We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter

Gamma Irradiation and High Hydrostatic Pressure Applied to Hamburger Conservation

Michelle Guimarães Horta, Fabiana Regina Lima, Carlos Alberto Gois Suzart and Poliana Mendes De Souza

Abstract

Human nutrition is an essential process, since it provides the essential nutrients for their development. Animal source foods are rich in protein, amino acids, vitamins, and minerals. And they are subject to contaminants from the raw material to the final consumption. To avoid microbial contamination and deterioration, various technologies are used to ensure their innocuity. These include gamma irradiation and high hydrostatic pressure (HHP), which are nonthermal treatments. Such treatments may reduce the known adverse effects that occur during thermal processing. In meat products, these technologies may induce lipid oxidation, and to limit this process, the addition of synthetic or natural food antioxidants or both are used. This chapter discusses the use of gamma irradiation, high hydrostatic pressure, and application of natural antioxidants in beef hamburger to ensure their quality.

Keywords: hamburger, gamma irradiation, high hydrostatic pressure, natural food additives, nonthermal technologies

1. Introduction

The nutrition is an essential process for humans as they provide the essential nutrients. Meat and meat products have a prominent position among foods in the human diet, since it is rich in high-quality protein, essential amino acids, B vitamins, minerals, and other nutrients [1, 2] . These nutrients are important in the formation of enzymes, hormones, antibodies, structural proteins, and transporters as well as in the construction and maintenance of tissues [3].

Meats are defined as muscle tissues, without or not include their bone base, and can come from different animal species as long as they are fit for consumption. Meat products are those obtained from meat, edible parts of different animal species in which the properties of the raw materials are modified by means of physical, chemical, or biological treatment techniques or a combination of these methods [4]. These techniques in general may involve the addition of ingredients or co-adjuvants of technology for the production of industrialized meat.

The nutritional composition of meat and meat products favors the possibility microorganism's proliferation [5]. Contamination of meat products may occur during processing and handling of food such as slaughtering, deboning, cutting,

fragmentation, processing, packaging, storage, and so forth. This may occur due to extrinsic and/or intrinsic factors such as water, air, soil, temperature, and pH [6, 7].

To improve food safety and quality, various technologies have been used and developed to preserve and protect food against microbial contamination and deterioration. These technologies include nonthermal, thermal, biological, and chemical treatments. Thermal treatments are efficient in inactivation of microorganisms but have the disadvantage of generating unwanted biochemical reactions, since temperature-altered treatment favors changes in food quality. Texture, color, vitamin amounts, and development of unpleasant flavors are included in this change [8].

As an alternative to thermal treatments, the nonthermal treatments were developed. Among them, we can list gamma, electron, X-ray irradiation, high hydrostatic pressure (HHP), and the addition of natural antimicrobials [5]. These processes do not use temperature as a way to inactivate microorganisms and enzymes [8], and further generally, the nonthermal treatments do not affect their nutritional and sensory characteristics [8]. The use of nonthermal treatments in meats and derivatives for industrial productions is shown in several studies that among them, the irradiation and HHP are the ones that offer practical possibilities of application [9].

The production of meat industrialized is a strategy for total or partial use of less noble meat. In this class of derivates, sausages, cured meat, ham, hamburger, meatball, and others are included.

The hamburger originated in the city of Hamburg, located in Germany, and this product was consumed raw. In the 1920s, it emerged in the United States. In Brazil, it arrived in the 1950s and became known after it was produced and distributed by fast food chain [10]. It is defined as a meat product, obtained from ground beef of different animal species, with or without the addition of ingredients, molded as a disc or an oval, and subjected to a specific technological process [4, 11]. Also, according to the US Federal Code of Regulation [12], the hamburger is defined as "fresh or frozen ground beef steak, with or without added fat and/or condiments, which should not contain more than 30% fat and should not contain added water."

