quality**

The microbial counts for the total aerobic bacteria and coliforms in the untreated and treated samples of TP and gamma irradiation were analysed. With increase in the dose of gamma irradiation, the microbial populations decreased significantly; as the storage period increased, the microbial contamination increased in aerobic packaging, while compared to aerobic packaging, the microbial contamination decreased in vacuum packaging. The results showed an elevated count (10.44 ± 0.04 log CFU/g) of the total aerobic bacteria (TAB), and it was found in the untreated sample (0 kGy) on the 14th day of storage in aerobic packaging, while a lower TAB count of 2.71 ± 0.08 log CFU/g was found with the dose of 2 kGy of gamma irradiation in vacuum packaging on 0 day of storage, as shown in Table 1. The results represented that complete decontamination was attained with 2 kGy + TP of the dose during all storage intervals (0, 7, and 14 days) in both aerobic and vacuum packaging. A higher coliform count (5.39 ± 0.16 log CFU/g) was found in the untreated sample (0 kGy) on the 14th day of storage in aerobic packaging, whereas a lower coliform count of 2.65 ± 0.08 log CFU/g was obtained with the dose of 1 kGy of gamma irradiation on day 0 of storage in vacuum packaging. These results indicated that complete decontamination was achieved with the dose of 1 kGy + TP and 2 kGy +
TP during all storage intervals (0, 7, and 14 days) in both aerobic and vacuum packaging. The results depicted that the treated chicken meat had higher values of TAB and coliforms in aerobic packaging as compared to vacuum packaging, while lower counts were found in the treated samples, which are in agreement with the findings of Montiel et al.;[29] they reported that irradiation of 1 and 2 kGy doses significantly curtailed the total viable counts in smoked salmon by 2 and 2.4 log units, respectively.[30] reported that irradiation reduced the load of bacteria and improved the shelf life, which is in agreement with the results of our study. The results of our study are also in agreement with the outcomes of,[31] who reported that irradiation at 5°C reduced the natural flora on chicken skin from $10^4$–$10^5$ to 10–500 cells/7 cm$^2$.[32] also stated that an irradiation dose of 2.0 kGy or more inactivated 99% of the microbial loads on chicken carcasses. Another study showed that combined treatments using bioactive compounds (cinnamaldehyde + ascorbic acid (0.5%, w/w), cinnamaldehyde (1.47%, w/w), or cinnamaldehyde + sodium pyrophosphate deca hydrate (0.1%, w/w)) and irradiation can significantly reduce the microbial load of meat samples compared to untreated control samples.[33]

**Physicochemical assay**

**Haem pigment**

The statistical results regarding the Mb content of chicken meat samples have a significant effect with respect to treatments and storage interval. Higher Mb content (39.65 ± 2.71%) was observed in treated (1 kGy + TP) vacuum-packaged samples on 0 day of storage, followed by aerobic-packaged treated (0 kGy +TP) chicken meat samples (39.64 ± 2.71%) on 0 day, whereas minimum content (6.15 ± 0.93%) was noticed in the vacuum-packaged samples treated with 1 kGy on the 14th day of storage, as listed in Table 2. The results showed that the Mb content significantly decreased in vacuum-packaged chicken meat samples as compared to aerobic samples. Moreover, the Mb content of untreated chicken samples (control) lessened gradually. Mb present in the treated and untreated chicken meat samples also increased with the addition of TP in both aerobic- and vacuum-packaged samples.

The results showed that the MbO$_2$ contents of treated and untreated chicken samples ranged from 11.44 ± 1.10% to 14.97 ± 1.49% and 11.02 ± 1.24% to 13.66 ± 0.80% in aerobic and vacuum packaging, respectively, on 0 day of storage, whereas in the treated and untreated chicken samples at the end of the storage interval (14 days) the values ranged from 19.64 ± 2.44% to 22.87 ± 2.39% and 19.22 ± 2.19% to 21.69 ± 1.10% in aerobic and vacuum packaging.

### Table 1. Total aerobic bacteria and coliforms of chicken meat treated with gamma irradiation and turmeric powder at different storage periods (0, 7th, and 14th days).

| Parameter | Treatments          | Aerobic 0 | Vacuum 0 | Aerobic 7 | Vacuum 7 | Aerobic 14 | Vacuum 14 |
|-----------|---------------------|-----------|----------|-----------|----------|------------|-----------|
| Total Aerobic Bacteria (log CFU/g) | 0 kGy | 8.36 ± 0.11a | 7.28 ± 0.24a | 9.34 ± 0.29a | 8.11 ± 0.06a | 10.44 ± 0.04a | 9.35 ± 0.07a |
|           | 1 kGy | 5.49 ± 0.32c | 4.74 ± 0.51c | 6.37 ± 0.38c | 5.32 ± 0.36c | 6.95 ± 0.01c | 6.74 ± 0.40c |
|           | 2 kGy | 3.22 ± 0.09e | 2.71 ± 0.08d | 4.86 ± 0.28e | 3.55 ± 0.38d | 5.14 ± 0.3e | 4.21 ± 0.80d |
|           | 0 kGy + TP | 6.38 ± 0.21b | 5.14 ± 0.51b | 7.36 ± 0.44b | 6.25 ± 0.21b | 8.35 ± 0.22b | 7.36 ± 0.39b |
|           | 1 kGy + TP | 4.12 ± 0.39d | ND | 5.41 ± 0.41d | 3.47 ± 0.6d | 6.36 ± 0.19d | 4.65 ± 0.04cd |
|           | 2 kGy + TP | ND | ND | ND | ND | ND | ND |
| Coliforms (log CFU/g) | 0 kGy | 4.65 ± 0.07a | 3.54 ± 0.10a | 4.89 ± 0.11a | 3.69 ± 0.42a | 5.39 ± 0.16a | 4.11 ± 0.25a |
|           | 1 kGy | 3.22 ± 0.15c | 2.65 ± 0.08c | 3.77 ± 0.22c | 2.99 ± 0.31c | 4.01 ± 0.15c | 3.65 ± 0.28c |
|           | 2 kGy | 2.88 ± 0.16d | ND | 3.65 ± 0.08c | ND | 3.77 ± 0.07d | ND |
|           | 0 kGy + TP | 3.87 ± 0.24b | 3.11 ± 0.09b | 4.31 ± 0.04b | 3.44 ± 0.25b | 4.73 ± 0.37b | 3.75 ± 0.09b |
|           | 1 kGy + TP | ND | ND | ND | ND | ND | ND |
|           | 2 kGy + TP | ND | ND | ND | ND | ND | ND |

TP, turmeric powder; ND, not detected
The values are mean ±SD of three independent determinations
Means carrying different letters in rows or columns differed significantly.

---

**Table 2.** Results of Mb and MbO$_2$ content (%) of chicken meat samples treated with gamma irradiation and turmeric powder at different storage periods (0, 7th, and 14th days).

