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Assessment of Dose-Dependent Effect of Linear Accelerator Electron-Beam Irradiation on Bacterial Load of Selected Animal Hides and Skins: Implications for Preservation

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ABSTRACT

The preservation of freshly flayed animal hides and skins is necessary to prevent microbial deterioration and maintain their suitability for subsequent leather processing. This study assessed the effect of electron-beam irradiation generated by a medical linear accelerator on the bacterial load of selected animal skins. Goat, cow and sheep skins were exposed to absorbed doses of 5, 10, 20, 30 and 50 Gy, while untreated samples served as controls. Bacterial load was determined using a viable plate-count method, with 30–300 CFU/mL considered the acceptable counting range. The untreated goat and cow samples were recorded as too numerous to count (TNC), whereas untreated sheep skin had a bacterial load of 112 CFU/mL. Irradiation produced a progressive reduction in bacterial load. Goat skin decreased from 159 CFU/mL at 10 Gy to 87 CFU/mL at 50 Gy, while cow skin decreased from 258 CFU/mL at 30 Gy to 104 CFU/mL at 50 Gy. Sheep skin demonstrated the clearest measurable response, decreasing from 112 CFU/mL in the untreated sample to 31 CFU/mL at 50 Gy, representing a 72.3% reduction. The findings indicate that electron-beam irradiation can reduce bacterial contamination of animal skins at Gy-range absorbed doses, although the response varies among animal species. Further evaluation of physico-mechanical, thermal, chemical and structural properties is required before an optimum preservation dose can be established.

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INTRODUCTION

Hides and skins are important raw materials for leather production and represent valuable by-products of the meat industry (Wu et al., 2017). Immediately after flaying, however, the high moisture and nutrient content of raw animal skin provide favourable conditions for microbial proliferation and enzymatic deterioration. Uncontrolled microbial activity can adversely affect the collagenous matrix and ultimately reduce the quality of leather produced from the raw material (Praveen et al., 2025).

Conventional preservation of hides and skins commonly involves salting, drying or the use of chemical preservatives. Although these approaches are effective to varying degrees, salt curing introduces substantial quantities of sodium chloride into tannery wastewater. The environmental implications associated with chloride and total dissolved solids have encouraged investigations into alternative preservation technologies. A Nigerian study by Akawu et al. (2023) similarly identified environmental concerns associated with conventional salt curing and investigated gamma

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irradiation as an alternative method for preserving goat skin.

Ionizing radiation is increasingly investigated as a non-thermal method of microbial control. Its antimicrobial action is associated primarily with damage to microbial DNA and other cellular components, resulting in loss of reproductive capacity. Recent electron-beam research has demonstrated substantial reductions in bacterial populations in biological materials. For example, Yang et al. (2022) reported that low-energy electron-beam irradiation significantly reduced bacterial loads in vacuum-packaged beef steaks.

More recently, Wen et al. (2024) demonstrated that electron-beam irradiation produced substantial microbial reduction in raw goat milk, with a 2-kGy treatment producing approximately a six-log reduction in total microbial count. Their study also showed that irradiation dose could influence protein structural characteristics, demonstrating the importance of evaluating both microbial and material responses when developing irradiation-based preservation systems.

The application of radiation to hides and skins has also been investigated directly. Gaidau et al. (2021) evaluated gamma irradiation of bovine hides at 25, 35 and 50 kGy and assessed microbiological load alongside collagen-related and physico-chemical properties. Their findings demonstrated that irradiation could substantially reduce microbial contamination while producing relatively limited structural changes at the selected preservation dose. Chebwogen et al. (2023) similarly investigated gamma irradiation for microbial control in hides. They reported substantial microbial reductions following 10 kGy irradiation and sterility at 40 and 50 kGy. Importantly, however, these investigations employed doses in the kilogray (kGy) range, which are considerably higher than the 5–50 Gy absorbed doses investigated in the present study.

This difference in dose range is important. One Gy represents one joule of absorbed radiation energy per kilogram of material, whereas 1 kGy equals 1,000 Gy. Consequently, 50 Gy is only 0.05 kGy. The present investigation therefore explores a substantially lower absorbed-dose range than many previous radiation-preservation studies.