In relation to world beef production, the United States produces about 19%, followed by Brazil with 17%, the European Union and China with 13% each, and India with 7% [13]. Brazil exports approximately US$ 500 million/month, being considered the largest exporter of beef [14]. In the year 2018, from January to September, 23.47 million heads of cattle were slaughtered [15]. Research conducted by the US Department of Agriculture is estimated that in 2019, there will be a 3% increase in production and a 5% increase in beef exports in Brazil [16].

The quality, safety, and nutritional profile of beef depend on several factors, such as genetic characteristics and animal feeding, slaughter, processing, handling, and others [13].

This chapter discusses the use of emerging nonthermal technologies in meats and derivatives for industrial production, in highlighting among them the irradiation and HHP, to ensure their sage consumption.

2. Nonthermal treatments

A discussion of the most representative nonthermal treatments is shown in this section. Further to the application of natural antioxidants among nonthermal treatments, irradiation and HHP are the ones that offer practical application possibilities in meats and derivatives for industrial production [9]. Despite the efficiency of these nonthermal treatments in food conservation, they may favor lipid oxidation of meat products. To avoid this, there is a tendency to combine these treatments

with the use of natural antioxidants to reduce the sensory changes that are caused by oxidation [17].

2.1 Gamma irradiation

Irradiation is a physical treatment in which the food is exposed to a defined ionizing radiation dose. The purpose of this treatment is to control insect infestation, reduce the number of pathogenic microorganisms or deterioration, delay, or eliminate natural biological processes (ripening, germination, or sprouting in fresh foods) [18].

According to [19], irradiated foods were evaluated by several surveys and tests over several years, thus ensuring a safe food for consumption, in relation to nutritional adequacy and toxicological and microbiological safety.

Before 1997, the use of irradiation was limited. However, after Food and Drug Administration (FDA) was approved of the use of irradiation in refrigerated or frozen meats and derivatives to control food-borne pathogens, the consumers began to check the benefits of irradiated food [20, 21].

Irradiation can be applied to any kind food. The Codex Alimentarius Commission [22] regulates that the maximum safe dosage for food in general is 10 kGy, where the minimum dosage absorbed by the food must be sufficient to achieve the technological purpose and the maximum dosage absorbed must not compromise the consumer's health or cause the food to be disposed of [22].

According to Codex Alimentarius Commission [22], there is no minimum dosage to be used in meats, but the corresponding maximum dosages of 4.5 kGy for refrigerated beefs, 7 kGy for frozen meats, and 3 kGy for poultry meats have been defined. In Brazilian legislation [23], it is defined for any food that the minimum dose should be sufficient to achieve the purpose, and the maximum should be lower than that which would compromise the functional and sensorial characteristics of the food.

According to Codex Alimentarius Commission [22] for irradiated foods, the radiation sources that can be used are gamma rays, the radionuclides ^{60}Co, or ^{137}Cs; X-rays generated with a maximum level of 5 MeV; and electrons generated with a maximum level of 10 MeV. These sources have high energy that changes the position of the electrons of the atoms and molecules, converting them into electrically charged particles (ions). It should be noted that these energies are not capable of inducing radioactivity in any material [18].

Irradiation is considered one of the best emerging technologies to guarantee microbiological safety, in which any food can be irradiated, including meats and derivatives [18]. It is effective in eliminating or reducing pathogenic microorganisms, such as *Listeria monocytogenes*, *Salmonella* spp., *Escherichia coli,* and *Staphylococcus aureus* [24].

Although the numerous advantages of the use of the irradiation in the foods, the use this process in the meat products may favor physicochemical and biochemical alterations, as for example the lipid oxidation increase. This oxidation is characterized by the formation of free radicals, that is, it is initiated in the unsaturated fraction of fatty acids by the uptake of a hydrogen atom and propagated as a radical-mediated chain reaction. This process depends on the chemical composition of the meat and access to light, oxygen, and storage temperature. As it causes the increase of oxidation, there are changes in taste, aroma, and nutritional value changes that affect the quality of the food [25–27]. The addition of antioxidants may contribute to the reduction of this process [28].

