Non Thermal Preservation of Meat by Irradiation: A Review

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Abstract
Meat and meat products are excellent sources of protein, containing good balance of essential amino acids, vitamins, minerals and having a good biological value providing an excellent environment for growth and multiplication of spoilage microorganism and food borne pathogens. Nowadays, consumers demand minimally processed food with retaining natural attributes and giving “freshness” like appearance. Irradiation is a non thermal technique that eliminates spoilage microorganisms and food borne pathogens while maintaining the naturality of food. Irradiation of meat helps in increasing the shelf life of meat. However there is change in the quality attributes of meat during irradiation.

Keywords: Meat Irradiation, Non thermal process, Nutritional quality, Safety.

1. Introduction

Meat is a very perishable commodity due to rich nutrient matrix, high moisture contents and almost neutral pH. These conditions provide an excellent environment for growth and multiplication of spoilage microorganism and food borne pathogens. Nowadays due to growing education and awareness, consumer demands are minimum processing products with retaining natural flavour, colour and texture along with high quality, convenient, innovative, regular and giving “freshness” like appearance with surety of health aspects (Aymerich \textit{et al}., 2008). New emerging non thermal techniques are developing to maintain these desires.

Recently, these techniques are-Irradiation, Pulse Electric Fields, Pulse Light, Oscillating Magnetic Fields, High Pressure Processing and High Power Ultrasound Waves. Non thermal techniques are some advantages like energy efficient and environmental friendly, eliminating spoilage microorganisms, food borne pathogens and also maintain naturality of meat. Application of radiations for preservation of meat has the benefit that it leaves the meat essentially unchanged in appearance. Another advantage is that they can be generated using relatively inexpensive machines (Umaraw \textit{et al}., 2015). The demands of minimum and naturally processed food are very high as compared to traditional foods (Chipurura and Muchuweti, 2010; Singh \textit{et al}., 2012).

Radiation is a form of energy travelling through space in a wave pattern originated either by natural sources (sun or rocks) or by man-made objects (microwaves, television sets). In 1896, the first concept of preservation of food by ionizing irradiation was proposed (Takeguchi, 1983). The importance of X ray irradiation in making the pork free from \textit{Trichinella} was begin in 1921 but the production of X rays was very tedious and with the introduction of accelerated electron technology, this process of X rays irradiation of pork become feasible and economical. During the World War II, this technology got its recognition in US and in 1955, US army started assessing the safety of commonly available foods undergoing irradiation. More than 90% of bacteria can be inactivate with increasing the shelf life of meat by use of lower dose irradiation (Lacroix \textit{et al}., 2000). Irradiated fresh chicken at 2.5 kGy leads to extended organoleptic quality from 6-10 days to 12-20 days (Lacroix \textit{et al}., 1991).

Irradiation has the potential to make meat and meat products safe by killing the various pathogens and parasites. This enhances the keeping quality and storage life of food by better maintaining the nutritive quality. Subjecting the meat and meat products under
irradiation helps to increase their shelf life. Irradiation destroy the spoilage and food borne pathogens without increased temperature. This process is known as “electronic pasteurization” or “cold sterilization” (Crawford and Ruff, 1996). Food preservation by irradiation technique provides consumers with wholesome and nutritious food items having improved hygiene and easy availability and quantity with increased storage life, convenience to transport.

2. Types of Radiation

Radiations are two types viz. ionizing and non-ionizing. Ionizing radiation is a part of the electromagnetic energy spectrum that consists of visible light, infrared, ultraviolet, microwaves, radio and television waves. In the preservation of food mainly ionizing radiations are used due to having high power energy. Ionizing radiation has enough energy to change atoms by knocking an electron form an ion but not high enough to split atoms and cause exposed objects to become radioactive. Wavelength of Ionizing radiation is 2000 Å or less. Examples: alpha particles, beta particles, high energy electron, gamma rays and x-rays.

Non-ionizing radiation does not have sufficient energy to create ions, instead it tends to excite molecules without removing electrons. They cause molecules to move, but they cannot structurally change the atoms in those molecules. Examples: visible light, microwaves, radio waves and television waves.

