Ultraviolet Radiation—An Effective Bactericide for Fresh Meat

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ABSTRACT

Ultraviolet radiation (UV), with principal energy at a wavelength of 253.7 nm, was effective in destroying bacteria on the surface of fresh meat. A radiation dose of 150 mW s/cm² (275 uW/cm² for 550 s) reduced bacteria on smooth surface meat (beef plate) about 2 log cycles (99% "kill"). Further increases in dose level to 500 mW s/cm² (275 uW/cm² for 1800 s) reduced the bacteria level one additional log cycle. Since UV radiation does not penetrate most opaque materials, it was less effective on rough surface cuts of meat such as round steak because bacteria were partly shielded from the radiation. Unlike gamma (ionizing) radiation, UV had no deleterious effects on color (Hunter "a", redness) or general appearance. UV treatment chambers could be easily installed in new or existing meat processing facilities at relatively low cost. Experimental results indicate that UV irradiation of meat carcases could effectively increase the lag phase of bacteria multiplication until adequate cooling had occurred.

Putrefaction—spoilage—of fresh meat can occur in a few hours as a result of the action of spoilage bacteria. Immediately after slaughter, the interior muscle is relatively sterile with the number of bacteria being on the order of 0.1 to 0.01/g (6), but under ideal conditions (30 to 40°C) the bacteria can multiply at the rate of 2³ per h (9). A much higher bacteria count (3 X 10³ to 1 X 10⁶/cm²) is on the surfaces of carcases because of contamination from worker's hands and tools and occasional gut spill (15).

The principal method for control of bacteria on meat is refrigeration. Hanna et al. (7) showed that numbers of aerobic bacteria increased very little when meat was held at −20°C but at 30°C, the increase was 3 log cycles in 12 h. Other methods that have been used are washing/sanitizing systems (1), spray chilling with mild acid solutions (5,16) and ionizing (gamma) radiation (10). Despite the proven effectiveness, Coon et al. (4) point out that ionizing radiation suffers from a negative public image because consumers fear possible carcinogenic effects. Gamma radiation also causes meat to darken and have a "warmed-over" flavor (18).

Ultraviolet (UV) radiation (wavelengths of 220 to 300 nm), like gamma radiation, has germicidal properties and destroys bacteria by degradation of the cell walls (2). Fortunately, the predominant mercury emission line is at 253.7 nm and accounts for about 90% of the energy radiated by a low pressure, mercury vapor discharge lamp equipped with a special lime glass or quartz envelope. Bachmann (2) showed incident energy levels of 253.7 nm UV necessary to inhibit colony formations in 90% of the organisms to range from 1100 mW s/cm² for Bacillus megatherium to 19800 mW s/cm² for Sarcina lutea.

The use of UV to reduce bacterial numbers in foods has received limited investigation. Kissinger and Willits (13) were successful in reducing microorganisms in flowing maple sap by 99% using UV. Treatment with high intensity UV extended the shelf-life of fresh mackerel fish by 7 d over the untreated (8). Kaess and Weideman (11,12) were able to increase the time for beef slices to reach a bacteria level of 10⁸/cm² from 12 d for controls to over 20 d for irradiated samples using continuous UV radiation of 0.2 to 24 uW/cm². During more recent times, high intensity UV-C lamps have become available (3) and enhanced the potential of destroying surface bacteria on foods by UV irradiation. These high intensity lamps are being used extensively in commercial water sterilization units².

The objectives of research reported herein were to determine (a) the effectiveness of UV in reducing bacteria on fresh meat, (b) the UV dose required and (c) the effect of UV treatment on the color and general appearance of fresh meat.

MATERIALS AND METHODS

UV Equipment

Several germicidal lamps (Sylvania Type G30T8, intensity of 80 W/cm² at 253.7 nm at 1 m and GE Type G36T6, intensity of 150 uW/cm²)² were obtained from the manufacturers. The lamps were mounted at the focal point of a parabolic polished...
aluminum reflector which gave an effective increase in intensity of approximately 100%. A sample holding tray was mounted 1 m from the lamp. Actual intensity measurements of the radiation were made with a Spectronic Type DM-254N ultraviolet radiometer before and after treating the samples. The manufacturer's literature stated that the radiometer was calibrated to ±5% accuracy to NBS standards by pyroelectric methods.