Regarding the label of the irradiated food, according to the Codex, food that goes through the irradiation process must include on the label a statement

indicating that the treatment has taken place and may optionally use the international symbol available [29]. However, under US law, the symbol must be used and must be declared: "Treated with radiation" or "Treated by irradiation." The Brazilian regulation should include in the main panel the words "FOOD TREATED BY IRRADIATION PROCESS" [23].

Table 1 shows data from the study by Kume et al. [30] that reported the quantity of meat and fish products that were irradiated in the listed countries.

In a research conducted by Chirinos et al. [31], samples of industrialized hamburger inoculated with *Escherichia coli* O157: H7 were subjected to the irradiation process. It was found that at low doses (1.08 kGy), it was sufficient to reduce the microorganism, without rejection by the trained tasters.

It was evaluated by Moura [32], the oxidation of cholesterol in beef burgers and chicken burgers submitted to irradiation and stored under freezing conditions. It was found that there was an 11% increase in cholesterol oxide levels in frozen burgers.

Frozen chicken hamburger was inoculated with *Salmonella* sp. and irradiated in a study conducted by Vieira [33], and it was found that dosages of 5 and 7 kGy would be sufficient to reduce the population of *Salmonella* sp. Sensory evaluation did not change significantly, and shelf life was 120 days the same as the conventional product.

2.2 High hydrostatic pressure

The effect of high hydrostatic pressure (HHP) processing was first reported in 1899 by Hite [34]. This process uses an isostatic pressure at room temperature between 100 and 600 MPa. The pressure in the closed and degassed chamber is transmitted by pumps through a liquid (usually uses water) uniformly and instantaneously, which causes the molecular volume to change. The physical effect of the process occurs in the molecules, in which bonds that are weaker, such as those of hydrogen and hydrophobic, are modified [9].

The behavior of food under pressure is determined by three principles: Le Chatelier principle (any reaction that is accompanied by the decrease in volume and increased by pressure); principle of microscopic ordering (increasing pressure increases the order of molecules at constant temperature); and isostatic principle (foods are subjected to uniform pressure from all directions and return to their original shape after release of pressure) [35].

High hydrostatic pressure processing has been used in the industries for the processing and preservation of meats and meat products. Its application can inactivate

Country	Irradiated meat and fish (tons)
The United States	8000
Belgium	5530
France	2789
The Netherlands	944
Indonesia	1008
Vietnam	14,200
Total	32,471

Table 1.
Quantity of meat and fish products that were irradiated in some countries.

pathogenic microorganisms and enzymes, increase shelf life, and maintain sensory quality [8, 35]. When compared to thermal treatments, the main advantage of this process is the maintenance of the sensorial and nutritional characteristics of the treated foods. With the wide application of this process, it is possible to develop value-added foods with better quality and shelf life compared to those produced in a conventional way [35].

Some of the important achievements in the treatment of meat product as chicken, pork, and beef processed by using HHP were presented in the works of [36–38], respectively.

The work of [36] applied HHP with control parameters 300 MPa for 5 min, at 20°C on fresh chicken breast fillets, and indicated that modified atmosphere packaging maintained their sensory attributes, color, tenderness, and microbiological quality. High hydrostatic pressure processing applied by Grossi et al. [37] indicated that treatment with 600 MPa for 6 min in pork affected the myofibrillar protein degradation pattern due to the increase of cathepsin activity. It was reported by Sanchez-Basurto et al. [38] that the HHP preserved raw meat over a longer-time period without significant difference of texture, tenderness, and color using the control parameters 172–620 MPa and 1–5 min in treatment.

In general, nonthermal technologies are not stand-alone techniques, and in order to improve the inactivation rates, several authors have proposed that HHP treatments are applied in combination with natural bioactive compounds, of which many originate from distinct natural sources [17].

In the work of Kalchayanand et al. [39], HHP treatment was used in roast beef samples inoculated with a mixture of clostridial spores that could be stored for 42 days at 4°C. It was observed that combined treatment of HHP and vacteriocin controlled the growth clostridium spores and extended the shelf life of roast beef for 84 days and can be stored at the same condition.

