The Use of Irradiation in Combined Treatments as an Advanced Process to Improve Meat Safety and Protect the Nutritional Value

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Summary

Food irradiation is an efficient technology that can be used to assure food safety by eliminating especially parasites, insects and pathogens and to prolong the shelf life by reducing the microbial flora. The process could be done on fresh or frozen products without affecting the nutritional value. Presently more than 50 countries have given approval for over 60 products to be irradiated in the world. Presently in Canada, only potatoes, onions, wheat, flour, whole flour, whole and ground spices, dehydrated seasoning preparation are approved for irradiation. A regulatory proposal was submitted in 2002 for ground beef, poultry, shrimp, prawn and mangoes but is still under consideration. The slow development in some countries could be due to differences in consumers' acceptance of irradiation technology. The present article summarizes the development of irradiation technologies on fresh meat and meat products.

What is irradiation treatment?

Irradiation is a physical treatment that consists of exposing foods to the direct action of electronic, electromagnetic rays to assure the food safety and to prolong the shelf life. The international unit of measurement of the irradiation dose absorbed by the product is the Gray (Gy). One gray represents one joule of energy absorbed per kilogram of irradiated product. One Gy is equivalent to 100 rad (radiation absorbed dose). Food irradiation must be conducted according to good management practice and comply with the Codex Alimentarius General Principles of Food Hygiene (Codex Alimentarius, FAO/WHO 2003).

Why irradiation of meat?

During processing and storage, meat and meat products are exposed to several internal and environmental conditions that increase food safety risks. A major cause of food safety risks is related to the contamination with many pathogenic bacteria such as *Escherichia coli* O157:H7, *Salmonella* Typhimurium, *Salmonella* spp., *Listeria monocytogenes*, *Campylobacter jejuni*, *Staphylococcus aureus* and *Yersinia enterocolitica* (Samelis *et al*., 2001; Farkas, 1998), spoilage microorganisms like *Pseudomonas, Acinetobacter and Lactobacillus* (Saha and Chopade, 2009; Lacroix and Ouattara, 2000; Schillinger and Lücke, 1989), viruses such as Hepatitis A and E, noroviruses, or parasites like *Trichinella spiralis*, *Toxoplasma gondii* and *Tania solium* (Velebit *et al*., 2015; O'Bryan *et al*., 2008, Molins et al., 2001; Farkas, 1998).

Salmonellosis is one of the most frequently reported foodborne diseases worldwide. Each year, approximately 40000 *Salmonella* infections are culture-confirmed, serotyped, and reported to the United States Centers for Disease Control and Prevention (CDCs). Of total salmonellosis cases, an estimated 96% are caused by the ingestion of contaminated poultry, beef, pork, eggs, and milk. *E. coli* O157:H7 is among the most serious foodborne pathogens. This is due to the severity of the illness and its low infective dose (<100 organisms). It was the cause of the death of four children and the severe illness of 600 people in the US linked to undercooked hamburgers containing *E. coli* O157:H7, which give serious doubts about food safety (USDA, 1994). The use of gamma irradiation for decontamination of foods is a promising technology that could be applied on the end product. This technology also has the advantage to be applied on fresh, frozen or on cooked products. It is a safe, environmentally clean and efficient technology.

Sensitivity of various organisms to irradiation

The dose needed to control the pest varies from 0.05 to 4 kGy. The dose required to inactivate parasites is normally very low and can be achieved at doses of 0.15-0.6 kGy (Farkas, 1987). An irradiation dose of 0.4 kGy can assure pork trichina-free (Kasprzak *et al*., 1993). Shelf life extension and elimination of pathogenic microorganisms such as *Salmonella, Yersinia* and *Campylobacter* require a dose of 2.5 - 5 kGy (Molins, 2001).

Normally gram negative bacteria are more sensitive than gram positive bacteria to irradiation. Ouattara *et al*. (2002ab) have observed that *Enterobacteriaceae* and other gram negative bacteria (total coliforms and *Pseudomonas* spp.) exhibited a greater sensitivity toward the irradiation treatment than the gram positive bacteria tested (*Brochothrix thermosphacta*, *Staphylococcus aureus*, and Lactic acid bacteria). According to their study, lactic acid bacteria appeared to be the most resistant organism tested, followed by *Brochothrix thermosphacta*, while presumptive *Staphylococcus aureus* showed sensitivity comparable to those of the gram negative bacteria, i.e. *Enterobacteriaceae*, total coliform, and *Pseudomonas* spp in ground beef.