| Parameter | Treatments | 0 Day | 7 Day | 14 Day |
|-----------|------------|-------| ------|--------|
| Mb (%)    | 0 kGy      | 39.65 | 39.64 | 6.15   |
|           | 1 kGy      | 39.64 | 39.64 | 6.15   |
|           | 2 kGy      | 39.64 | 39.64 | 6.15   |
| MbO$_2$(%)| 0 kGy      | 19.64 | 19.64 | 19.64  |
|           | 1 kGy      | 19.64 | 19.64 | 19.64  |
|           | 2 kGy      | 19.64 | 19.64 | 19.64  |
| Parameter          | Treatments | 0       | 7       | 14      | Storage period (days) |
|--------------------|------------|---------|---------|---------|-----------------------|
|                    |            | Aerobic | Vacuum  | Means   | Aerobic | Vacuum  | Means   | Aerobic | Vacuum  | Means   |
| Myoglobin (%)      |            | 38.93 ± 2.64 | 37.69 ± 2.15 | 38.31 ± 1.50a | 19.89 ± 2.74 | 18.61 ± 1.14 | 19.25 ± 1.80b | 7.94 ± 0.80 | 6.62 ± 0.70 | 7.28 ± 0.71c |
|                    | 1 kGy      | 37.95 ± 2.24 | 37.25 ± 2.30 | 37.60 ± 1.80a | 18.75 ± 1.25 | 19.19 ± 0.98 | 18.47 ± 1.40b | 6.82 ± 0.72 | 6.15 ± 0.93 | 6.48 ± 0.04c |
|                    | 2 kGy      | 37.63 ± 2.10 | 38.47 ± 2.41 | 38.05 ± 0.40a | 18.54 ± 1.24 | 19.31 ± 2.70 | 18.92 ± 0.70b | 6.59 ± 0.73 | 7.45 ± 0.94 | 7.01 ± 0.07c |
|                    | 0 kGy + TP | 39.64 ± 2.71 | 38.97 ± 2.67 | 39.30 ± 1.30a | 20.57 ± 2.10 | 19.98 ± 1.58 | 20.27 ± 0.30b | 8.51 ± 0.83 | 7.99 ± 0.76 | 8.25 ± 0.40c |
|                    | 1 kGy + TP | 38.55 ± 2.27 | 39.65 ± 2.71 | 39.10 ± 2.10a | 19.48 ± 2.47 | 20.60 ± 2.11 | 20.04 ± 0.64b | 7.87 ± 0.76 | 8.60 ± 0.89 | 8.23 ± 0.90c |
|                    | 2 kGy + TP | 37.49 ± 2.29 | 39.44 ± 2.65 | 38.46 ± 1.00a | 18.38 ± 1.33 | 20.41 ± 1.94 | 19.39 ± 1.50b | 6.22 ± 0.71 | 8.41 ± 0.94 | 7.31 ± 1.40c |
| Means              | 38.36 ± 0.50a | 38.57 ± 0.07a | 19.26 ± 1.00b | 19.51 ± 1.50b | 7.32 ± 1.160c | 7.53 ± 1.14c |
| Oxymyoglobin (%)   | 0 kGy      | 13.31 ± 0.95 | 12.43 ± 1.17 | 12.87 ± 1.18hi | 16.25 ± 2.03 | 15.52 ± 2.42 | 15.88 ± 0.08def | 21.45 ± 1.09 | 20.90 ± 1.55 | 21.17 ± 1.50abc |
|                    | 1 kGy      | 14.32 ± 1.33 | 12.66 ± 1.18 | 13.49 ± 1.19ghi | 17.59 ± 2.14 | 15.79 ± 1.99 | 16.68 ± 1.70de | 22.63 ± 2.31 | 20.99 ± 1.44 | 21.81 ± 1.90ab |
|                    | 2 kGy      | 14.97 ± 1.49 | 13.66 ± 0.80 | 14.31f±0.07fgh | 17.98 ± 1.97 | 16.58 ± 1.58 | 17.28 ± 1.10d | 22.87 ± 2.39 | 21.69 ± 1.10 | 22.28 ± 1.10a |
|                    | 0 kGy + TP | 12.37 ± 1.17 | 11.02 ± 1.24 | 11.69 ± 0.02i | 15.45 ± 2.15 | 14.14 ± 1.47 | 14.79 ± 1.80efgh | 20.79 ± 1.51 | 19.22 ± 2.19 | 20.00 ± 0.20bc |
|                    | 1 kGy + TP | 12.34 ± 1.17 | 11.39 ± 1.12 | 11.86 ± 0.10i | 15.40 ± 2.15 | 14.47 ± 1.98 | 14.93 ± 1.20defg | 20.51 ± 1.96 | 19.40 ± 2.06 | 19.95 ± 0.44bc |
|                    | 2 kGy + TP | 11.44 ± 1.10 | 11.99 ± 1.02 | 11.71 ± 0.06i | 14.58 ± 1.52 | 14.89 ± 1.53 | 14.73 ± 1.00fgh | 19.64 ± 2.44 | 19.90 ± 1.66 | 19.77 ± 1.55c |
| Means              | 13.12 ± 1.70c | 12.19 ± 1.20c | 16.20 ± 1.10b | 15.23 ± 1.70b | 21.31 ± 1.80a | 20.34 ± 1.10a |
| Metmyoglobin (%)   | 0 kGy      | 41.12 ± 2.51 | 38.65 ± 1.93 | 39.78 ± 1.4 ± 0.70gh | 52.24 ± 3.21 | 49.04 ± 3.43 | 50.63 ± 1.12de | 62.73 ± 4.02 | 59.73 ± 3.07 | 61.23 ± 0.09ab |
|                    | 1 kGy      | 44.64 ± 2.22 | 40.21 ± 2.10 | 42.42 ± 1.2 ± 0.09g | 54.27 ± 3.46 | 51.54 ± 3.23 | 52.90 ± 1.19d | 65.50 ± 3.99 | 61.28 ± 3.19 | 63.39 ± 0.08a |
|                    | 2 kGy      | 44.99 ± 2.45 | 40.98 ± 2.51 | 42.98 ± 2.0 ± 0.80g | 54.80 ± 3.56 | 51.97 ± 2.73 | 53.19 ± 0.60d | 65.98 ± 3.35 | 61.70 ± 2.83 | 63.83 ± 1.7a |
|                    | 0 kGy + TP | 37.36 ± 1.75 | 35.24 ± 1.22 | 36.30 ± 0.8 ± 1.60i | 48.26 ± 3.60 | 45.16 ± 2.56 | 46.71 ± 1.80f | 58.43 ± 2.68 | 56.14 ± 3.38 | 57.28 ± 1.8c |
|                    | 1 kGy + TP | 36.47 ± 1.42 | 35.91 ± 1.43 | 36.18 ± 0.90i | 47.41 ± 2.95 | 45.86 ± 2.68 | 46.63 ± 1.50f | 60.57 ± 3.03 | 56.61 ± 3.32 | 58.58 ± 1.12bc |
|                    | 2 kGy + TP | 36.82 ± 1.62 | 36.41 ± 1.32 | 36.61 ± 0.70hi | 47.94 ± 2.46 | 47.30 ± 2.62 | 47.62 ± 0.40ef | 60.98 ± 3.03 | 60.22 ± 3.40 | 60.60 ± 1.9ab |
| Means              | 40.19 ± 0.08e | 37.89 ± 1.00f | 50.81 ± 0.80c | 48.48 ± 1.51d | 62.36 ± 1.80a | 59.28 ± 0.40b |

TP, turmeric powder
The values are mean ±SD of three independent determinations
Means carrying different letters in rows or columns differed significantly
respectively. Higher value of MbO\textsubscript{2} (22.87 ± 2.39\%) was observed in treated (2 kGy) aerobic-packaged samples on the 14th day of storage, followed by vacuum-packaged treated (2 kGy) chicken meat samples (21.69 ± 1.10\%) on the 14th day, whereas minimum value (11.02 ± 1.24\%) was revealed in vacuum-packaged samples that were treated with 0 kGy + TP on 0 day of storage. The results depicted that the MbO\textsubscript{2} content significantly decreased in vacuum-packaged chicken meat samples as compared to aerobic samples. Furthermore, the MbO\textsubscript{2} in untreated chicken samples (control) increased with the passage of time. The MbO\textsubscript{2} contents in treated and untreated chicken meat samples also decreased with the addition of TP in both aerobic- and vacuum-packaged samples.

Higher value of MMb (65.98 ± 3.55\%) was observed in treated (2 kGy) aerobic-packaged samples on the 14th day of storage, followed by vacuum-packaged treated (2 kGy) chicken meat samples (61.70 ± 2.83\%) on the 14th day, whereas minimum value (35.24 ± 1.22\%) was found in the vacuum-packaged samples treated with 0 kGy + TP on 0 day of storage. The results revealed that the MMb content significantly decreased in vacuum-packaged chicken meat samples as compared to aerobic samples. Moreover, the MMb in untreated chicken samples (control) increased with the passage of time. The MMb contents in treated and untreated chicken meat samples also decreased with the addition of TP in both aerobic- and vacuum-packaged samples.

The results showed that the treated samples of chicken meat have a lower content of Mb in aerobic packaging, but in the cases of MbO\textsubscript{2} and MMb, lower contents were found in vacuum packaging; however, a higher content of Mb was found in the untreated sample (control), and in MbO\textsubscript{2} and MMb, higher contents were found in treated samples, which is agreement with the findings of\cite{30} who reported that a higher level of Mb was found in the control samples on 0 day under aerobic packaging, but at 4.5 kGy the lowest level was found. In the samples that were irradiated with 4.5 kGy, higher levels of MbO\textsubscript{2} and MMb were found on the 40th day of storage under aerobic packaging, while in the non-irradiated control sample (0 kGy), low levels of MbO\textsubscript{2} and MMb were found on 0 day. Our results are in agreement with the outcomes of\cite{34} who reported that with the passage of time and increase in the level of dose via an intermediate MbO\textsubscript{2} phase, the Mb oxidized into MMb. There are numerous mechanisms that are responsible for the pro-oxidant capacities of Mb’s, for instance, the ability to decompose hydro-peroxide, and because of the conversion to the ferryl/perferryl form, they can serve as a free radical. Hydrogen peroxide and superoxide anions are produced by the oxidation process, which in turn, after reacting with iron (Fe), generate hydroxyl radicals. These hydroxyl radicals, after diffusing with the hydrophobic lipid region of the muscles, facilitate the oxidation of lipids. The hydroxyl radicals that were produced from water due to ionizing radiation convert the Mb into MMb or even serve as a catalyst to eliminate the ferric ion haem and speed up the oxidation of lipids\cite{35,36}.\textcolor{red}{\textit{Hunter’s colour.}} The statistical results regarding the \textit{L*} value of chicken meat samples have a significant effect with respect to treatments and packaging. Higher value of \textit{L*} (56.12 ± 2.02) was observed in treated (0 kGy + TP) aerobic-packaged samples on the 14th day of storage, followed by vacuum-packaged treated (0 kGy + TP) chicken meat samples (53.44 ± 3.16) on the 14th day, whereas minimum value (49.11 ± 2.51) was found in the vacuum-packaged samples treated with an irradiation dose of 1 kGy on 0 day of storage, as listed in Table 3. The results described that the \textit{L*} value significantly decreased in vacuum-packaged chicken meat samples as compared to aerobic samples. Furthermore, the \textit{L*} value in untreated chicken samples (control) increased with the passage of time. The \textit{L*} values in treated and untreated chicken meat samples also increased with the addition of TP in both aerobic- and vacuum-packaged samples. The results showed that the treated sample of chicken meat has a higher value of \textit{L*} in aerobic packaging, while a lower value was found in treated samples. Our results are in accordance with the outcomes of\cite{37} who stated that as the dose was increased from 0 to 4 kGy, the \textit{L*} values of irradiated pork jerky also increased. It was reported by\cite{33} that the \textit{L*} value increased as the irradiation dose was increased in ground beef. Likewise\cite{38} the addition of citric or ascorbic acid increased the \textit{L*} values of irradiated meat, resulting in lighter overall colour impression to meat.
### Table 3. Hunter’s colour of chicken meat treated with gamma irradiation and turmeric powder at different storage periods (0, 7th and 14th days).