3. Doses

Radiation dose is the quantity of radiation energy absorbed by the food as it passes through the radiation field during processing. It is measured in Gray (Gy) or kilograys (kGy) (Osterholm and Norgan, 2004). 1Gy equals one joule of energy absorbed per kilogram of food being irradiated. In rad, 1Gy is equal to 100 rads. 1 kGy raises the temperature by less than 0.5°F. International group of microbiologist (1964) giving term for radiation treatment of food as follows:

- **Radurization**: May be considered equivalent to pasteurization, enhance keeping quality of food. Dose rate-0.75-2.75 kGy for fresh meat, poultry, seafood and other food.
- **Radiicidation**: Equivalent to pasteurization. Dose rate-2.5-10 kGy for frozen meat and other food.
- **Radappertization**: Equivalent to sterilization or “commercial sterilization”. Dose rate-30-40 kGy.

Osterholm and Norgan (2004) described three levels of irradiation viz. Low, Medium (pasteurization) and High. Low level dose up to 1 kGy kills insects and parasites (especially Trichinella spiralis) and inhibits the sprouting of potatoes. Medium level radiation dose range is 1-10 kGy inactivates the spoilage microorganism and food borne pathogens and extend the shelf life of meat and other food products. Sterilization of meat and meat products is treated with dose rate of more than 10 kGy dose of irradiation in high level.

4. Mode of Action

Ionizing radiation has an ability to damage the genetic material of microbes and cause to death of microbes. There are two methods by direct or indirect “hits”. In direct hits ionizing radiation damage to nucleic acid at the bond of sugar and phosphate molecules, which are joined weakly by hydrogen bonds.

In indirect method, ionizing radiation ionise the adjacent molecules and form different lethal by-products. Water is the largest components of all living organism including microbes and food. By the ionizing radiation water molecules form H2O’ and an electron. These intermediate molecules reacts other water molecules to produce various compounds like-hydroxyl radicals, hydrogen, oxygen and hydrogen peroxide (H2O2). Nucleic acids (single or double strand) are made up of sugar, phosphate and nitrogen base by various bonds like hydrogen bonds. Hydroxyl radical and hydrogen peroxide are very reactive and damage the bonds of nucleic acids of microbes and impaired for replication. Bartek and Lucas (2003) explained that every biological system in the earth has an ability to reform of genetic materials single strands or double strands breaks of DNA backbone. Razskazovskiy et al. (2003) reported that damage by ionizing radiation is random and extensive. There is nearly impossible to repair radiation damage by microbes.

5. Source of Ionizing Radiation

Energies from radiation sources are too low to induce radioactivity in any materials, including food. There are as following:

5.1 Gamma Radiation

Gamma rays are widely use in the irradiation of food using nucleosides of the Co60 and Cs137. The most common source of radioactive radiation is Co60 which produces 1.33MeV of gamma radiation during natural disintegration to nickel. These rays are easily
penetrated the food container and destroy the growing microorganisms without causing the food radioactive.

These nucleosides are relatively cheap source of radiation as by-products of atomic fission. Materials to be irradiated are placed on a suitable distance from the source as for desire doses. The half life of Co$,^{60}$ is 5.27 years requires changing regularly to maintain desire dose. To overcome this drawback use of Cs$,^{137}$ has half life of about 30 years.

Main drawback of this technique is that radioactive are emitted radiation in all direction and all time and cannot be controlled and “off” or “on”.

5.2 Accelerated Electron Machines (E-Beam)

The electron beam is a stream of high energy electron, propelled out of an electron gun. The electron can penetrate food only depth of 3-5 cm having a maximum energy of 10 Mev. This energy is not so enough to create radioactivity in any food materials. Koch and Eisenhower (1965) explained advantage over radiation from radio nucleocides, high efficiency for direct deposition of energy, easily control of electron beam energy by current control, conveniently convert of electron power to X-ray power, easy to “off” or “on”.