**Inoculated agar plates**

A preliminary experiment was conducted to determine the survival ratio of bacteria commonly found on meat—mostly *Pseudomonas*, *Micrococcus*, and *Staphylococcus* species. The bacterial cultures were obtained by swabbing spoiled meat known to have high counts of bacteria. The swabs were subsequently agitated in tryptic soy broth which was allowed to incubate for approximately 24 h at 25°C. Pour plates of Trypticase Soy Agar were prepared with at least four dilution levels of bacterial cultures. The plates were subjected to various doses of UV radiation and incubated at 25°C for 48 h before counting the bacteria. On all bacterial determinations, no attempt was made to identify species—counts were made of total colony forming units (CFU).

**UV Treated beef round samples**

Beef round steaks, approximately 1-cm thick were purchased at local supermarkets, cut into uniform pieces approximately 90 mm in diameter and placed in sterile petri dishes. The upper exposed surface of each piece of meat was inoculated with bacterial cultures (tryptic soy broth) prepared as described above. An atomizer spray bottle held at approximately 30 cm from the samples was used to uniformly distribute the bacteria on the meat. Samples were allowed to dry for 1 d at 0°C and then exposed to UV with dose levels of 0, 75, 190, 385 and 575 mW sec/cm². The meat was then sampled for bacteria using sterile Calgiswab swabs on 10 cm² of surface area. The bacteria were incubated on agar pour plates 48 h at 25°C before being counted.

**Bacteria Survival ratio on beef plate meat**

Beef plates from chilled carcasses (48-h post mortem) were obtained from a local slaughter plant. Beef plate was chosen since it has a smooth surface covered with connective tissue (epimysium). This type of structure is typical of the exterior of a beef or lamb carcass. The plate meat was prepared and inoculated with bacteria as described above. Samples were exposed to UV radiation doses of 0 to 500 mW s/cm². The wide range was used to obtain a survival ratio curve. Koller (14) gave the relationship of survival ratio, \( N/N_0 \), to intensity of ultraviolet radiation as

\[
\frac{N}{N_0} = e^{kit}
\]

where \( N \) = number of bacteria after irradiation for time, \( t \) (sec)
\( N_0 \) = initial number of bacteria
\( k \) = constant depending on microbial strain and environmental condition
\( i \) = intensity of UV radiation

If \( ki \) is held constant, \( \ln \frac{N}{N_0} \) and \( t \) are expected to have a linear relationship.

**Storage study of UV-irradiated beef**

Ninety-six steaks approximately 1-cm thick were sliced from chilled eye of the round fresh beef obtained from a local slaughter plant. The steaks were scored visually for general appearance on a scale of 1 to 8 (1 being least desirable) and for odor. Tristimulus color values (Hunter L, a, and b) were determined with a Hunter Color Difference Meter. Half of the steaks were irradiated with 500 mW s/cm² of UV radiation on each side and half were unirradiated. The 96 steaks were divided into 8 sets of 12 (6 irradiated, 6 unirradiated) to provide one set for immediate bacteria content evaluation (0-time storage) and one set for each of 7 weeks of storage. After initial evaluation, day 0, all steaks except those sampled for initial bacteria count (set 0) were placed in sterile petri dishes, vacuum-packaged, and placed in dark cold storage (0°C). One set was removed weekly and evaluated for odor, visual color, Hunter tristimulus color values and total bacteria count.

**RESULTS**

**UV-Treated agar plates**

Ultraviolet radiation was very effective in reducing bacteria on agar plates. Figure 1 shows the reduction in the plate count of bacteria versus the radiation dose. A

![Figure 1. Survival ratio of bacteria exposed to various dose levels of ultraviolet radiation. (Untreated controls at log10 APC 9.30.)](http://www.journaloffoodprotection.org/article-pdf/50/2/108/1651190/0362-028x-50_2_108.pdf)
survival ratio of 0.07 was obtained with a radiation dose of 2 mW s/cm² (275 µW/cm² for 8 s) and a survival ratio of 0.001 (99.9% kill) was obtained with a dose of 4 mW s/cm². These results compare favorably with those obtained by Bachman (2) who obtained 90% destruction of Pseudomonas fluorescens with a radiation dose of 3.5 mW s/cm².