| Parameter | Treatments | Storage period (days) | 0 | 7 | 14 |
|-----------|------------|-----------------------|---|---|----|
|           |            |                       | Aerobic | Vacuum | Means | Aerobic | Vacuum | Means | Aerobic | Vacuum | Means |
| L* 0 kGy  | 51.22 ± 3.05 | 49.22 ± 3.20 | 50.21 ± 0.80b | 51.45 ± 2.79 | 49.70 ± 2.25 | 50.57 ± 1.9b | 51.77 ± 2.33 | 50.12 ± 2.65 | 52.61 ± 1.74ab |
| 1 kGy     | 50.77 ± 2.94 | 49.11 ± 2.51 | 49.94 ± 0.60b | 50.81 ± 3.35 | 49.20 ± 3.34 | 50.00 ± 1.16b | 50.88 ± 3.33 | 49.47 ± 3.01 | 50.17 ± 1.10b |
| 2 kGy     | 51.12 ± 3.59 | 49.44 ± 3.84 | 50.28 ± 1.00b | 51.31 ± 1.76 | 49.35 ± 3.05 | 50.32 ± 1.18b | 51.55 ± 3.07 | 49.55 ± 2.92 | 50.55 ± 1.41b |
| 0 kGy + TP| 53.77 ± 3.20 | 52.12 ± 2.57 | 52.94 ± 1.20ab | 54.12 ± 3.04 | 52.09 ± 3.51 | 53.10 ± 1.02ab | 56.12 ± 2.02 | 53.44 ± 3.16 | 54.78 ± 1.65a |
| 1 kGy + TP| 52.44 ± 3.04 | 50.19 ± 2.13 | 51.31 ± 1.18b | 52.78 ± 3.07 | 51.11 ± 1.85 | 51.94 ± 1.17ab | 53.92 ± 3.32 | 52.47 ± 3.01 | 53.19 ± 1.54ab |
| 2 kGy + TP| 52.19 ± 2.09 | 50.12 ± 2.65 | 51.15 ± 1.70b | 52.63 ± 3.17 | 51.44 ± 2.81 | 52.03 ± 1.19ab | 52.99 ± 3.28 | 52.78 ± 3.07 | 52.88 ± 1.00ab |
| Means     | 51.91 ± 1.16abc | 50.03 ± 1.18c | 52.18 ± 1.10abc | 50.48 ± 1.17bc | 53.42 ± 1.10a | 51.30 ± 1.17bc | 12.94 ± 1.15c | 13.91 ± 1.00b | 11.04 ± 0.50a |

| a* 0 kGy  | 11.19 ± 0.57 | 12.72 ± 1.00 | 11.95 ± 0.02d | 10.77 ± 1.21 | 13.22 ± 0.96 | 11.99 ± 1.14d | 10.52 ± 1.19 | 13.77 ± 1.14 | 12.14 ± 1.13d |
| 1 kGy     | 11.32 ± 0.88 | 12.91 ± 1.07 | 12.11 ± 0.71d | 10.91 ± 1.29 | 13.98 ± 1.28 | 12.44 ± 1.90d | 10.61 ± 1.14 | 14.47 ± 0.89 | 12.53 ± 1.18d |
| 2 kGy     | 11.78 ± 1.05 | 13.01 ± 1.46 | 12.39 ± 0.1d | 11.07 ± 1.86 | 14.21 ± 0.79 | 12.63 ± 1.60d | 10.69 ± 0.96 | 15.11 ± 0.55 | 12.90 ± 1.00cd |
| 0 kGy + TP| 14.12 ± 0.98 | 14.34 ± 1.15 | 14.23 ± 0.7ab | 13.19 ± 1.04 | 15.22 ± 0.71 | 14.20 ± 1.90abc | 12.42 ± 1.33 | 15.56 ± 0.63 | 13.98 ± 0.10bc |
| 1 kGy + TP| 14.44 ± 1.54 | 15.07 ± 1.76 | 14.75 ± 1.12ab | 14.01 ± 1.27 | 15.88 ± 1.66 | 14.94 ± 1.05ab | 13.72 ± 1.25 | 16.11 ± 1.43 | 14.91 ± 0.24ab |
| 2 kGy + TP| 14.79 ± 1.00 | 15.45 ± 0.65 | 15.12 ± 1.17ab | 14.43 ± 0.97 | 16.26 ± 0.73 | 15.34 ± 0.80a | 14.02 ± 1.28 | 16.43 ± 0.94 | 15.22 ± 0.70ab |
| Means     | 12.94 ± 1.15c | 13.91 ± 1.00b | 14.79 ± 0.80a | 12.39 ± 1.10cd | 14.99 ± 0.50d | 15.24 ± 1.10a | 11.04 ± 0.50a |

| * 0 kGy   | 8.21 ± 1.54  | 6.66 ± 0.62  | 7.43 ± 2.0b  | 8.11 ± 0.93  | 6.41 ± 1.20  | 7.26 ± 1.17b  | 8.05 ± 0.98  | 6.39 ± 0.91  | 7.22 ± 0.05b  |
| 1 kGy     | 8.35 ± 0.88  | 6.71 ± 1.16  | 7.53 ± 1.5b  | 8.44 ± 0.81  | 6.91 ± 1.37  | 7.42 ± 1.0b   | 8.57 ± 1.02  | 6.94 ± 1.09  | 7.75 ± 0.04b  |
| 2 kGy     | 8.55 ± 1.60  | 6.92 ± 1.59  | 7.73 ± 1.05b | 8.63 ± 1.03  | 6.98 ± 1.36  | 7.80 ± 1.14b  | 8.77 ± 0.88  | 7.06 ± 1.02  | 7.91 ± 1.0b   |
| 0 kGy + TP| 13.44 ± 1.47 | 10.11 ± 1.11 | 11.77 ± 1.7a | 13.21 ± 1.53 | 9.92 ± 0.71  | 11.56 ± 1.0a  | 13.14 ± 1.49 | 9.87 ± 1.28  | 11.46 ± 1.2a  |
| 1 kGy + TP| 13.71 ± 1.24 | 10.43 ± 1.20 | 12.16 ± 1.14a| 13.84 ± 1.57 | 10.72 ± 1.17 | 12.28 ± 1.16a | 13.88 ± 0.90 | 10.91 ± 0.37 | 12.39 ± 1.5a  |
| 2 kGy + TP| 13.82 ± 1.58 | 10.55 ± 2.04 | 12.18 ± 1.80a| 13.86 ± 1.57 | 10.84 ± 1.33 | 12.34 ± 1.14a | 13.91 ± 0.91 | 10.92 ± 1.03 | 12.41 ± 1.9a  |
| Means     | 11.04 ± 0.50a | 8.56 ± 1.10b | 11.01 ± 1.80a | 8.54 ± 1.14b | 11.04 ± 1.19a | 8.68 ± 1.10b |

**TP, turmeric powder**

The values are mean ±SD of three independent determinations.

Means carrying different letters in rows or columns differed significantly.
In agreement with these findings, significantly higher values of $L^*$ in beef steaks treated with lactic acid and clove oil were reported by.\(^{[39]}\)

The statistical results regarding the $a^*$ value of chicken meat samples have significant effects with respect to treatments and packaging. Higher value of $a^*$ ($14.79 \pm 1.00$) was observed in treated (2 kGy + TP) aerobic-packaged samples on 0 day of storage, followed by vacuum-packaged treated (2 kGy + TP) chicken meat samples ($16.43 \pm 0.94$) on the 14th day, whereas minimum value ($10.52 \pm 1.19$) was found in the untreated (0 kGy) aerobic-packaged samples on the 14th day of storage. The results represented that the $a^*$ value significantly increased in vacuum-packaged chicken meat samples as compared to aerobic samples. Moreover, with the passage of time, the $a^*$ value in untreated chicken samples (control) decreased. The $a^*$ values of the treated and untreated chicken meat samples also increased with the addition of TP in both aerobic- and vacuum-packaged samples. The results showed that treated chicken meat has a higher value of $a^*$ in vacuum packaging, and a lower value was found in untreated (control) samples.\(^{[40]}\) reported that the $a^*$ value (redness) of poultry breast was increased by irradiation in both aerobic- and vacuum-packaged systems. Our results agreed with the findings of,\(^{[38]}\) who reported that the raw breast meat of chicken and turkey treated with irradiation had increased redness ($a^*$).\(^{[41]}\) noted that the combined effect of chitosan and rosemary extract improved the redness of beef burger during frozen storage and improved colour stability using chitosan or rosemary extract alone compared to the control. The results are in line with another study, use of plum sliced increased shear force values, cook loss and redness ($a^*$ values) in ham.\(^{[42]}\)