Different conditions for cooked ham were considered in the works of [40–42]. These studies compare samples submitted only to HHP treatment and in combination with some antimicrobials. The results reported by the authors generally show control of pathogen growth and increased shelf life.

A wide range of studies have been conducted to determine and enhance the efficacy in the combination of antimicrobial compounds with HHP treatments in the inactivation induced by pressure of pathogenic microorganisms. More details of the main recent results can be found in the work of [17].

2.3 Natural antioxidants

Lipid oxidation is the main cause for loss of sensory quality in meat products [28]. It is a chemical process that generates unpleasant odors, deterioration of the color, texture, and nutritive value of meat and meat products, which diminishes consumer acceptance, since the main attribute for evaluation of the food by the consumer is their appearance [1].

Meat proteins are also susceptible to oxidative reactions during heating and storage, and these reactions damage membranes and cellular functions, altering water retention, color, and reducing essential amino acids [1, 2].

To avoid the development of oxidative reactions, the industries use synthetic and natural antioxidants. Antioxidants have the functions of delaying or preventing oxidation processes, for example, in the elimination of free radicals. In this way, it will increase the shelf life and maintenance of food quality and safety [26, 43].

There are laws that regulate the use of antioxidants in food products. Sodium isocyanurate, butylhydroxyanisole (BHA), and butylhydroxytoluene (BHT) have

Source of antioxidant	Products	Main results	References
Plum	Irradiated turkey breast	Reduced lipid oxidation	[45]
	Precooked roast beef		[46]
Grape seed extract	Precooked sausages	Kept the odor of fresh meat cooked and longer flavor	[47]
Pomegranate	Chicken patties (hamburgers)	Reduced TBARS	[48]
	Cooled chicken meat		[49]
Rosemary	Frozen beef hamburgers	Red color stability during storage	[50]
	Irradiated frozen beef hamburgers	Reduced lipid oxidation	[25]
Oregano	Irradiated frozen beef hamburgers	Decreased lipid oxidation, but not as efficient when compared to rosemary extract	[25]

Table 2.
Natural extract used in meat and meat products.

been used in meat products. There are studies that show that synthetic antioxidants have the potential to cause toxicological effects, so it may be desirable to replace conventional antioxidants with natural antioxidants [25, 27, 43, 44].

These natural antioxidants are extracted in the form of extracts from different sources such as fruits (grapes and pomegranate), vegetables (broccoli and potatoes), herbs, and spices (tea, rosemary, oregano, cinnamon, sage, thyme, mint, ginger, and clove) [27]. The antioxidant, antimicrobial, and antifungal properties of these spices and extracts are mainly related to their bioactive components, such as phenolic compounds, flavonoids, vitamins, minerals, carotenoids, and phytoestrogens [1, 25].

Table 2 lists some studies that used natural extracts in meat and meat products.

In meat and poultry products, rosemary extract (*Rosmarinus officinalis*) is one of the most studied natural antioxidants, and its efficiency in turkey meat, ground beef, and pork has been reported [43].

The antioxidant activity of rosemary extract has been associated with the presence of several phenolics, such as carnosic acid, carnosol, rosmanol, and rosmaridiphenol, which has the function of breaking free-radical chains by electron and metal ion donation [25]. However, rosemary extract can be extracted from leaves and branches [27].

The use of synthetic and natural antioxidants helps to preserve the desirable characteristics of food. It is important to emphasize that when using a natural antioxidant, it is important to evaluate its impact on the sensorial analysis and quality of the final product [2, 43].

3. Conclusions

Consumers want to purchase quality meat products that are safe, nutritious, and natural, with appropriate appearance and flavor. To ensure the innocuity of products to consumers, various technologies and treatments can be used to achieve this result, such as nonthermal treatments, which ensure a safe and better quality product. In addition to these, treatments can use natural antioxidants to ensure a food with its natural characteristics. However, further studies are necessary to

check the advantages and disadvantages of the beef hamburger irradiation process as well as in the use of combined processes may be involving the freezing, addition of natural antioxidants and irradiation.