5.3 X-rays Radiation

X-rays is a newest technology of irradiation to food. X-rays has more penetration power than accelerated electron beam and pass through thick food with easy power control. X-ray machines having a maximum energy of 5 million electron volts (Mev). Mono-directional characteristic of electron beam and X-rays are more convenient to food package design. The productions of X-rays are energy intensive and inefficient as the out of total electrons, only about 4-6% is producing X-rays (Brewer, 2004).

6. Effect Radiation on Meat Quality

Most of studied suggested that irradiation does not significant effect on the sensory attributes and nutritive value of meat at medium doses. Radiation dose, dose rate, temperature, amount of oxygen and other factor affect the quality of product. Packaging environment play a significant role in muscle food colour. At the lower dose cause no significant loss in protein but higher dose form loss of some amino acids and form produced various by products like ammonia, hydrogen, carbon-dioxide and amides which causes off flavour and off odour. Sulphur volatiles that cause irradiation off-flavour produced by radiolytic degradation of sulphur amino acids

Lipids are very sensitive to irradiation, high level leads to rancidity due to formation of various peroxide. But at low level Lee et al. (1996) explained that pre-rigor beef treated with 2 kGy radiation of dose stored with modified atmosphere packing at 20$^\circ$C temperature did not lead to more oxidation.

Pork chops are treated with 1 kGy dose of radiation and stored at vacuum packed for fourteen days, without any significant change of organoleptic property. Arthur et al. (2005) reported that 1 kGy does of E-beam radiation decrease the number of 4 log cycle of $E.\ coli$ without any significant adverse sensory and nutritive effects in the chilled beef primal cuts.

Table 1: Effect of irradiation on vitamins in cooked chicken

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Non irradiated</th>
<th>Irradiated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vit A, IU</td>
<td>2200</td>
<td>2450</td>
</tr>
<tr>
<td>Vit E, mg</td>
<td>3.3</td>
<td>2.15</td>
</tr>
<tr>
<td>Thiamin, mg</td>
<td>0.58</td>
<td>0.42</td>
</tr>
<tr>
<td>Riboflavin, mg</td>
<td>2.10</td>
<td>2.25</td>
</tr>
<tr>
<td>Niacin, mg</td>
<td>58.0</td>
<td>55.5</td>
</tr>
<tr>
<td>Vit B$_6$, mg</td>
<td>1.22</td>
<td>1.35</td>
</tr>
<tr>
<td>Vit B$_{12}$, mg</td>
<td>21</td>
<td>28</td>
</tr>
<tr>
<td>Pantothenic acid, mg</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>Folacin, mg</td>
<td>0.23</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Some vitamins are affected but trace elements and minerals are not influenced by irradiation (Table 1). However this loss is not nutritionally significant and the total destruction depends on the dose, temperature, presence of oxygen and food types. The losses of vitamins are lesser at lower temperature in the absence of oxygen followed by storing in sealed container at low temperature. The sensitivity of vitamins to irradiation follows such order as thiamine> ascorbic acid> pyridoxine> riboflavin> folic acid>coalmine> nicotinic acid for water solube vitamins and vitamins E> carotene> vitamin A> vitamin K > vitamin D for fat soluble vitamins (FDA, 1998).

According to Fox et al. (1995) a 2.3% of loss of thiamine in pork products irradiated at the dose of 3 kGy and the total advantage is far more than the slight loss of thiamine. Irradiation increases the shelf life of meat, by reducing initial load of present spoilage organism. The microorganism responsible for meat spoilage and foodborne pathogens like- $Pseudomonas$,
Table 2: Radiation doses for food safety and preservation

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Effective dose (kGy)</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhibiting sprouting</td>
<td>0.06-0.2</td>
<td>Potato, onion, garlic</td>
</tr>
<tr>
<td>Insect disinfection</td>
<td>0.15-1.0</td>
<td>Dried fish, meat fruit, cereals</td>
</tr>
<tr>
<td>Parasite infestation</td>
<td>0.3-1.0</td>
<td>Fresh pork, fresh water fish</td>
</tr>
<tr>
<td>Extension of shelf life</td>
<td>1.0-3.0</td>
<td>Raw fish and sea food, fruits, vegetable</td>
</tr>
<tr>
<td>Inactivation of spoilage and</td>
<td>1.0-7.0</td>
<td>Raw and frozen sea food, meat, poultry,</td>
</tr>
<tr>
<td>pathogenic bacteria</td>
<td></td>
<td>spice</td>
</tr>
</tbody>
</table>