The results showed that statistical results regarding the $b^*$ value of chicken meat samples have significant effects with respect to treatments and packaging. Higher value of $b^*$ ($13.91 \pm 0.91$) was observed in treated (2 kGy + TP) aerobic-packaged samples on the 14th day of storage, followed by vacuum-packaged treated (2 kGy + TP) chicken meat samples ($10.92 \pm 1.03$) on day 14; however, minimum value ($6.39 \pm 0.91$) was found in untreated (0 kGy) vacuum-packaged samples on day 14 of storage. The results showed that the $b^*$ value significantly decreased in vacuum-packaged chicken meat samples as compared to aerobic samples. Furthermore, the $b^*$ value in untreated chicken samples (control) decreased gradually. The $b^*$ values in treated and untreated chicken meat samples also increased with the addition of TP in both aerobic- and vacuum-packaged samples. The results showed that the treated samples of chicken meat have a lower value of $b^*$ in vacuum packaging and a higher value was found in treated samples, in agreement with the results in,\(^{[43]}\) who showed that combined treatment of meat with ionizing radiation and citric acid positively affected the values of $L^*$ and $b^*$. It was reported by\(^{[37]}\) that as the dose was increased from 0 to 4 kGy, the $b^*$ values of the irradiated pork jerky also increased. Our results agreed with the outcomes of\(^{[43]}\) that the $b^*$ (yellowness) value changes with no specific pattern in poultry products by any treatment (a combination of chitosan and thyme oil). Further studies that corroborate the results of the present study included the work of,\(^{[45]}\) who showed that the $b^*$ values in samples treated with Herbalox™ were different from those of the control. The yellow value ($b^*$) increased compared with the control. During the four-month storage period, the $b^*$ value of the GSE-containing sample decreased slightly. However, no uniform pattern of change was observed for the antioxidant or storage time effect.\(^{[46]}\)

**Thiobarbituric acid reactive substances (TBARS).** The results regarding the TBARS value of chicken meat samples have significant effects with respect to treatments, packaging, and storage interval. Higher value of TBARS ($0.66 \pm 0.04$ MDA/kg) was observed in treated (2 kGy) aerobic-packaged samples on day 14 of storage, followed by vacuum-packaged treated (2 kGy) chicken meat samples ($0.63 \pm 0.04$ MDA/kg) on day 14, whereas the minimum value ($0.32 \pm 0.04$ MDA/kg) was obtained for the vacuum-packaged samples treated with 0 kGy + TP on 0 day of storage, as listed in Table 4. The results depicted that the TBARS value significantly decreased in vacuum-packaged chicken meat samples as compared to aerobic samples. Besides, the TBARS value in untreated chicken samples (control) increased with the passage of time. The TBARS values in treated and untreated chicken meat samples also decreased with the addition of TP in both aerobic- and vacuum-packaged samples. The results depicted that the treated chicken meat
Table 4. Thiobarbituric acid reactive substances (TBARS) and peroxide value (POV) value of chicken meat treated with gamma irradiation and turmeric powder at different storage periods (0, 7th, and 14th days).

| Parameter | Treatments | Storage period (days) |          |          |          |          |          |          |          |
|-----------|------------|-----------------------|----------|----------|----------|----------|----------|----------|----------|
|           |            | 0                     | 7        | 14       |          |          |          |          |          |
| TBARS     |            |                        |          |          |          |          |          |          |          |
| (MDA/kg)  | 0 kGy      | 0.42 ± 0.03            | 0.37 ± 0.02 | 0.39 ± 0.05ijkl | 0.49 ± 0.03 | 0.40 ± 0.01 | 0.44 ± 1.20fgh | 0.56 ± 0.03 | 0.45 ± 0.01 | 0.50 ± 1.80d |
|           | 1 kGy      | 0.49 ± 0.04            | 0.41 ± 0.04 | 0.44 ± 0.09fg | 0.54 ± 0.02 | 0.44 ± 0.03 | 0.49 ± 1.80de | 0.59 ± 0.03 | 0.49 ± 0.02 | 0.54 ± 0.47c |
|           | 2 kGy      | 0.56 ± 0.03            | 0.52 ± 0.01 | 0.53 ± 1.00c | 0.61 ± 0.04 | 0.57 ± 0.02 | 0.58 ± 1.60b  | 0.66 ± 0.04 | 0.63 ± 0.04 | 0.64 ± 1.00a |
|           | 0 kGy + TP | 0.34 ± 0.01            | 0.32 ± 0.04 | 0.32 ± 0.50m | 0.38 ± 0.03 | 0.35 ± 0.01 | 0.36 ± 0.21  | 0.43 ± 0.01 | 0.39 ± 0.02 | 0.40 ± 1.80ijk |
|           | 1 kGy + TP | 0.41 ± 0.02            | 0.35 ± 0.03 | 0.38 ± 0.70kl | 0.44 ± 0.01 | 0.39 ± 0.04 | 0.41 ± 1.70hij | 0.49 ± 0.02 | 0.45 ± 0.03 | 0.46 ± 1.17ef |
|           | 2 kGy + TP | 0.47 ± 0.04            | 0.40 ± 0.02 | 0.43 ± 1.70ghi | 0.52 ± 0.04 | 0.44 ± 0.03 | 0.48 ± 1.00de | 0.59 ± 0.02 | 0.51 ± 0.01 | 0.55 ± 1.14c |
| Means     | 0.44 ± 1.20c | 0.39 ± 1.80d            |          |          |          |          |          |          |          |          |
| POV       |            |                        |          |          |          |          |          |          |          |          |
| (meq peroxide/kg) |            |                      |          |          |          |          |          |          |          |
|           | 0 kGy      | 0.31 ± 0.02            | 0.29 ± 0.03 | 0.29 ± 1.0l | 0.36 ± 0.02 | 0.33 ± 0.04 | 0.34 ± 0.20ijkl | 0.43 ± 0.04 | 0.38 ± 0.03 | 0.40 ± 1.02def |
|           | 1 kGy      | 0.39 ± 0.04            | 0.36 ± 0.02 | 0.37f±1.50fgh | 0.44 ± 0.01 | 0.35 ± 0.02 | 0.39 ± 0.80efg | 0.49 ± 0.02 | 0.41 ± 0.02 | 0.45 ± 1.50bc |
|           | 2 kGy      | 0.45 ± 0.03            | 0.42 ± 0.04 | 0.43 ± 0.50cd | 0.53 ± 0.04 | 0.40 ± 0.02 | 0.46 ± 0.01b  | 0.59 ± 0.02 | 0.46 ± 0.03 | 0.52 ± 0.80a |
|           | 0 kGy + TP | 0.27 ± 0.01            | 0.26 ± 0.01 | 0.26 ± 0.09m | 0.33 ± 0.03 | 0.30 ± 0.03 | 0.31 ± 0.09kl  | 0.38 ± 0.03 | 0.34 ± 0.01 | 0.35 ± 0.40hj |
|           | 1 kGy + TP | 0.35 ± 0.03            | 0.31 ± 0.01 | 0.33 ± 0.70jk | 0.38 ± 0.03 | 0.35 ± 0.01 | 0.36 ± 1.00ghi | 0.44 ± 0.01 | 0.39 ± 0.04 | 0.41 ± 1.60de |
|           | 2 kGy + TP | 0.41 ± 0.02            | 0.35 ± 0.03 | 0.38 ± 0.01fgm | 0.45 ± 0.04 | 0.39 ± 0.04 | 0.41 ± 1.20de | 0.51 ± 0.04 | 0.45 ± 0.04 | 0.48 ± 1.00b |
| Means     | 0.36 ± 0.20c | 0.33 ± 0.80d            |          |          |          |          |          |          |          |          |

TP, turmeric powder  
The values are mean ±SD of three independent determinations  
Means carrying different letters in rows or columns differed significantly.
had higher values of TBARS in aerobic packaging, while a lower value was found in untreated (control) samples. [47] stated that an increase in the irradiation dose in Atlantic salmon fillets from 0.5 to 3 kGy, stored at a temperature of 4°C, led to a significant increase in the TBARS value, which was in agreement with the results of our study. The results of this study were also in agreement with the results of [48] and [49] that only under the aerobic packaging conditions, the irradiation can increase the TBARS in cooked and raw meat. Under aerobic conditions, TBARS had a strong link to the content of total volatiles, ketones, and aldehydes in irradiated meat, but is not related to volatiles under vacuum conditions. Another study demonstrated that due to the antioxidant properties of ascorbic acid, it significantly reduced the TBARS value from 0.24 ± 0.01 mg/kg to 0.68 ± 0.05 mg/kg. There was 38% less abundance of the TBARS value of the combined effect of meat treated with a dose of 2 kGy and cinnamaldehyde + ascorbic acid as compared to meat that was only irradiated. [50] depicted that the peroxide value and TBARS values were further increased at the end of the storage period in beef burger steaks. The TBARS values of the 3% water-soluble yellow pigment extracted from turmeric with the irradiated samples were slightly increased when measured up to the control samples.