Furthermore, most published hide-preservation studies have focused on gamma irradiation rather than electron beams generated by medical linear accelerators. The use of a linear accelerator offers the possibility of controlled, on-demand electron-beam irradiation without relying on a continuously radioactive source. Recent electron-beam studies in food and agricultural materials have demonstrated the capacity of electron beams to reduce microbial contamination while allowing investigation of dose-dependent quality changes.

The Nigerian context is particularly relevant because previous research has already demonstrated interest in irradiation-based preservation of animal skins. Akawu et al. (2023) investigated gamma irradiation as an alternative to salt curing in Sokoto Red goat skin and reported measurable effects on the resulting leather's physico-mechanical properties. The present study extends this line of investigation by examining goat, cow and sheep skins exposed to Gy-range electron-beam irradiation from a linear accelerator. The objective of the present study was therefore to assess the effect of increasing electron-beam irradiation dose on bacterial load in selected animal skins and to evaluate the potential implication of the observed microbial reduction for preservation technology.

MATERIALS AND METHODS

Experimental Design

An experimental design was adopted to investigate the response of goat, cow and sheep skins to increasing absorbed doses of electron-beam radiation. The irradiation treatments consisted of an untreated control and five absorbed doses: 5, 10, 20, 30 and 50 Gy.

Sample Preparation

Freshly flayed goat, cow and sheep skins were prepared under appropriate laboratory conditions. The samples were washed and trimmed into relatively uniform pieces of size

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10x10 cm^2 and handled aseptically before irradiation and microbiological analysis.

Electron-Beam Irradiation

The samples were irradiated using a medical linear accelerator. The radiation was delivered as an electron beam with an energy of 6 MeV. The absorbed doses investigated were 5, 10, 20, 30 and 50 Gy. Untreated samples received 0 Gy and served as controls. The use of Gy-range doses was deliberate because the objective was to investigate whether comparatively low absorbed doses could achieve useful microbial reduction without necessarily exposing the collagen matrix to the much higher doses commonly used in industrial radiation sterilization studies.

Microbiological Analysis

Bacterial load was determined using a viable plate-count procedure. Samples were processed aseptically, serially diluted and inoculated onto appropriate microbiological culture media. Following incubation under the specified laboratory conditions, visible bacterial colonies were enumerated. Plates containing between 30 and 300 colonies were considered suitable for enumeration. Results exceeding the upper counting limit were recorded as TNC (Too Numerous to Count). The bacterial load was expressed as CFU/mL.

Calculation of Percentage Reduction

Where both control and irradiated samples produced numerical counts within the countable range, percentage reduction was calculated as:

$$\textbf{Percentage reduction} = \frac{N_0 - N_D}{N_0} \times 100$$

Where:

1. N_0= initial or untreated value (before treatment/irradiation)
2. N_D = value after treatment at dose D
3. $N_0 - N_D$ = the amount by which the value has decreased
4. Dividing by N_0 gives the reduction relative to the original value.
5. Multiplying by 100 converts it to a percentage.

Because the untreated goat and cow samples were TNC, exact percentage reductions relative to their untreated controls could not be calculated from the available data.

RESULTS

Bacterial Load of Irradiated Animal Skins

The bacterial-load results obtained following electron-beam irradiation are presented in Table 1.

Table 1. Bacterial load of selected animal skins following electron-beam irradiation.

Irradiation dose	Goat skin (CFU/mL)	Cow skin (CFU/mL)	Sheep skin (CFU/mL)
Untreated (0 Gy)	TNC	TNC	112
5 Gy	TNC	TNC	84
10 Gy	159	TNC	67
20 Gy	121	TNC	55
30 Gy	103	258	49
50 Gy	87	104	31

Note. TNC = Too Numerous to Count; acceptable enumeration range = 30–300 CFU/mL.

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Figure 1. Representative bacterial culture plates of cow, sheep and goat skin samples following exposure to 0, 5, 10, 20, 30 and 50 Gy electron-beam irradiation using a linear accelerator. The plates provide qualitative visual evidence of changes in microbial growth with increasing irradiation dose.