UV-Treated beef round samples
Relatively low kills of bacteria were obtained during this experiment. Two factors contributed to the low kill. First, because the steaks were cut across the fibers, bacteria culture broth entered into the meat—did not remain on the surface—and was therefore partly shielded from exposure to UV. Second, in sampling for bacteria by swabbing, meat fibers separated enough to permit the swabs to absorb some of the effluent from below the surface. Nevertheless, the survival ratios ranged from 0.12 for the 75 mW s/cm² dose to 0.04 for the 575 mW s/cm² dose.

Bacteria survival ratio on beef plate meat
The results (Fig. 2) show that UV-irradiation can be highly effective in destroying bacteria when the UV actually impinges directly on the bacteria. More than 97% (N/N₀ = 0.03) of the bacteria were destroyed with a dose of 16 mW s/cm² (275 µW/s for 60 s). Higher doses of UV radiation reduced the bacteria by additional amounts (1 to 2%). For example, doses of 64 and 128 mW s/cm² (275 µW/cm² for 240 and 480 s, respectively) reduced the survival ratio to about 1%—a reduction of about 2% over the 16 mW s/cm² dose. We believe that the beneficial effect of higher doses is diminished because a proportion of the bacteria is shielded from the UV.

Storage study of UV-irradiated beef
Bacteria. Figure 3 shows the bacteria levels of irradiated and control samples versus weeks in storage. Apparently, because the samples were from beef round cut across the meat fibers, we again experienced a low "kill" of bacteria. The graph shows that there was an initial reduction in bacteria from approximately 3000 to 2400 as a result of the radiation treatment. An additional reduction in bacteria (down to 1800) was observed at the end of week 1. We attribute this reduction to the effect of vacuum packaging and storage at 0°C. After 1 week of storage, we believe that anaerobic bacteria became predominant and began to increase.

Color, appearance, odor and shelf-life. The results showed no significant differences in organoleptic scores for odor and appearance between control and irradiated samples at the end of the storage period (6 weeks). Average scores showed that most samples were acceptable at the end of 5 weeks. As pointed out above in the discussion on bacteria, irradiation probably had a negligible effect on shelf-life because of vacuum packaging. In retrospect, it would probably have been more meaningful if the samples had not been vacuum packaged.

Hunter tristimulus color values showed that the irradiated samples maintained higher “a” (redness) values (P<0.001) than did the control samples (Fig. 4). Hunter “L” and “b” values had similar trends but were considered of little value for evaluating meat since maintenance of the desired “cherry-red” color is of most importance. We noted, in particular, that those samples which appeared to be from “dark cutter” (a condition caused by preslaughter stress) carcasses, improved in redness (Hunter “a”) due to the UV treatment. Thus the UV irradiation treatment given these samples did not have a deleterious effect on color as previously reported (17).

Figure 2. Survival ratio of bacteria on inoculated beef plate meat exposed to various dose levels of ultraviolet radiation.

Figure 3. Bacteria (log₁₀ APC) on UV treated and untreated inoculated vacuum packaged beef round steak versus time in storage.
cles (10^2 to 10^3) could be expected if freshly dressed beef carcasses were exposed to 250 mW s/cm^2 of UV radiation. A bacteria reduction of about 2 to 3 log cycles would allow the surface of the carcass to cool to 5 to 10°C, thereby retarding the bacterial growth rate to < 2.5^10/h.

We visualize that a UV treatment chamber could be designed to expose all sides of a carcass, for example, S-shaped with reflective walls. Common germicidal lamps would require an exposure of about 10 min. However, with new high-intensity lamps now available, adequate exposures could be obtained in 10 s.

Additional research is needed to (a) investigate mechanical flexing of the meat to expose bacteria that may be imbedded in the fibers and (b) determine the effectiveness of UV in extending the shelf-life of meat in cold storage.

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The mention of company or tradenames does not imply endorsement by the U.S. Department of Agriculture over others not named.

REFERENCES