Conflict of interest

The authors declare no conflict of interest.

Acronyms and abbreviations

BHA	butylhydroxyanisole
BHT	butylhydroxytoluene
FDA	Food and Drug Administration
HHP	high hydrostatic pressure
kGy	kiloGrays
TBARS	thiobarbituric acid reactive substances

Author details

Michelle Guimarães Horta, Fabiana Regina Lima, Carlos Alberto Gois Suzart and Poliana Mendes de Souza*
Universidade Federal dos Vales do Jequitinhonha e Mucuri, Brazil

*Address all correspondence to: poliana.souza@ict.ufvjm.edu.br

IntechOpen

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

References

[1] Hygreeva D, Pandey M, Radhakrishna K. Potential applications of plant based derivatives as fat replacers, antioxidants and antimicrobials in fresh and processed meat products. Meat Science. 2014;**98**(1):47-57

[2] Ribeiro JS, Santos MJMC, Silva LKR, Pereira LCL, Santos IA, da Silva Lannes SC, et al. Natural antioxidants used in meat products: A brief review. Meat Science. 2018;**148**:181-188

[3] Cuppari L. Guia de nutrição: Nutrição clínica do adulto. In: Guia de nutrição: Nutrição clínica do adulto. 2005

[4] BRASIL. Ministério da Agricultura e do Abastecimento. Decreto n° 9013, de 29 de março de 2017. Decreto dispõe sobre o regulamento da inspeção industrial e sanitária de produtos de origem animal. Diário Oficial da União, Brasília. 2017

[5] Aymerich T, Picouet PA, Monfort JM. Decontamination technologies for meat products. Meat Science. 2008;**78**(1-2):114-129

[6] Stellato G, La Storia A, De Filippis F, Borriello G, Villani F, Ercolini D. Overlap of spoilage-associated microbiota between meat and the meat processing environment in small-scale and large-scale retail distributions. Applied and Environmental Microbiology. 2016;**82**(13):4045-4054

[7] Chai C, Lee SY, Oh SW. Shelf-life charts of beef according to level of bacterial contamination and storage temperature. LWT—Food Science and Technology. 2017;**81**:50-57

[8] Wang CY, Huang HW, Hsu CP, Yang BB. Recent advances in food processing using high hydrostatic pressure technology. Critical Reviews in Food Science and Nutrition. 2016;**56**(4):527-540

[9] Hugas M, Garriga M, Monfort J. New mild technologies in meat processing: High pressure as a model technology. Meat Science. 2002;**62**(3):359-371

[10] Nascimento MDGF, Oliveira CZF, Nascimento ER. Hambúrguer: Evolução comercial e padrões microbiológicos. Boletim do Centro de Pesquisa de Processamento de Alimentos. 2005;**23**(1):59-74

[11] Brasil. Ministério da Agricultura e do Abastecimento. Instrução Normativa n° 20, 31 jul. 2000. Dispõe sobre os regulamentos técnicos de identidade e qualidade de almôndega, de apresuntado, de fiambre, de hambúrguer, de kibe, de presunto cozido e de presunto, conforme consta dos anexos desta instrução normativa. Diário Oficial da União, Brasília. 2000

[12] Romans JR, Costello WJ, Jones K, Carlson CW, Ziegler PT, et al. The Meat We Eat. Danville: The Interstate Printers and Publishers Inc.; 2000

[13] Ojha KS, Tiwari BK, Kerry JP, Troy D. Beef. In: Caballero B, Finglas PM, Toldrá F, editors. Encyclopedia of Food and Health. Oxford: Academic Press; 2016. pp. 332-338. Available from: http://www.sciencedirect.com/science/article/pii/B9780123849472000568

[14] Pires RN, Caurio CF, Saldanha GZ, Martins AF, Pasqualotto AC. Clostridium difficile contamination in retail meat products in Brazil. The Brazilian Journal of Infectious Diseases. 2018;**22**(4):345-346