Table 3: D value of different meat pathogen in respect of irradiation dose and temperature

<table>
<thead>
<tr>
<th>Pathogen organism / target</th>
<th>Irradiation Temperature (°C)</th>
<th>Meat suspension media/product</th>
<th>D value (kGy)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>0-5</td>
<td>Poultry</td>
<td>0.35-0.45</td>
<td>Thayer et al. (1992; 1995).</td>
</tr>
<tr>
<td><em>Salmonella</em> spp.</td>
<td>0-5</td>
<td>Poultry, beef</td>
<td>0.24-0.78</td>
<td>Thayer et al. (1990; 1995); Tarkowski et al. (1984); Licciardello et al. (1970).</td>
</tr>
<tr>
<td><em>Listeria monocytogen</em></td>
<td>2-5</td>
<td>Poultry/ beef</td>
<td>0.45</td>
<td>Huhtanen et al. (1989).</td>
</tr>
<tr>
<td><em>E. coli</em> O157:H7</td>
<td>2-5</td>
<td>Beef patties</td>
<td>0.24-0.38</td>
<td>Clavero et al. (1994); Lopez-Gonzales et al. (1999).</td>
</tr>
<tr>
<td><em>Campylobacter jejuni</em></td>
<td>2-30</td>
<td>Poultry/ beef</td>
<td>0.16-0.19</td>
<td>Lambert and Maxcy (1984); Clavero et al. (1994).</td>
</tr>
<tr>
<td><em>Clostridium botulinum</em></td>
<td>30</td>
<td>Poultry</td>
<td>3.65</td>
<td>Anellis et al. (1971).</td>
</tr>
</tbody>
</table>

*D-value: Decimal reduction or dose required to destroy 90% of micro-organisms*

Lactobacillus, Salmonella, Yesinia, Campylobacter, Staphylococcus, E. coli, Clostridium, are easily destroyed by irradiation. Dose of 1.0 to 10.0 KGy is enough to decontamination of all type food including meat (Table 2-3). Irradiated meat should be packed in air containing packaging materials than MAP (modified atmosphere packaging) or vacuuming packaging for better efficacy (Thayer and Body, 1999). Parasites are easily destroyed at very lower dose 0.15-0.6 KGy (Farkas, 1987). Trichinella spiralis can be inactivating at the dose rate of 0.4 KGy in the pork (Kasprzak et al., 1993). Various pathogenic and spoilage bacteria are commonly present in the meat can be easily eliminated and extend the shelf life of products at the dose rate of 2.5-5.0 KGy (Molins, 2001).

The water is the major components of meat and meat products. On radiation, water produces various reactive ions and free radicals (Thakur and Singh, 1994). In frozen state, the effect of these reactive compounds decreases due to production of original compounds formed by the combination of ions and free radicals due to their reduced chances of getting the other food components (Nam et al., 2001).

Meat colour is also affected by the irradiation as due susceptibility of iron of the myoglobin, the major meat pigment. The rapid production of brown, green or in some cases bright red oxymyoglobin like red pigments in the irradiated fresh pork and beef have been observed during irradiation (Millar et al., 1996). During irradiation, ozone, a strong oxidizer is produced from oxygen leading to bleaching discolouration by oxidizing myoglobin (Oslo, 1998). The change in colour decreases the acceptability of the meat (Montgomery et al., 2003). The myoglobin is sufficiently destroyed at irradiation dose of 50 KGy or more (Brewer, 2004). According to Brewer (2004) the ideal colour of meat can be retained under irradiation process by pre-slaughter feeding of antioxidants to livestocks, adding of antioxidants, packaging technique and suitable temperature. Pink colour of meat is developed by combine effect of heme pigment and radiolytic carbon monoxide (Nam and Ahn, 2002).

The high dose of irradiation causes the production of objectionable off odours and meat darkening whereas low dose irradiation minimizes -
odour, flavour and colour problems (Sudarmadji and Urbain, 1972).