The increase of bacterial sensitivity to irradiation by combined treatment

Combining irradiation to one or more preservation techniques is a new approach. Several combinations such as modified atmosphere packaging, free or encapsulated natural antibacterial compounds or heat treatment increase the bacterial radiosensitization (Ayari, et al., 2012; Lacroix et al., 2013; Lacroix & Ouattara, 2000). This new alternative has the advantage to reduce the dose needed to eliminate pathogens and can preserve further the sensory and nutritional quality of the commodity. For example, encapsulated oregano essential oil, cinnamon essential oil and nisin were used in combination with irradiation gamma to evaluate their efficiency to inhibit the growth of *Listeria monocytogenes* on ham. It was found that the combined treatment of cinnamon essential oil, nisin and gamma irradiation was able to increase the bacterial radiosensitization by 2.5 times and the microencapsulation of this antimicrobial formulation was able to further increase the *Listeria* radiosensitization showing a bacterial radiosensitization of 5 times (Table 1; Huq *et al.,* 2015). Also, the encapsulation was able to protect the antimicrobial efficiency during the storage of irradiated ham treated at 1.5 kGy (Fig. 1; Huq *et al.,* 2015). Microencapsulated cinnamon and nisin in combination with γ -irradiation (at 1.5 kGy) showed 0.03 ln CFU/g/day growth rate of *L. monocytogenes* whereas the growth rate of non-microencapsulated cinnamon and nisin in combination with γ-irradiation was 0.17 ln CFU/g/day. Also, ham treated with free cinnamon, nisin and gamma irradiation exhibited a bacterial count of 3.96 log CFU/g after 35 days of storage and a lag phase of 7 days as compared to 1.80 log CFU/g after 35 days of storage and a lag phase of 28 days when the antimicrobial formulation was encapsulated before irradiation treatment (Huq *et al.,* 2015).

Table 1. D_{10} and radiosensitivity (RS) of *L. monocytogenes* of free and microencapsulated antimicrobial compounds on ready to eat cooked ham (Huq *et al*., 2015).

	D_{10} (kGy)	RS
C	0.54 (R^2=0.99)	1.00
OR	0.45 (R^2=0.90)	1.20
CN	0.29 (R^2=0.67)	1.86
N	0.28 (R^2=0.96)	1.93
OR+N	0.26 (R^2=0.82)	2.08
CN+N	0.23 (R^2=0.99)	2.35
C(E)	0.55 (R^2=0.99)	1
OR(E)	0.43 (R^2=0.91)	1.28
CN(E)	0.33 (R^2=0.92)	1.67
N (E)	0.30 (R^2=0.68)	1.83
OR+N(E)	0.19 (R^2=0.87)	2.89
CN+N (E)	0.11 (R^2=1.00)	5.00

C : Control; OR : Free oregano; CN: Cinnamon essential oil; N: Nisin; (E): Microencapsulated antimicrobial formulation

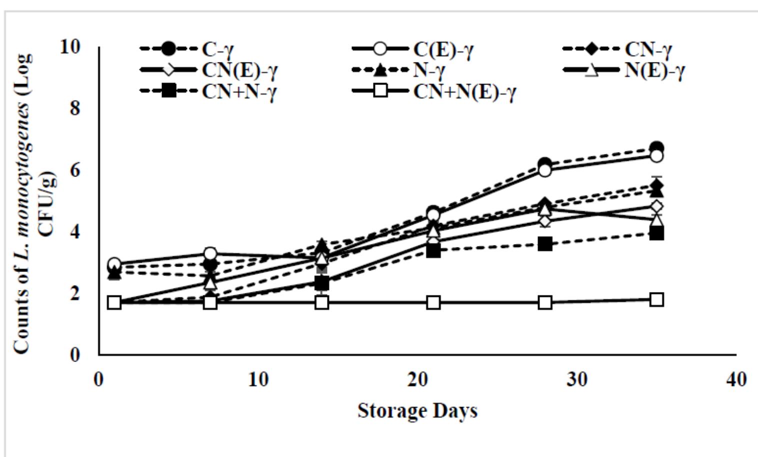

Figure 1. Synergistic effect of microencapsulated *Cinnamomum cassia* + nisin and γ-irradiation on ready to eat cooked ham during storage at 4°C (Hug et al., 2015). Dotted lines represent without microencapsulation. Where, γ indicates formulation irradiated at 1.5 kGy.

The utilization of a marinating solution in combination with a lower dose of γ-irradiation (1.5 kGy) in ready-to-cook (RTC) pork loin was also evaluated for immunocompromised people. Results also showed a synergy to eliminate the level of pathogenic bacteria (Fig. 2; Ben Fadhel et al., 2016). This combination was also able to increase the shelf life of the RTC pork meat without affecting its color, sensory and nutritional quality. When meat was irradiated at 1,5kGy and 3 kGy, the total mesophilic count was still under undetectable level until day 5 and day 13, respectively, showing an increase of the lag phase of the bacterial growth. A respective lag phase of 15 and 21 days was reached for marinated sample treated at same doses of irradiation (Fig.2). The shelf life of irradiated pork treated in combined treatments was more than 21 days, according to the microbiological suggestion for immunocompromised people. However, meat without marination treated at 1.5 kGy and 3 kGy had a shelf life of 6 and 14 days. Lactic acid bacteria were under the limit of detection for samples treated at both doses of irradiation for the whole storage showing also a synergy between marinating and irradiation treatment (Fig.3).