[15] Instituto Brasileiro de Geografia e Estatística (IBGE). Estatística da Produção Pecuária. Brasil, Rio de Janeiro: IBGE; 2018

[16] United States Department of Agriculture (USDA). Livestock and Poultry: World Markets and Trade. Foreign Agricultural Service, out. 2018. Available from: https://apps.fas.usda.gov/psdonline/circulars/livestock_poultry.pdf [Accessed: 27 May 2019]

[17] Oliveira TLC, Ramos AL, Ramos EM, Piccoli RH, Cristianini M. Natural antimicrobials as additional hurdles to preservation of foods by high pressure processing. Trends in Food Science & Technology. 2015;**45**(1):60-85

[18] Arvanitoyannis IS. Irradiation of Food Commodities: Techniques, Applications, Detection, Legislation, Safety and Consumer Opinion. Cambridge: Academic Press; 2010

[19] Farkas J. Irradiation for better foods. Trends in Food Science & Technology. 2006;**17**(4):148-152

[20] Diehl J. Food irradiation—Past, present and future. Radiation Physics and Chemistry. 2002;**63**(3-6):211-215

[21] Morehouse KM, Komolprasert V. Irradiation of food and packaging: An overview. In: ACS Symposium Series. Washington: ACS Publications; 2004. pp. 1-13

[22] Codex Alimentarius Commission (CAC). Codex general standard for irradiated foods. CODEX STAN. 2003:106-1983

[23] Brasil. Agência Nacional de Vigilância Sanitária. Resolução RDC nº 21, de 26 de janeiro de 2001. Dispõe sobre o regulamento técnico para irradiação de alimentos. Diário Oficial da União, Brasília. 2001

[24] Stefanova R, Toshkov S, Vasilev NV, Vassilev NG, Marekov IN. Effect of gamma-ray irradiation on the fatty acid profile of irradiated beef meat. Food Chemistry. 2011;**127**(2):461-466

[25] Trindade R, Mancini-Filho J, Villavicencio A. Natural antioxidants protecting irradiated beef burgers from lipid oxidation. LWT-Food Science and Technology. 2010;**43**(1):98-104

[26] Babuskin S, Babu PAS, Sasikala M, Sabina K, Archana G, Sivarajan M, et al. Antimicrobial and antioxidant effects of spice extracts on the shelf life extension of raw chicken meat. International Journal of Food Microbiology. 2014;**171**:32-40

[27] Shah MA, Bosco SJD, Mir SA. Plant extracts as natural antioxidants in meat and meat products. Meat Science. 2014;**98**(1):21-33

[28] Trindade R, Lima A, Andrade-Wartha E. Consumer's evaluation of the effects of gamma irradiation and natural antioxidants on general acceptance of frozen beef burger. Radiation Physics and Chemistry. 2009;**78**(4):293-300

[29] Codex Alimentarius Commission (CAC). General standard for the labelling of prepackaged foods. CODEX STAN. 1985:1-1985

[30] Kume T, Furuta M, Todoriki S, Uenoyama N, Kobayashi Y. Status of food irradiation in the world. Radiation Physics and Chemistry. 2009;**78**(3):222-226

[31] Chirinos RR, Vizeu DM, Destro MT, Franco BD, Landgraf M. Inactivation of Escherichia coli O157: H7 in hamburgers by gamma irradiation. Brazilian Journal of Microbiology. 2002;**33**(1):53-56

[32] Moura AFPd. Efeito da radiação ionizante sobre a oxidação do colesterol em hambúrgueres de frango e bovino congelados. In: Universidade de São Paulo. 2004

[33] Vieira VdS. Avaliação do potencial de aplicação do processo de irradiação na redução da população de Salmonella

sp. inoculada em hambúrguer de carne de frango: Aspectos sensoriais e vida de prateleira. In: Universidade de São Paulo. 2005

[34] Sun XD, Holley RA. High hydrostatic pressure effects on the texture of meat and meat products. Journal of Food Science. 2010;**75**(1):R17-R23

[35] Yordanov D, Angelova G. High pressure processing for foods preserving. Biotechnology & Biotechnological Equipment. 2010;**24**(3):1940-1945

