Dose Mapping of Frozen Chickens Using 10 MeV Electrons

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Abstract
Irradiation of locally produced and imported food products was approved in the Kingdom of Saudi Arabia (KSA) in 2002. SureBeam Middle East (SME) has constructed the first food irradiation facility in Riyadh, KSA and will begin production irradiation in Q4 of 2005. In an effort to find efficient and cost effective means of irradiating frozen whole body chickens, SME has sponsored dose mapping studies using a 10 MeV dual electron beam processing system at the Electron Beam Food Research Facility at Texas A&M University (TAMU). Frozen chickens available to consumers in KSA range in size from nominal 600 grams to 1400 grams. Poultry processors typically provide retailers with equal weight birds packaged ten to a box (2 rows of 5 birds). Areal densities of the packages increase with the weight of the birds. For this study equivalent size birds were grown and processed by the Department of Poultry Science at TAMU and packaged in the same manner as in KSA. The goal of this investigation was to determine which size birds could be processed at a minimum dose of 2.5 kGy and not have the maximum dose exceed the level where negative sensory effects become noticeable. The minimum dose was chosen to reduce the population of any salmonella contamination by more than a factor of 1000. A description of the experimental set up and results of the dose mapping of frozen whole body chickens are reported herein, as are the results which indicate that electron beam processing of frozen chickens up to approximately 1000 grams can be readily accomplished and that processing of chickens up to 1400 grams may be possible.

Keywords : Irradiation, Salmonella, Electron Beam

1. Introduction

In 2002 irradiation of locally produced and imported food products was approved in the Kingdom of Saudi Arabia. The first electron beam facility for food irradiation in Saudi Arabia, constructed by SureBeam Middle East in Riyadh, is scheduled to begin operation in the fourth quarter of 2005.

One of the key goals of this irradiation initiative is to reduce the number of cases of food-borne illness resulting from the various strains of Salmonella bacteria. Chicken products have been identified as a major source of Salmonella contamination and have been targeted for irradiation.

Frozen whole body chicken is a common offering found in supermarkets and other retail food markets in Saudi Arabia. The chickens offered to consumers range in weight from approximately 600 grams to 1400 grams. Processor or wholesalers in Saudi Arabia typically package the chickens in corrugated cardboard boxes, 2 rows of 5 chickens per box in one layer, as shown in Figure 1.

Fig. 1 Box of Frozen Whole Body Chicken

Boxes range in size from 53 cm x 34 cm x 9.5 cm to 61 cm x 41 cm x 10 cm, depending on the size of the birds. Therefore, the average areal density (defined as the product of physical depth and density) of the boxed chickens ranged from approximately 3.2 gm/cm^2 to approximately 6.0 gm/cm^2.

When the particular strain of Salmonella bacteria is indeterminate, then it is customary to assume a D_{10} value of 0.8 kGy and set the minimum required dose (which also accounts for measurement uncertainties) at 2.5 kGy. This dose, therefore, will reduce any Salmonella population by at least a factor of 1000. Sensory effects of the irradiation process on frozen chicken can be discerned at approximately 7 kGy[i]. This implies that for electron beam processing to be effective, then the max:min ratio must be less than 2.8.

The goal of this investigation is to determine which size frozen chickens can be irradiated using 10 MeV electrons and have a max:min ratio of substantially less than 2.8.

2. Materials and Methods

Electron Beam System :

The Electron Beam Food Research Facility (EBFRF) at Texas A&M University maintains both research and development capabilities as well as production irradiation capability using both electron beams and x-rays.

For the dose mapping investigation, the dual 10 MeV electron beam system at EBFRF was employed. The electron beam systems are positioned with their axes vertical, one pointing down (tower linac) and the other pointing up (pit linac). Each linac has a nominal 61 cm wide Titanium foil window at the exit flange of the scan horn. A process table is positioned between the exit windows of the two linacs and carries product at a precisely controlled rate through each beam.

The beam parameters for these experiments are summarized in Table 1. The distance from the exit window of the pit linac to the bottom of product is approximately 30 centimeters. This distance is approximately 71 centimeters for the tower linac. Consequently, there are differences in several beam parameters to ensure that there is both good surface dose uniformity, as well as approximate symmetry in the dose profile provided by the two beams.