**Peroxide value.** The results pertaining to the POV of the meat samples of chicken have significant effects with respect to treatments, packaging, and storage interval. Higher POV (0.59 ± 0.02 meq peroxide/kg) was observed in treated (2 kGy) aerobic-packaged samples on the 14th day of storage, followed by vacuum-packaged treated (2 kGy) chicken meat samples (0.46 ± 0.03 meq peroxide/kg) on day 14, whereas a minimum value (0.26 ± 0.01 meq peroxide/kg) was observed in the vacuum-packaged samples treated with 0 kGy + TP on day 0, as listed in Table 4. The results depicted that the POV significantly decreased in vacuum-packaged chicken meat samples as compared to aerobic samples. Furthermore, the POV in untreated chicken samples (control) increased with the passage of time. The POV in treated and untreated chicken meat samples also decreased with the addition of TP in both aerobic- and vacuum-packaged samples. The results indicated that the treated sample of chicken meat had a lower value in vacuum packaging and higher POV in treated samples, which is in agreement with the results of, [37] who stated that similar to the value of TBARS, with an increase in the dosage of irradiation and expanded storage intervals, POV also increased. Our results concur with other studies indicating the increases in the levels of hydroxyl radicals following irradiation due to the radiolysis of water. Another study reported the strong suppression of lipid oxidation (both PV and TBARS) by hydrolysed potato protein in cooked beef patties. [51] [52] also reported that antioxidant activity possessed by natural agents in the marinades, improve the quality of the beef and reduce POV throughout the storage period as compared to the control. Studies of [53] provide further corroboration, who concluded that reduction in POVs with cassia essential oil was observed in deep-fat-fried beef as compared to the control.

**Antioxidant potential**

**DPPH free radical scavenging activity**

The results regarding the DPPH value of chicken meat samples have significant effects with respect to treatments, packaging, and storage interval. Higher value of DPPH (81.00 ± 1.58%) was observed in treated (0 kGy + TP) vacuum-packaged samples on day 0 of storage, followed by aerobic-packaged treated (0 kGy + TP) chicken meat samples (76.00 ± 2.51%) on day 0, while minimum value (51.00 ± 1.16%) was observed in the aerobic-packaged samples treated with 2 kGy on the 14th day of storage (Table 5). The results indicated that the DPPH value significantly increased in vacuum-packaged chicken meat samples as compared to aerobic samples. Moreover, with the passage of time, the DPPH value in untreated chicken samples (control) also decreased. Also in the treated and untreated chicken meat samples, the DPPH value increased with the addition of TP in both aerobic- and vacuum-packaged samples. The result showed that the treated chicken meat had a lower value of DPPH in aerobic packaging, while a higher value of DPPH was found in untreated (control) samples. [54] reported that the extract of *Bidens pilosa* leaf exhibited
Table 5. 2,2-diphenyl-1-picrylhydrazyl (DPPH) and total phenolic content (TPC) of chicken meat treated with gamma irradiation and turmeric powder at different storage periods (0, 7th, and 14th days).

| Parameter | Treatments | Storage period (days) |
|-----------|------------|-----------------------|
|           |            | 0                     | 7                     | 14                     |
|           |            | Aerobic | Vacuum | Means | Aerobic | Vacuum | Means | Aerobic | Vacuum | Means |
| DPPH (%)  | 0 kGy      | 66.00 ± 2.64 | 70.00 ± 2.27 | 68.00 ± 1.00 | 63.00 ± 1.83 | 67.00 ± 2.44 | 65.00 ± 1.02 | 59.00 ± 1.71 | 63.00 ± 1.83 | 60.99 ± 0.40 |
|           | 1 kGy      | 62.00 ± 2.80 | 67.00 ± 2.44 | 64.49 ± 1.02 | 59.00 ± 2.49 | 65.00 ± 2.11 | 61.99 ± 1.50 | 57.00 ± 2.41 | 61.00 ± 2.56 | 59.00 ± 0.80 |
|           | 2 kGy      | 59.00 ± 2.49 | 64.00 ± 1.79 | 61.49 ± 1.20 | 55.00 ± 1.89 | 62.00 ± 2.80 | 58.50 ± 1.16 | 51.00 ± 1.16 | 57.00 ± 2.17 | 54.00 ± 1.6 |
|           | 0 kGy + TP | 76.00 ± 2.51 | 81.00 ± 1.58 | 78.50 ± 1.00 | 74.00 ± 2.41 | 79.00 ± 2.89 | 76.49 ± 1.30 | 68.00 ± 2.67 | 76.00 ± 2.40 | 71.99 ± 1.20 |
|           | 1 kGy + TP | 72.00 ± 2.08 | 75.00 ± 2.85 | 73.50 ± 0.50 | 69.00 ± 3.20 | 74.00 ± 2.41 | 71.50 ± 1.70 | 66.00 ± 2.64 | 71.00 ± 2.39 | 68.49 ± 1.90 |
|           | 2 kGy + TP | 68.00 ± 2.82 | 72.00 ± 2.08 | 69.99 ± 1.50 | 64.00 ± 1.79 | 68.00 ± 2.82 | 65.99 ± 0.80 | 61.00 ± 2.56 | 64.00 ± 2.26 | 62.55 ± 1.70 |
| TPC (mg/g GAE) | Means | 67.16 ± 1.50c | 71.50 ± 1.13a | 64.00 ± 1.17d | 69.16 ± 1.02b | 60.34 ± 0.90e | 65.33 ± 1.40d |
|           | 0 kGy      | 97.00 ± 2.66 | 104.00 ± 2.43 | 100.50 ± 0.50 | 95.00 ± 2.94 | 103.00 ± 2.95 | 99.00 ± 0.8 | 92.00 ± 5.00 | 99.00 ± 2.66 | 95.50 ± 1.15 |
|           | 1 kGy      | 93.00 ± 3.38 | 95.00 ± 3.11 | 91.50 ± 2.00 | 84.00 ± 2.17 | 91.00 ± 4.01 | 87.50 ± 1.9k | 79.00 ± 3.58 | 88.00 ± 3.38 | 83.50 ± 2.06 |
|           | 2 kGy      | 84.00 ± 2.17 | 92.00 ± 5.00 | 88.00 ± 0.9k | 81.00 ± 3.40 | 88.00 ± 3.38 | 84.50 ± 1.1lm | 74.00 ± 2.41 | 83.00 ± 1.26 | 78.50 ± 1.70 |
|           | 0 kGy + TP | 118.00 ± 2.11 | 126.00 ± 2.59 | 122.00 ± 1.2a | 113.00 ± 1.28 | 122.00 ± 2.66 | 117.50 ± 1.0b | 109.00 ± 2.71 | 119.00 ± 2.36 | 114.00 ± 1.60 |
|           | 1 kGy + TP | 106.00 ± 2.41 | 113.00 ± 1.28 | 109.50 ± 1.60d | 102.00 ± 3.05 | 110.00 ± 3.21 | 106.00 ± 1.80 | 97.00 ± 2.66 | 107.00 ± 2.69 | 102.00 ± 1.21 |
|           | 2 kGy + TP | 102.00 ± 3.35 | 107.00 ± 2.69 | 104.50 ± 1.70ef | 99.00 ± 2.66 | 104.00 ± 2.43 | 101.50 ± 1.16fg | 96.00 ± 1.96 | 101.00 ± 2.73 | 98.50 ± 1.54 |
| TPC (mg/g GAE) | Means | 99.17 ± 1.20c | 106.17 ± 1.16a | 95.66 ± 1.18d | 103.00 ± 0.70b | 91.17 ± 1.14e | 99.50 ± 1.50c |

TP, turmeric powder
The values are mean ±SD of three independent determinations
Means carrying different letters in rows or columns differed significantly
higher antiradical activity against 2,2-diphenyl-2-picrylhydrazyl (DPPH) and radicals of 2,2’azino-
bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) than *Moringa oleifera* leaf extract and standard 
butylated hydroxy toluene (BHT) fresh ground beef during 6 days of cold storage. In the DPPH 
assay, the highest antioxidant activities (expressed as μ mol TE/g) were observed for *S. aromaticum* 
(8.19 ± 0.12) and *C. cassia* (6.36 ± 0.17) extracts, followed by *B. nigra* (4.80 ± 0.12) and *O. vulgare* 
(3.30 ± 0.09) in raw chicken meat. Another study demonstrated that chicken nuggets containing 
the antioxidants alpha lipoic acid and alpha tocopherol acetate retain higher percentage of DPPH 
inhibition all through the storage duration. The result of our findings is also in accordance with 
the results reported by and; they reported that the antiradical power was increased by these 
extracts (sage and vitamin E extract) as compared to control treatment.

**TPCs**
The results regarding the TPC of chicken meat samples have significant effects with respect to 
treatments, packaging, and storage interval. Higher TPC (126.00 ± 2.59 mg/g GAE) was observed in 
treated (0 kGy + TP) vacuum-packaged samples on day 0 of storage, followed by aerobic-packaged 
treated (0 kGy + TP) chicken meat samples (118.00 ± 2.11 mg/g GAE) on day 0, whereas minimum 
value (74.00 ± 2.41 mg/g GAE) was observed in the aerobic-packaged samples treated with a dose of 
2 kGy on the 14th day of storage (Table 5). The results proved that the TPC significantly increased in 
vacuum-packaged chicken meat samples as compared to aerobic samples. Also, with the passage of 
time, the TPC in untreated chicken samples (control) declined. TPC found in treated and untreated 
chicken meat samples also increased with the addition of TP in both aerobic- and vacuum-packaged 
samples. The result showed that the treated sample of chicken meat had higher TPC in untreated 
(control) samples, whereas a lower value was found in aerobic packaging, which is in agreement with 
the results of; they reported that the total phenolic content decreased significantly at each interval 
of storage period in vacuum-packaged fresh chicken sausages. However, treated products showed 
a slower rate of decrease, indicating that these possess better oxidative stability than the control. Our 
results agreed with other studies demonstrating that the meat from goat fed with *Moringa oleifera* 
leaves had a higher concentration of total phenolic content (mainly tannin content) than the meat of 
goat fed a control diet. Another study stated that the highest level of TPC was found in *S. aromaticum*, while *C. cassia* showed the lowest level in raw chicken meat. It is considered 
that during the storage period, the phenolic content decreased significantly in all fresh chicken 
sausage products at each interval of storage period.