[36] Rodríguez-Calleja J, Cruz-Romero M, O'sullivan M, García-López M, Kerry J. High-pressure-based hurdle strategy to extend the shelf-life of fresh chicken breast fillets. Food Control. 2012;**25**(2):516-524

[37] Grossi A, Gkarane V, Otte JA, Ertbjerg P, Orlien V. High pressure treatment of brine enhanced pork affects endopeptidase activity, protein solubility, and peptide formation. Food Chemistry. 2012;**134**(3):1556-1563

[38] Sanchez-BasurtoBE,Ramírez-GillyM, Tecante A, Severiano-Pérez P, Wacher C, Valdivia-Lopez MA. Effect of high hydrostatic pressure treatment on the preservation of beef meat. Industrial & Engineering Chemistry Research. 2011;**51**(17):5932-5938

[39] Kalchayanand N, Dunne CP, Sikes A, Ray B. Inactivation of bacterial endospores by combined action of hydrostatic pressure and bacteriocins in roast beef. Journal of Food Safety. 2003;**23**:219-233

[40] Marcos B, Jofre A, Aymerich T, Monfort JM, Garriga M. Combined effect of natural antimicrobials and high pressure processing to prevent Listeria monocytogenes growth after a cold chain break during storage of cooked ham. Food Control. 2008;**19**:76-81

[41] Vercammen A, Vanoirbeek KGA, Lurquin I, Steen I, Goemaere O, Szczepaniak S. Shelf-life extension of cooked ham model product by high hydrostatic pressure and natural preservatives. Innovative Food Science & Emerging Technologies. 2011;**12**:407-415

[42] Jofre A, Aymerich T, Garriga M. Assessment of the effectiveness of antimicrobial packaging combined with high pressure to control Salmonella sp. in cooked ham. Food Control. 2008;**19**:634-638

[43] Karre L, Lopez K, Getty KJ. Natural antioxidants in meat and poultry products. Meat Science. 2013;**94**(2):220-227

[44] Jayathilakan K, Sharma G, Radhakrishna K, Bawa A. Antioxidant potential of synthetic and natural antioxidants and its effect on warmedover-flavour in different species of meat. Food Chemistry. 2007;**105**(3):908-916

[45] Lee E, Ahn D. Quality characteristics of irradiated turkey breast rolls formulated with plum extract. Meat Science. 2005;**71**(2):300-305. DOI: 10.1016/j.meatsci.2005.03.017

[46] Gonzalez MN, Hafley B, Boleman R, Miller R, Rhee K, Keeton J. Antioxidant properties of plum concentrates and powder in precooked roast beef to reduce lipid oxidation. Meat Science. 2008;**80**(4):997-1004

[47] Kulkarni S, DeSantos F, Kattamuri S, Rossi S, Brewer M. Effect of grape seed extract on oxidative, color and sensory stability of a pre-cooked, frozen, re-heated beef sausage model system. Meat science. 2011;**88**(1):139-144

[48] Naveena BM, Sen AR, Vaithiyanathan S, Babji Y, Kondaiah N. Comparative efficacy of pomegranate

juice, pomegranate rind powder extract and BHT as antioxidants in cooked chicken patties. Meat Science. 2008;**80**(4):1304-1308 Available from: http://www.sciencedirect.com/science/article/pii/S0309174008002064

[49] Vaithiyanathan S, Naveena B, Muthukumar M, Girish P, Kondaiah N. Effect of dipping in pomegranate (Punica granatum) fruit juice phenolic solution on the shelf life of chicken meat under refrigerated storage (4 C). Meat science. 2011;**88**(3):409-414

[50] Milani LIG, Terra NN, Fries LLM, Kubota EH. Effect of the extract of persimmon (Diospyros kaki L.) cv.'Rama Forte'and rosemary oily extract (Rosmarinus officinalis L.) on the sensory characteristics and color stability of frozen beef burgers. Semina: Ciências Agrárias. 2012;**33**(3):1085-1094