Table 1. Summary of Beam Parameters

Parameter	Tower	Pit
Approx. Energy (MeV)	10.0	10.0
Avg. Beam Current (ma)	1.42	1.31
Avg. Beam Power (kW)	14.2	13.1
Scan Magnet Current (A)	78.5	100.8
Approx. Scan Width (cm)	75	70
Modulator Rep Rate (Hz)	240	290
Pulses per Scan	64	32

With these beam parameters, the process table speed required to produce a 2.5 kGy front surface dose is calculated to be 13.63 cm/s for the tower and 13.47 cm/s for the pit according to the following formula.

$$D_{fs}(kGy) = 1.8x10^{6}\ I(amps) / [v(cm/s)\ W(cm)] \qquad (1)$$

However, because of temporary limits in the control software that constrained the maximum allowable speed of the process table, it was operated at 9.14 cm/s. At this speed the front surface dose is predicted to be 3.73 kGy for the tower and 3.68 kGy for the pit. The important parameter for this study- max:min ratio- remains constant for a specific product irradiated over a wide range of doses.

Source of Chickens :

Although it was first contemplated that frozen birds would be imported to the United States from Saudi Arabia under special license with the United States Department of Homeland Security, it was later determined that equivalent specimens could be readily obtained at Texas A&M University (TAMU). The Department of Poultry Science at TAMU raised four groups of birds for this study that when processed and frozen, the specimens nominally weighed 600, 800, 1200 or 1400 grams each.

The cardboard boxes (shown in Figure 2) in which Saudi poultry producers package their products were shipped from Saudi Arabia to EBFRF and used in this experiment.

Fig. 2 Example boxes of frozen chickens

Preparation of Specimens for Dose Mapping **:**

The frozen chickens were split in two planes to allow for placement of dosimeter pellets in the cavity and in the bulk meat of the birds. For each size three specimens were split vertically and one specimen was split horizontally.

Approximately four millimeter diameter by two millimeter deep holes were "drilled" into the frozen chickens for placement of alanine dosimeter pellets. For the vertically split birds dosimeters were placed on the outer surface as well as on the cavity surface as shown in Figure 3a. For the horizontally split birds dosimeters were placed in the bulk of the meat and in the cavity as shown in Figure 3b.

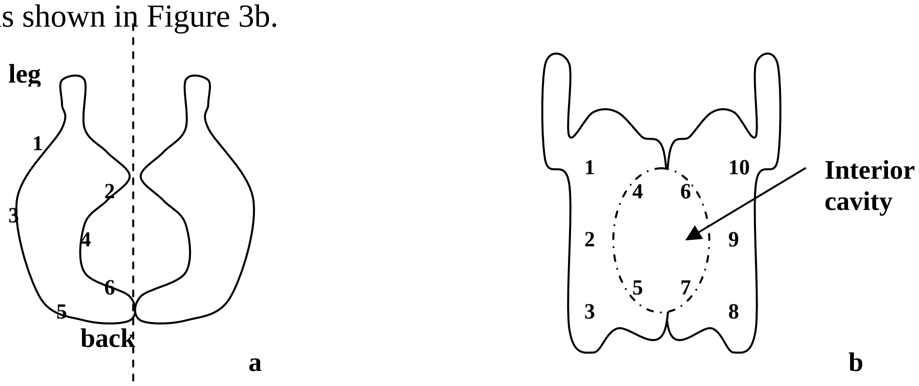

Fig. 3 (a) The frozen chickens were split vertically; dosimeters were placed on the exterior regions (1,3,5), and in the interior cavity (2,4,6); (b) one chicken was cut in half horizontally, and dosimeters were implanted in the meaty regions (1,2,3,8,9,10), and in the interior cavity (4,5,6,7).

After dosimeters were fixed in their positions, the chicken halves were held together using a latex band. Each bird was also weighed using an analytical balance.

The dosimeter laden specimens were placed along with unprepared specimens into a cardboard box. The positioning of the specimens within the box is shown schematically in Figure 4.