Goat Skin

The goat-skin plates show visible bacterial growth in the untreated and lower-dose treatments, with a progressive reduction in the apparent density of colonies as the irradiation dose increased. The untreated and 5 Gy samples were recorded as TNC, indicating that their bacterial populations exceeded the upper limit of the selected counting range. At 10 Gy, the bacterial load became countable at 159 CFU/mL and subsequently declined to 121, 103 and 87 CFU/mL at 20, 30 and 50 Gy, respectively. The culture plates in Figure 1 provide visual support for this progressive reduction in microbial growth. Between 10 and 50 Gy, the measurable bacterial load decreased by approximately 45.3%.

Cow Skin

The cow-skin plates also demonstrate differences in visible microbial growth between irradiation treatments. The untreated, 5, 10 and 20 Gy samples were recorded as TNC, indicating bacterial populations above the upper limit of the selected counting range. At 30 Gy, the bacterial population became countable at 258 CFU/mL. A further increase to 50 Gy resulted in a reduction to 104 CFU/mL, representing an approximate 59.7% reduction between the two measurable dose levels. The comparatively delayed appearance of countable bacterial populations in the cow samples may reflect differences in initial microbial burden or microbial response; however, the TNC results prevent precise estimation of the magnitude of the lower-dose reductions.

Sheep Skin

The sheep-skin plates showed measurable bacterial growth at all investigated doses. The numerical results demonstrate a continuous decrease in bacterial load from 112 CFU/mL in the untreated sample to 84, 67, 55, 49 and 31 CFU/mL at 5, 10, 20, 30 and 50 Gy, respectively. The photographic evidence in Figure 1 is consistent with the progressive reduction in visible colony density observed with increasing irradiation dose. At 50 Gy, the bacterial load had

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decreased by approximately 72.3% relative to the untreated sheep sample, indicating the clearest measurable dose-response pattern among the three animal species.

DISCUSSION OF FINDINGS

Visual and Quantitative Evidence of Radiation-Induced Microbial Reduction

The combination of the quantitative bacterial-load results (Table 1) and the culture-plate observations (Figure 1) provides complementary evidence of the antimicrobial effect of electron-beam irradiation. The culture plates demonstrate visible differences in microbial growth across the irradiation treatments, while the numerical plate counts provide quantitative measurements of these differences. In general, increased irradiation dose was associated with reduced bacterial growth, although the response varied among goat, cow and sheep skins.

The progressive reduction in visible colony development with increasing irradiation dose is consistent with the established antimicrobial action of ionizing radiation. Electron beams can produce direct molecular damage to microbial DNA and indirect damage through radiolytic processes, thereby reducing microbial viability and reproductive capacity. Recent electron-beam studies have similarly demonstrated dose-dependent microbial reduction in biological materials, although the doses used in those studies were generally higher than those investigated in the present work (Yang et al., 2022; Wen et al., 2024).

The visual differences among the plates are particularly important when considered alongside the numerical data. For example, the sheep samples show a progressive decline in bacterial load from 112 CFU/mL in the untreated sample to 31 CFU/mL at 50 Gy. This corresponds to a 72.3% reduction and is supported qualitatively by the lower apparent colony density at the higher irradiation doses. Similarly, the goat samples became countable from 10 Gy onward, while the cow samples remained TNC until 30 Gy. These differences indicate that the microbial response to irradiation may vary according to animal species and initial microbial burden.

Species-Dependent Response to Irradiation

The three animal skins displayed different apparent responses to increasing irradiation dose. Sheep skin showed measurable bacterial counts at all doses and the clearest progressive decline. Goat skin became countable from 10 Gy, whereas cow skin remained TNC until 30 Gy. Such differences may be related to variations in initial contamination, moisture content, skin thickness, surface characteristics and the composition of the resident microbial population. These factors should be considered when developing species-specific irradiation preservation protocols.

Implications for Preservation

The observed bacterial reduction indicates potential for Gy-range electron-beam irradiation as a preservation intervention.

CONCLUSION

Electron-beam irradiation produced a general dose-dependent reduction in bacterial load in the investigated goat, cow and sheep skins. The strongest measurable response occurred in sheep skin, where bacterial load decreased from 112 CFU/mL in the untreated sample to 31 CFU/mL at 50 Gy. Goat skin decreased from 159 CFU/mL at 10 Gy to 87 CFU/mL at 50 Gy, while cow skin decreased from 258 CFU/mL at 30 Gy to 104 CFU/mL at 50 Gy. The culture-plate photograph provides qualitative support for the numerical findings.

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