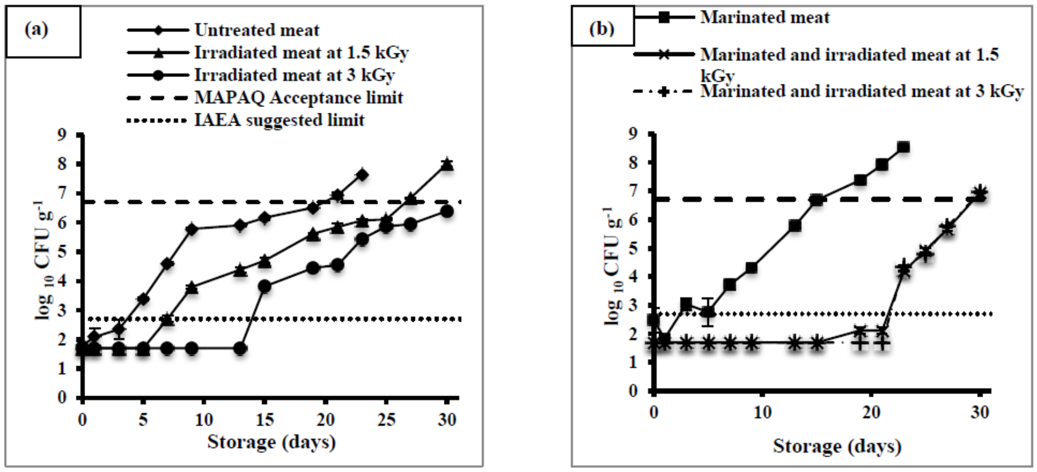

Figure 2. Effects of γ-irradiation on the TMF counts in (a) non-marinated and (b) marinated meat stored under vacuum at 4°C (Ben Fadhel et al., 2016).

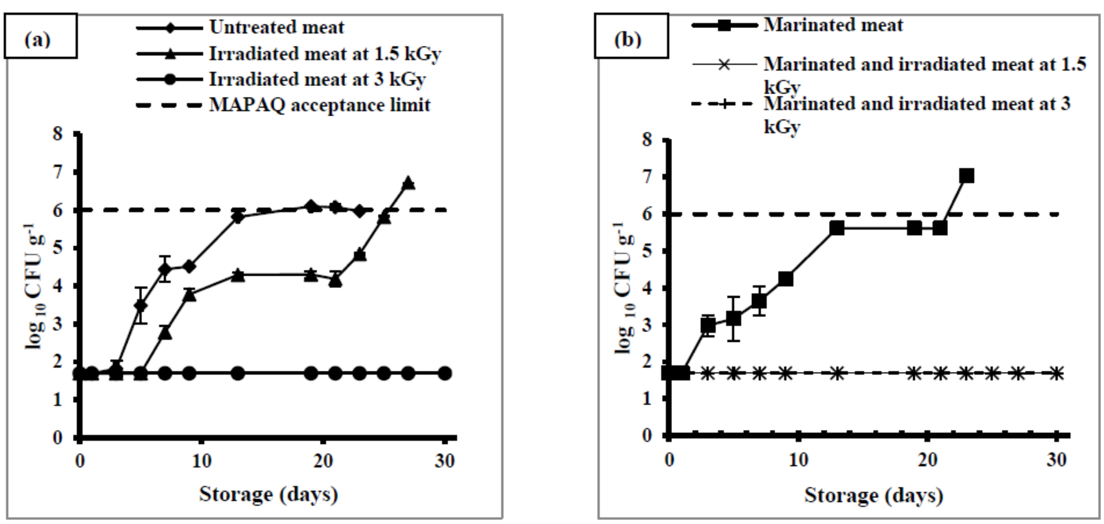

Figure 3. Effects of γ-irradiation on the LAB counts in (a) non-marinated and (b) marinated meat stored under vacuum at 4°C (Ben Fadhel et al., 2016).

Conclusion

Irradiation is a safe and effective process for controlling foodborne disease and for shelf life extension. One of the advantages of this technology is that it can be used for fresh and frozen food items, as well as packaged foods. The development of combined treatments using irradiation is a promising avenue because of the possibility of enhancing product safety and obtaining higher quality products. The overall treatment efficiency is strengthened through synergistic action and it could be possible to reduce the irradiation doses without affecting the food quality. Microencapsulation technology of antimicrobial compounds in combination with irradiation could be an advanced process to improve the food safety for ready to eat meat. These new technologies can offer opportunities to introduce new food products to the market.

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