7. Regulations

The Food and Drug Administration has approved irradiation (Table 4) as an effective food quality technique for preservation and increasing storage life of meat, fresh fruits, vegetables and spices. Any effect on the people and animal are not seen by eating irradiated food over 40 years by various studied. The USDA in 1986 approved the use of irradiation in making pork Trichinella free (USDA, 1986). Food and Drug Administration (FDA), Food and Agriculture Organization (FAO), International Atomic Energy Agency (IAEA), World Health Organization (WHO) and Codex Alimentarius approved the maximum irradiation dose permitted 10 kGy in food application. Several international agencies concluded that any dose of irradiation to achieve intended objective is safe to human consumption and nutritional adequate. USDA (United State Department of Agriculture) and HACCP (Hazard Analysis Critical Control Point) system maximum irradiated dose permitted chilled meat is 4.5 kGy and frozen meat is 7 kGy. FDA (USA) allows frozen meat for NASA sterilize minimum dose of 44 kGy. FDA and USDA have approved for irradiation to fresh or frozen meat and meat products in 1997 and 1999 respectively. The food irradiation within the specific limits can reduce the pathogenic germs to great extent and rendering the food safe for consumption under HACCP (Osterholm and Potter, 1997; Osterholm and Norgan, 2004).

8. Global Scenario

Irradiation is not new technique but use at commercial level as concern to meat and meat products is very low globally. In some developed countries little use of this techniques to preservation of meat and meat products at consumer levels. At present about there are at least 60 irradiated products are in market in about 50 countries. According to EU (2004) reports on irradiated food, Germany produced 7954, Netherland 7114, France 5129, Belgium 6613 tonnes of irradiated food including meat, sea food, spices, seasonings, herbs etc. USA produced 45000 tonnes of irradiated food. The total volume of food treated with irradiation worldwide is estimated to reach over 500,000 metric tons annually (Kume et al., 2009; Farkas and Mohacsi-Farkas, 2011).

9. Public Acceptance of Irradiated Foods

Public acceptance plays a very significant role to further development of any new technology. Young (2003) explained the public acceptance about canned food products that have taken 50 years even its technology introduction. He demonstrated the 80% increase in public acceptance to irradiated food by the consumer upon briefing them the use and purpose of the irradiated food. Public opinion has great challenges to accept new modern technology. In concern of the irradiation, due to very misunderstanding and lack of awareness, and radioactive association lead to drop benefits of this technology to society. But new advanced research and facts about safe to health aspects, environment friendly and special benefits to food irradiation change the global acceptance (Molins, 2001). The dissemination of information helped the consumers to change the negative attitudes and fears of the irradiated food resulting in the increasing the acceptance of irradiated food by them. The irradiated poultry has been sold in US since 1993 and in California, the fresh irradiated produce was in use since 1997 (Pszczola, 1997). Irradiation facilitates the global trade by making packaged food safe for consumption as well as proving an effective quarantine measure. In 2004, USDA allowed the irradiated ground beef for National School Lunch Programme in US and irradiated cold cuts and processed meat (Osterholm and Norgan, 2004).

10. Merits

Irradiated meat and meat products are safe to human consumption. This technique able to reduce the
microbial load, kill microbe and make food sterilise at different doses without increasing high temperature. Irradiation does not significant loss of nutritious value, flavour, odour, texture and freshness. This technique does not leave any toxic residue in irradiated meat. A more advantage of this technique is that food materials can be easily treated after packaging and protected from recontamination up to consumer level (Derr, 1993). The technique is energy efficient and environmental friendly.

References


11. Constraints

There is very little use of this technology in preservation of meat and meat products. Initial high capital cost, safety concerns, misconception about irradiated food safety levels are the most important concerns. High does leads to deteriorative change in quality of the products. Negative image in the consumer about this technique that treated product is harmful to health and become radioactive, cause cancer like disease.
Razskazovskiy Y, Debi
tje MG, Howerton SB, Wiliams LD and Bernhard WA (2003). Strand breaks in X-irradiated crystal
Thayer DW and Boyd G (1999). Irradiation and modified atmosphere packaging for the control of L.