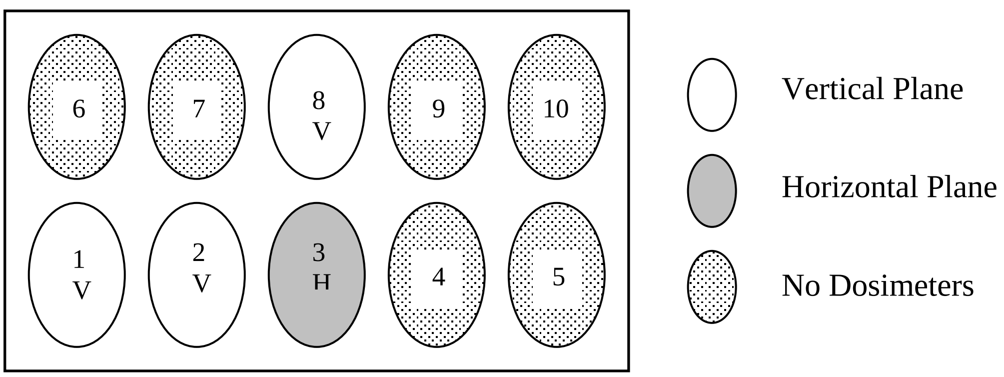

Fig. 4 Position of Specimens within Box

3. Results

Following the irradiation process the dosimeter pellets were retrieved from the specimens and read using a Bruker ESR spectrometer. The measurements are tabulated below.

Table 2. Summary of Vertical Dosimeter Data (Doses in kGy)

Position	600g	800g	1200g	1400g
1-1	3.58	5.99	5.42	5.55
1-2	4.65	5.07	4.81	5.52
1-3	7.96	3.74	3.93	5.24
1-4	5.05	4.31	3.14	4.70
1-5	3.81	5.22	5.62	8.83
1-6	5.16	5.02	4.46	7.76
2-1	3.46	3.69	3.86	3.69
2-2	7.25	3.47	3.81	3.91
2-3	7.85	7.45	9.38	4.46
2-4	6.24	4.47	4.55	5.66
2-5	4.26	4.14	3.79	3.74
2-6	7.23	4.39	3.79	3.97
8-1	3.55	6.05	3.97	3.67
8-2	4.74	4.60	3.91	3.90
8-3	4.33	3.58	3.71	4.82
8-4	5.82	5.25	3.46	4.09
8-5	4.69	4.94	4.32	3.54
8-6	4.61	4.61	3.97	4.36

Table 3. Summary of Horizontal Dosimeter Data (Doses in kGy)

Position	600g	800g	1200g	1400g
3-1	6.61	4.46	5.00	2.23
3-2	6.36	5.41	3.56	2.64
3-3	5.15	5.72	5.07	3.03
3-4	6.60	5.19	6.68	4.26
3-5	7.70	6.18	7.14	3.96
3-6	7.22	3.80	4.30	4.49
3-7	7.17	5.88	5.36	4.63
3-8	6.15	4.83	3.95	5.24
3-9	6.15	3.82	4.10	4.34
3-10	6.08	3.63	4.22	2.72

Table 4. Summary of Weight Data (in grams)

Position	600g	800g	1200g	1400g
1	570	824	1260	1433
2	560	869	1120	1405
3	Not recorded	828	1196	1648
4	n/a	n/a	n/a	n/a
5	n/a	n/a	n/a	n/a
6	n/a	n/a	n/a	n/a
7	n/a	n/a	n/a	n/a
8	540	756	1280	1474
9	n/a	n/a	n/a	n/a
10	n/a	n/a	n/a	n/a
Average	557	819	1214	1490

4. Discussion

Given well-established data for double-sided electron beam irradiation at 10 MeV[ii], as shown in Figure 5, it can be predicted that for the range of sizes of frozen chickens with areal densities of 9.0 g/cm^2 or less processing of these birds should result in acceptable max:min ratios that insure product safety without compromise to important sensory characteristics of the food product.