**TVBN assay**
The results regarding the TVBN value of chicken meat samples have significant effects with respect 
to treatments, packaging, and storage interval. Higher value of TVBN (5.26 ± 0.39 mg/100 mL) was 
observed in untreated (0 kGy) aerobic-packaged control samples on day 14 of storage, followed by 
vacuum-packaged untreated (0kGy) chicken meat samples (5.11 ± 0.35 mg/100 mL) on day 14, 
whereas the results showed that the minimum value (2.98 ± 0.20 mg/100 mL) was observed in the 
vacuum-packaged samples treated with 0 kGy + TP on day 0 of storage, as listed in Table 6. The 
results depicted that the TVBN value significantly decreased in vacuum-packaged chicken meat 
samples as compared to aerobic samples. Moreover, the TVBN value in untreated chicken samples 
(control) increased with the passage of time, while irradiation with and without TP suppressed the 
increase of TVBN value with storage intervals. The TVBN value in treated and untreated chicken 
meat samples also decreased with the addition of TP in both aerobic- and vacuum-packaged 
samples. The results indicated that the treated samples of chicken meat have a lower value in 
vacuum packaging, while a higher value of TVBN was found in treated samples, which are in 
consistent with the results of, who confirmed that in irradiated camel meat, volatile basic nitrogen 
(VBN) tends to diminish after its storage for about 2 weeks. By reducing the initial level of common 
spoilage bacteria, increasing the applied dose can reduce the rate of VBN formation during storage.
Table 6. Total volatile basic nitrogen (TVBN) of chicken meat treated with gamma irradiation and turmeric powder at different storage periods (0, 7th, and 14th days).

| Parameter | Treatments | Storage period (days) |  |  |  |
|-----------|------------|-----------------------|---|---|---|
|           |            | 0                     | 7 | 14 |
| TVBN (mg/100 mL) | 0 kGy | 3.45 ± 0.21 | 3.39 ± 0.23 | 3.42 ± 1.30ij | 4.76 ± 0.33 | 4.23 ± 0.25 | 4.49 ± 0.50c | 5.26 ± 0.39 | 5.11 ± 0.35 | 5.18 ± 1.60a |
|           | 1 kGy     | 4.13 ± 0.30 | 4.07 ± 0.27 | 4.10 ± 1.21def | 3.66 ± 0.25 | 3.45 ± 0.21 | 3.55 ± 1.80hi | 4.06 ± 0.27 | 3.74 ± 0.25 | 3.89 ± 2.10fg |
|           | 2 kGy     | 4.96 ± 0.33 | 4.72 ± 0.30 | 4.84 ± 1.40b  | 4.12 ± 0.31 | 3.97 ± 0.24 | 4.04 ± 1.30ef | 4.45 ± 0.24 | 4.32 ± 0.29 | 4.38 ± 1.30cd |
|           | 0 kGy +TP | 3.14 ± 0.21 | 2.98 ± 0.20 | 3.06 ± 1.00k  | 4.23 ± 0.25 | 3.45 ± 0.21 | 3.84 ± 2.00fgfgh | 4.87 ± 0.32 | 4.02 ± 0.24 | 4.44 ± 2.00c |
|           | 1 kGy + TP| 3.93 ± 0.25 | 3.71 ± 0.25 | 3.82 ± 0.80fggh | 4.23 ± 0.16 | 3.07 ± 0.22 | 3.15 ± 1.90gk | 3.74 ± 0.25 | 3.69 ± 0.22 | 3.71 ± 1.07ghi |
|           | 2 kGy + TP| 4.39 ± 0.31 | 4.08 ± 0.27 | 4.23 ± 1.10cde | 3.84 ± 0.20 | 3.34 ± 0.23 | 3.59 ± 1.10hi | 4.21 ± 0.25 | 3.95 ± 0.27 | 4.07 ± 1.01ef |
| Means     | 3.99 ± 1.06bc | 3.82 ± 1.70c | 3.97 ± 1.62bc | 3.58 ± 1.43d | 4.43 ± 0.74a | 4.13 ± 0.88b |

TP, turmeric powder
The values are mean ±SD of three independent determinations
Means carrying different letters in rows or columns differed significantly
Another study depicted that TVBN increased at the storage period increased which is in line with the findings of the current study. This indicates that an increase in TVBN was suppressed by a dose of 0.5 kGy, with a significant difference observed between the irradiated and non-irradiated samples.\textsuperscript{[47]} [33] demonstrated that TVBN content significantly increased with the storage interval but radiation treatment supresses the formation of TVBN during storage period. Another study depicted that, TVBN increased at day 0 without the radiation treatment but due to irradiated samples, the TVBN value decreased during storage interval of day 40 as compared to non-irradiated samples.\textsuperscript{[30]}

\textbf{Sensory evaluation}

The mean scores for appearance, texture, taste, odour of the sensory evaluation, and the overall gamma irradiation tolerability of the meat of chicken treated with turmeric powder were determined. The sensory attributes decreased with the increase in gamma irradiation dose. They also decreased in aerobic packaging as the storage period increased, whereas sensory attributes increased in vacuum packaging as compared to aerobic packaging. The sensory score for appearance ranged from 7.4 ± 0.23 to 6.8 ± 0.25 and 7.8 ± 0.08 to 7.4 ± 0.22, texture 7.6 ± 0.31 to 6.6 ± 0.25 and 7.6 ± 0.08 to 6.8 ± 0.09, taste 7.4 ± 0.28 to 6.4 ± 0.24 and 7.6 ± 0.06 to 6.6 ± 0.41, odour 7.6 ± 0.01 to 6 ± 0.8 and 7.8 ± 0.2 to 6.2 ± 0.24, and overall acceptability 7.45 ± 0.32 to 6.45 ± 0.4 and 7.65 ± 0.08 to 6.65 ± 0.14 in aerobic and vacuum packaging, respectively, on day 0 of storage (Table 7). As the storage intervals increased, the sensory scores designed for the different sensory attributes decreased considerably. This was all a consequence of reduction in the sensory score during storage due to the increase in lipid oxidation levels caused by the irradiation, which results in lower acceptability, but on the whole the acceptability was within the acceptable range. The outcomes of the present study correlate with [63] and [64] who reported that with storage period, the taste of nuggets significantly decreased. There was a significant decrease in all the sensory scores with the advancement in the duration of storage. Furthermore, the acquired results are in agreement with those of [65] who found that the taste, texture, colour, and odour of camel meat reduced in vacuum packaging. The changes in the odour and colour of the irradiated meat are highly dependent on the packaging conditions. Another study stated the decrease in the sensory score during storage for e-beam-irradiated and vacuum-packaged grass carp surimi.\textsuperscript{[66]} Our results are in agreement with those of [1] who reported that in poultry meat treated with irradiation, on the 28th day of storage, the sensory score decreased gradually. [67] observed that turmeric showed significant effects on the control of fat oxidative rancidity of cara beef pastirma.

\textbf{Conclusion}

This study points out that using different doses of gamma irradiation significantly improved the quality of chicken meat with some insignificant changes in physicochemical properties during storage. The population of TAB in the chicken meat was decontaminated by using a dose of 2 kGy + TP in both aerobic and vacuum packaging on the 0, 7\textsuperscript{th}, and 14th days of storage, whereas complete decontamination of coliforms was achieved by different doses of gamma irradiation during storage, in both aerobic and vacuum packaging. A decreasing trend of the antioxidant profile was observed during storage, but it was higher in vacuum packaging compared to aerobic packaging. Similarly, the TVBN value was suppressed in vacuum packaging compared to aerobic packaging by using different doses of gamma irradiation all through the storage period. Negligible effect with respect to the irradiation dose was observed in the diverse sensory parameters, but during storage, a decreasing trend was observed. There is a synergistic effect caused by the low dose of gamma irradiation and vacuum packaging on the quality and shelf life of chicken meat.
| Storage period (days) | 0 | 7 | 14 |
|-----------------------|---|---|----|
| **Means**             | 7.3 ± 0.01 | 7.6 ± 0.10 | 6.83 ± 0.18 |
| **Texture**           | 7.22 ± 0.29 | 7.25 ± 0.16 | 6.63 ± 0.19 |
| **Taste**             | 6.6 ± 0.11 | 6.4 ± 0.01 | 6.2 ± 0.02 |
| **Odor**              | 6.4 ± 0.19 | 6.4 ± 0.01 | 6.2 ± 0.02 |
| **Overall Acceptability** | 6.93 ± 0.35 | 7.17 ± 0.48 | 6.5 ± 0.35 |

TP, turmeric powder

The values are mean ± SD of 10 independent determinations.
Acknowledgments

The authors are highly thankful to Government College University Faisalabad, Pakistan, and Nuclear Institute for Food and Agriculture, Peshawar, Pakistan, for providing financial support for this study.