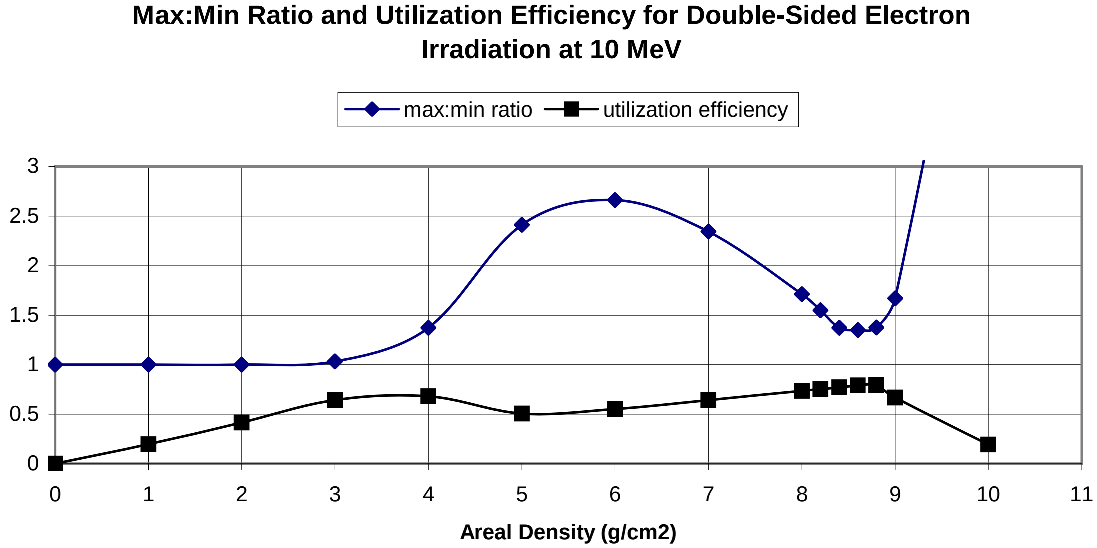

Fig. 6 Max:Min ratios for varying areal densities

As noted earlier the average areal density for the boxes of chickens surveyed in KSA ranged from 3.2 g/cm^2 to 6.0 g/cm^2. However, there is considerable empty space in the boxes because of the generic size of the packages combined with the irregular shape of the chickens.

The max:min ratios for the data collected is summarized in Table 5.

Table 5. Summary of Min: Max Ratios

Size	Minimum (kGy)	Maximum (kGy)	Max:min Ratio
600g	3.46	7.96	**2.3**
800g	3.47	7.45	**2.2**
1200g	3.14	9.38	**3.0**
1400g	2.23	8.83	**4.0**

For all specimens the maximum dose measured occurs on the outer surface of the chicken in a region where the areal density of the meat (approximately at the equatorial plane) is very small. In the regions where the surface was likely exposed to only one beam (i.e. the areal density of those cross sections exceeded 5 $g/cm^{2)}$ the values are consistent with the prediction of ~ 3.7 kGy based on machine operating parameters.

The results for the 600 and 800 gram chickens indicate that the maximum areal density of the chickens was in the range of 5 to 7 g/cm^2. The dose measured in the meaty part of the birds indicates that the minimum dose is achieved throughout the entire volume.

The results for the 1200 gram chickens indicate this size is marginal for electron beam processing. The minimum dose of 3.14 occurred in the cavity of one of the chickens mapped, implying that the areal density in at least one region of that bird was marginally greater than 9 g/cm^2.or perhaps some shadowing from an adjacent bird occurred in that region. The dosimeters in the meaty portion of the specimen all measured doses that exceeded the minimum.

The max:min ratio for the 1400 gram chickens reflects the fact that the areal density of the meaty portion of the specimen exceeds 9.0 g/cm^2. When the maximum and minimum doses on the surfaces of the specimens are compared, the ratio is 2.5. The fact that the minimum dose was not achieved within the bulk of the meat may not be a problem, because (unlike an organism such as the trichina worm) salmonella is a surface contaminant and does not reside within the muscle tissue.

In conclusion, this dose mapping investigation has demonstrated that a range of frozen chicken products can be processed using double-sided 10 MeV electron beams. The data clearly supports processing up to 800 gram chickens and can be conservatively extrapolated to 1000 gram chickens. Further investigation is required to determine whether 1200 and 1400 gram chickens can also be processed in this manner.

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[i] Private conversation with Dr. Al Khatani of King Saud University, Riyadh, KSA in March 2005

[ii] Miller, R.B. 2005. Electronic Irradiation of Foods, Springer, New York.