Funding

The authors also extend their appreciation to the International Scientific Partnership Program (ISPP) at King Saud University for funding this research work through ISPP# 0023.

ORCID

Zaid Amjad  http://orcid.org/0000-0002-3971-2043
Fairhan Saeed  http://orcid.org/0000-0001-5340-4015

References

[1] Lewis, S. J.; Velasquez, A.; Cuppett, S. L. Effect of Electron Beam Irradiation on Poultry Meat Safety and Quality. Poult. Sci. 2002, 81(6), 896–903. DOI: 10.1093/ps/81.6.896.
[2] Pelicia, K.; Garcia, E. A.; Molino, A. B.; Santos, G. C.; Vieira Filho, J. A.; Santos, T. A.; Berto, D. A. Chicken Meat Submitted to Gamma Radiation and Packed with or without Oxygen. Rev Bra de Ciênc Aví. 2015, 17(2), 255–261. DOI: 10.1590/1516-635x1702255-262.
[3] Sajilata, M. G.; Singhal, R. S. Effect of Irradiation and Storage on the Antioxidative Activity of Cashew Nuts. Radi. Phy. Chem. 2006, 75(2), 297–300. DOI: 10.1016/j.radphymchem.2005.07.004.
[4] Yilmaz, I.; Geçgel, U. Effects of Gamma Irradiation on Trans Fatty Acid Composition in Ground Beef. Food Cont. 2007, 18(6), 635–638. DOI: 10.1016/j.foodcont.2006.02.009.
[5] Geçgel, U.; Gumus, T.; Tasan, M.; Daglioglu, O.; Arici, M. Determination of Fatty Acid Composition of γ-irradiated Hazelnuts, Walnuts, Almonds, and Pistachios. Radi. Phy. Chem. 2011, 80(4), 578–581. DOI: 10.1016/ j.radphymchem.2010.12.004.
[6] Baptista, R. F.; Teixeira, C. E.; Lemos, M.; Monteiro, M. L. G.; Vital, H. C.; Marsico, E. T.; Júnior, C. C.; Mano, S. B. Effect of High-Dose Irradiation on Quality Characteristics of Ready-To-Eat Broiler Breast Fillets Stored at Room Temperature. Poult. Sci. 2014, 93(10), 2651–2656. DOI: 10.3932/ps.2014-03980.
[7] Kuan, Y. H.; Bhat, R.; Patras, A.; Karim, A. Radiation Processing of Food Proteins–A Review on the Recent Developments. Trends Food Sci. Technol. 2013, 30(2), 105–120. DOI: 10.1016/j.tifs.2012.12.002.
[8] Arzina, H.; Zahid Hasan, M. D.; Al-Mahin, A.; Or-Rashi, H. Effect of Gamma Radiation and Low Temperature on Pathogenic Staphyloccocus Aureus Isolated from Pizza. Am. J. Food Technol. 2012, 7(4), 204–213. DOI: 10.3923/ajft.2012.204.213.
[9] Henriques, L. S. V.; Henry, F. D. C.; Barbosa, J. B.; Ladeira, S. A.; Pereira, S. M. D. F.; Antonio, I. M. D. S.; Teixeira, G. N.; Martins, M. L. L.; Vital, H. D. C.; Rodrigues, D. D. P.; et al. Elimination of Coliforms and Salmonella Sp. In Sheep Meat by Gamma Irradiation Treatment. Brazilian J. Microbiol. 2014, 44(4), 1147–1153. DOI: 10.1590/S1517-83822014005000003.
[10] Sarwar, U.; Iqtedar, M.; Naz, S. Reduction of Bioburden by Optimizing Gamma Dose for Enhancing Export Value of Pakistani Peaches. 2014.
[11] Mitsumoto, M.; Cassens, R. G.; Schaefer, D. M.; Arnold, R. N.; Scheller, K. K. Improvement of Color and Lipid Stability in Beef Longissimus with Dietary Vitamin E and Vitamin C Dip Treatment. J. Food Sci. 1991, 56(6), 1489–1492. DOI: 10.1111/j.1365-2621.1991.tb08622.x.
[12] Prashar, D.; Khokra, S. L.; Purohit, R.; Sharma, S. Curcumin: A Potential Bioactive Agent. Res. J. Pharm. Biol. Chem. Sci. 2011, 4(2), 44–52.
[13] Pfeiffer, E.; Höhle, S.; Solyom, A. M.; Metzler, M. Studies on the Stability of Turmeric Constituents. J. Food Eng. 2013, 56(2), 257–259. DOI: 10.1016/S0260-8774(02)00264-9.
[14] World Health Organization. Safety Evaluation of Certain Food Additives and Contaminants. USA: World Health Organization, 2014; Vol. 68.
[15] Osawa, T.; Sugiyama, Y.; Inayoshi, M.; Kawakishi, S. Antioxidative Activity of Tetrahydrocurcuminoids. Biosci., Biotechnol., Biochem. 1995, 59(9), 1609–1612. DOI: 10.1271/bbb.59.1609.
[16] Stankovic, I. C.; Chemical and Technical Assessment, 61st JECFA (CTA). FAO. 2004, I(8), 1–14.
[17] Lal, J.; Turmeric, Curcumin and Our Life: A Review. Bull. Environ. Pharmacol. Life Sci. 2012, 1(7), 11–17.
[18] Dorman, H. J. D.; Deans, S. G. Antimicrobial Agents from Plants: Antibacterial Activity of Plant Volatile Oils. J. Appl. Microbiol. 2000, 88(2), 308–316. DOI: 10.1046/j.1365-2672.2000.00969.x.
[21] Burt, S.; Essential Oils: Their Antibacterial Properties and Potential Applications in Foods—A Review. *Int. J. Food Microbiol.* 2004, 94(3), 223–253. DOI: 10.1016/j.ijfoodmicro.2004.03.022.

[22] Khan, R. U.; Naz, S.; Javdani, M.; Nikousefat, Z.; Selvaggi, M.; Tufarelli, V.; Laudadio, V. The Use of Turmeric (Curcuma Longa) in Poultry Feed. *World’s J. Poult. Sci.* 2012, 68(01), 97–103. DOI: 10.1017/S0043933912000104.

[23] Gahukar, R.; Evaluation of Plant-Derived Products against Pests and Diseases of Medicinal Plants: A Review. *Crop Prot.* 2012, 42, 202–209. DOI: 10.1016/j.cropro.2012.07.026.

[24] Krzywicki, K.: The Determination of Haem Pigments in Meat. *Meat Sci.* 1982, 7(1), 29–36. DOI: 10.1016/0309-1740(82)90095-X.

[25] Ahn, D. U.; Olson, D. G.; Jo, C.; Chen, X.; Wu, C.; Lee, J. I. Effect of Muscle Type, Packaging, and Irradiation on Lipid Oxidation, Volatile Production, and Color in Raw Pork Patties. *Meat Sci.* 1998, 49(1), 27–39.

[26] Koniecko, E. K. *Handbook for Meat Chemists.* Chapter 6. Wayne, NJ: Avery Publishing Group Inc., 1979; pp 68–69.

[27] Brand-Williams, W.; Cuvelier, M. E.; Berset, C. L. W. T. Use of a Free Radical Method to Evaluate Antioxidant Activity. *LWT-Food Sci. Technol.* 1995, 28(1), 25–30. DOI: 10.1016/S0043-6624(95)80008-5.

[28] Seneverathne, M.; Kim, S. H.; Siriparksin, N.; Ha, J. H.; Lee, K. W.; Jeon, Y. J. Antioxidant Potential of Ecklonia Cavaon Reactive Oxygen Species Scavenging, Metal Chelating, Reducing Power and Lipid Peroxidation Inhibition. *Food Sci. Technol. Int.* 2006, 12(1), 27–38. DOI: 10.1177/1082013206062422.

[29] Meilgaard, M.; Civille, G. V.; Carr, B. T. Overall Difference Tests: Does a Sensory Difference Exist between Samples. *Sens. Evalu. Techni.* 2007, 4, 63–104.

[30] Steel, R.; Torrie, J. Principles and Procedures of Statistics: A Biometrical Approach MCGraw-Hill Book Company Toronto. *Rev. Sci.* 2012, 13(6), 481.

[31] Montiel, R.; Cabeza, M. C.; Bravo, D.; Gayá, P.; Cambero, I.; Ordóñez, J. A.; Medina, M. A Comparison between E-Beam Irradiation and High-Pressure Treatment for Cold-Smoked Salmon Sanitation: Shelf-Life, Colour, Texture and Sensory Characteristics. *Food Bio. Technol.* 2013, 6(11), 3177–3185. DOI: 10.1007/s11947-012-0954-y.

[32] An, K. A.; Arshad, M. S.; Jo, Y.; Chung, N.; Kwon, J. H. E-Beam Irradiation for Improving the Microbiological Quality of Smoked Duck Meat with Minimum Effects on Physicochemical Properties during Storage. *J. Food Sci.* 2017, 82(4), 865–872. DOI: 10.1111/1750-3841.13671.

[33] Firstenberg-Eden, R.; Rowley, D. B.; Shattuck, G. E. Competitive Growth of Chicken Skin Microflora and Clostridium Botulinum Type E after an Irradiation Dose of 0.3 Mrad. *J. Food Prot.* 1983, 46(1), 12–15. DOI: 10.4315/0362-028X-46.1.12.

[34] Katta, S. R.; Rao, D. R.; Sunki, G. R.; Chawan, C. B. Effect of Gamma Irradiation of Whole Chicken Carcasses on Bacterial Loads and Fatty Acids. *Meat Sci.* 1991, 56(2), 371–372. DOI: 10.1011/j.1365-2621.1991.tb05283.x.

[35] Ayari, S.; Han, J.; Vu, K. D.; Lacroix, M. Effects of Gamma Radiation, Individually and in Combination with Bioactive Agents, on Microbiological and Physicochemical Properties of Ground Beef. *Food Cont.* 2016, 64, 173–180. DOI: 10.1016/j.foodcont.2015.12.034.

[36] Reddy, K. J.; Jayathilakan, K.; Pandey, M. C. Effect of Ionizing Radiation on the Protein and Lipid Quality Characteristics of Mutton Kheema Treated with Rice Bran Oil and Sunflower Oil. *Radia. Phy. Chem.* 2015, 117, 217–224. DOI: 10.1016/j.radphyschem.2015.09.002.

[37] Min, B.; Cordray, J. C.; Ahn, D. U. Effect of NaCl, Myoglobin, Fe (II), and Fe (III) on Lipid Oxidation of Raw and Cooked Chicken Breast and Beef Loin. *Animal Indu Rep.* 2011, 657(1), 2.

[38] Feng, X.; Moon, S. H.; Lee, H. Y.; Ahn, D. U. Effect of Irradiation on the Parameters that Influence Quality Characteristics of Raw Turkey Breast Meat. *Radi. Phy. Chem.* 2017, 130, 40–46. DOI: 10.1016/j.radphyschem.2016.07.015.

[39] Kim, H. J.; Kang, M.; Yong, H. I.; Bae, Y. S.; Jung, S.; Jo, C. Synergistic Effects of Electron-Beam Irradiation and Leek Extract on the Quality of Pork Jerky during Ambient Storage. *Asian-Australas. J. Anim. Sci.* 2013, 26(4), 596. DOI: 10.5713/ajas.2012.12580.

[40] Nam, K. C.; Ahn, D. U. Carbon Monoxide-Heme Pigment Is Responsible for the Pink Color in Irradiated Raw Turkey Breast Meat. *Meat Sci.* 2002, 60(1), 25–33.

[41] Naveena, B. M.; Muthukumar, M.; Sen, A. R.; Babji, Y.; Murthy, T. R. K. Improvement of Shelf-Life of Buffalo Meat Using Lactic Acid, Clove Oil and Vitamin C during Retail Display. *Meat Sci.* 2006, 74(2), 409–415. DOI: 10.1016/j.meatsci.2006.04.020.

[42] Ahn, D. U.; Kim, I. S.; Lee, E. J. Irradiation and Additive Combinations on the Pathogen Reduction and Quality of Poultry Meat. * Poult. Sci.* 2013, 92(2), 534–545. DOI: 10.3382/ps.2012-02722.

[43] Georganetis, D.; Blekas, G.; Katikou, P.; Ambrosiadis, I.; Fletouris, D. J. Effect of Rosemary Extract, Chitosan and α-tocopherol on Lipid Oxidation and Colour Stability during Frozen Storage of Beef Burgers. *Meat Sci.* 2007, 75(2), 256–264. DOI: 10.1016/j.meatsci.2006.07.018.

[44] De-Gonzalez, M. N.; Halley, B. S.; Bolesman, R. M.; Miller, R. M.; Rhee, K. S.; Keeton, J. T. Qualitative Effects of Fresh and Dried Plum Ingredients on Vacuum-Packaged, Sliced Hams. *Meat Sci.* 2009, 83(1), 74–81. DOI: 10.1016/j.meatsci.2009.04.002.

[45] Sommers, C. H.; Fan, X.; Handel, A. P.; Sokorai, K. B. Effect of Citric Acid on the Radiation Resistance of Listeria Monocytogenes and Frankfurter Quality Factors. *Meat Sci.* 2003, 63(3), 407–415.
Istrati, D.; Constantin, O.; Ionescu, A.; Vizireanu, C.; Dinica, R. Study of the Combined Effect of Spices and Marination on Beef Meat Vacuum Packaged. The Annals of the University of Dunarea De Jos of Galati. Fascicle VI. Food Technol. 2011, 35(2), 75.

Du, H.; Li, H. Antioxidant Effect of Cassia Essential Oil on Deep-Fried Beef during the Frying Process. Meat Sci. 2008, 78(4), 461–468. DOI: 10.1016/j.meatsci.2007.07.015.

Falowo, A. B.; Muchenje, V.; Hugo, A.; Ayiegoro, O. A.; Fayemi, P. O. Antioxidant Activities of Moringa Oleifera L. And Bidens Pilosa L. Leaf Extracts and Their Effects on Oxidative Stability of Ground Raw Beef during Refrigeration Storage. CyTA-J. Food. 2017, 15(2), 249–256. DOI: 10.1080/19476337.2016.1243587.

Babuskin, S.; Babu, P. A. S.; Sasikala, M.; Sabina, K.; Archana, G.; Sivarajan, M.; Sukumar, M. Antioxidant and Antimicrobial Effects of Spice Extracts on the Shelf Life Extension of Raw Chicken Meat. Int. J. Food Microbiol. 2014, 171, 32–40. DOI: 10.1016/j.ijfoodmicro.2013.11.011.

Sohail, M.; Anjum, F. M.; Khan, M. I.; Arshad, M. S.; Shahid, M. Enhancement of Lipid Stability of Broiler Breast Meat and Meat Products Fed on Alpha Lipoic Acid and Alpha Tocopherol Acetate Supplemented Feed. Lipids Health Dis. 2012, 11(1), 57. DOI: 10.1186/1476-511X-11-57.

Mielnik, M. B.; Aaby, K.; Skrede, G. Commercial Antioxidants Control Lipid Oxidation in Mechanically Deboned Turkey Meat. Meat Sci. 2003, 65(3), 1147–1155. DOI: 10.1016/S0309-1740(02)00345-5.

Fasseas, M. K.; Mountzouris, K. C.; Tarantilis, P. A.; Polissiou, M.; Zervas, G. Antioxidant Activity in Meat Treated with Oregano and Sage Essential Oils. Food Chem. 2008, 106(3), 1188–1194. DOI: 10.1016/j.foodchem.2007.07.060.

Sharma, H.; Mendiratta, S. K.; Agarwal, R. K.; Kumar, S.; Soni, A. Evaluation of Anti-Oxidant and Anti-Microbial Activity of Various Essential Oils in Fresh Chicken Sausages. J. Food Sci. Technol. 2017, 54(2), 279–292. DOI: 10.1007/s13197-016-2461-z.

Sharma, H.; Mendiratta, S. K.; Agrawal, R. K.; Gurunathan, K.; Kumar, S.; Singh, T. P. Use of Various Essential Oils as Bio Preservatives and Their Effect on the Quality of Vacuum Packaged Fresh Chicken Sausages under Frozen Conditions. LWT-Food Sci. Technol. 2017, 81, 118–127. DOI: 10.1016/j.lwt.2017.03.048.

Qwele, K.; Hugo, A.; Oyedemi, S. O.; Moyo, B.; Masika, P. J.; Muchenje, V. Chemical Composition, Fatty Acid Content and Antioxidant Potential of Meat from Goats Supplemented with Moringa (Moringa Oleifera) Leaves, Sunflower Cake and Grass Hay. Meat Sci. 2013, 93(3), 455–462. DOI: 10.1016/j.meatsci.2012.11.009.

Al-Bachir, M.; Zeinou, R. Effect of Gamma Irradiation on Microbial Load and Quality Characteristics of Minced Camel Meat. Meat Sci. 2009, 82(1), 119–124. DOI: 10.1016/j.meatsci.2008.12.012.

Biswas, S.; Chakraborty, A.; Sarkar, S. Comparison among the Qualities of Patties Prepared from Chicken Broiler, Spent Hen and Duck Meats. J. Poult. Sci. 2006, 43(2), 180–186. DOI: 10.2141/jpsa.43.180.

Kumar, D.; Tanwar, V. K. Utilization of Clove Powder as Phytopreservative for Chicken Nuggets Preparation. J. Stored Prod. Postharvest. Res. 2011, 2(1), 11–14.

Nam, K. C.; Ahn, D. U. Combination of Aerobic and Vacuum Packaging to Control Lipid Oxidation and Off-Odor Volatiles of Irradiated Raw Turkey Breast. Meat Sci. 2003, 63(3), 389–395.

Zhang, H. F.; Wang, W.; Zhang, S. F.; Wang, H. Y.; Ye, Q. F. Influence of 10-Mev E-Beam Irradiation and Vacuum Packaging on the Shelf-Life of Grass Carp Surimi. Food Bioprocess. Technol. 2016, 9(5), 830–838. DOI: 10.1007/s11947-016-1675-4.

Maurya, P.; Borpuzari, R. N.; Nath, D. R.; Nath, N. C. Effect of Starter Culture and Turmeric on Physico-Chemical Quality of Carabeef Pastirma. J. Food Sci. Technol. 2010, 47(1), 89–93. DOI: 10.1007/s13197-010-0021-5.