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Food Chemistry 76 (2002) 197–205

Food Chemistry

www.elsevier.com/locate/foodchem

The effects of herbal pre-seasoning on microbial and oxidative changes in irradiated beef steaks

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Received 27 February 2001; received in revised form 1 June 2001; accepted 1 June 2001

Abstract

This study was undertaken to examine the effects of electron beam (e^- beam) irradiation, with and without pre-seasoning with ginseng and garlic herbs, on microbial growth and oxidative stability of beef sirloin steaks. All dosages (e.g. 2, 3 and 4 kGy) of e^- beam irradiation were effective at reducing the population of psychrotrophic bacteria in beef steaks. A further reduction in psychrotroph count was observed with the pre-seasoning of garlic, in both non-irradiated and irradiated steaks. The use of 3 and 4 kGy irradiation dosages, however, increased lipid oxidation during 4 weeks of storage. Ginseng decreased malondialdehyde concentrations in sirloin steaks more than garlic after e^- beam irradiation of meats but had no effect on psychrotroph count. Inhibition of lipid oxidation by ginseng also minimized the discolouration of surface redness on sirloin steaks. The pre-application of garlic to irradiated steaks resulted in a lower hardness value and relative moisture loss. Electron beam irradiation, after pre-seasoning with ginseng or garlic, was shown to enhance the quality of beef sirloin steaks. © 2002 Published by Elsevier Science Ltd.

Keywords: Ginseng; Garlic; Irradiation; Oxidative damage; Antioxidant activity; Antimicrobial activity; Surface redness; Hardness

1. Introduction

There is increasing consumer demand for high quality meat products that are easy to prepare, nutritious and which taste good. A market survey, conducted by the Food Marketing Institute in 1999, reported that one in five shoppers chose supermarkets to be their main source of food consumed, but not prepared entirely from home (Anonymous, 1999). As a result, the food industry has drastically increased the production of ready-to-cook (RTC) and ready-to-eat (RTE) meat products to be marketed at supermarket or retail stores.

Microbial spoilage is the primary factor in quality deterioration of fresh meats. Sanitary processing practices and refrigeration of RTC and RTE products are often the principle means to control spoilage and foodborne pathogens in these types of foods (Hao et al., 1998). RTE products are less likely to cause foodborne illness than RTC products since adequate thermal treatment, applied during cooking, can reduce or eliminate all foodborne pathogens (Waters, 2000). The RTC products, which are essentially pre-portioned and pre-marinated fresh beef products, can be subjected to temperature abuse and thus lead to foodborne illness. In RTE and RTC meat products, *Escherichia coli* O157:H7, *Listeria monocytogenes and Clostridium perfringens* are the main pathogens of concern (Grant & Patterson, 1992; Hao, Bracket, & Doyle, 1998). The recent acceptance of ionizing irradiation of ground beef provides a method to eradicate foodborne pathogens in meats without significantly affecting organoleptic qualities (Grant & Patterson, 1992; Murano, 1995; Shamsuzzaman et al., 1992, 1995). Therefore, the combination of ionizing irradiation with refrigeration can be an effective measure to reduce foodborne illness and extend the shelf-life of RTC and RTE meat products.

The application of antimicrobial agents can also provide an additional level of protection beyond low temperature storage. Synthetic preservatives have traditionally been

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0308-8146/02/$ - see front matter © 2002 Published by Elsevier Science Ltd.
PII: S0308-8146(01)00265-5

used in food processing; however, increasing consumers' awareness of the potential side effects of synthetic preservatives had led to a decrease in acceptance of their use in foods (Namiki, 1990). To replace synthetic preservatives, natural compounds such as lactoferrin (Branen & Davidson, 2000; Chantaysakorn & Richter, 2000) and plant extracts (Hao et al., 1998) have been examined for controlling foodborne pathogens. Most of the examined plant extracts (e.g. bay leaf, marjoram, or thyme) are commonly used cooking herbs. The application of these herbs to RTC and RTE products can add value to meat by improving food safety and enhancing flavour (Lipsky, 2000).

Lipid oxidation is another critical factor in the rapid spoilage of meats. Phospholipid fractions in cooked-chilled meat products are especially prone to lipid oxidation, leading to the rapid development of Warm-Over Flavour (WOF) during storage (Igene, Pearson, & Gray, 1981). Furthermore, pre-marinated meats are also susceptible to lipid oxidation due to the addition of a prooxidant, salt (Chang & Watts, 1950). Previous studies involving several herbs, namely rosemary, oregano, thyme, sage, garlic and ginger, have demonstrated antioxidant activity in food systems such as egg yolk, sunflower oil and dry pork sausages (Aguirrezabal, Mateo, Dominguez, & Zumalacarregui, 2000; Al-Jalay, Blank, McConnel, & Al-Khayat, 1987; Botsoglou, Yannakopoulos, Fletouris, Tserveni-Goussi, & Fortomaris, 1997; Dapevicius, Venskutonis, van Beek, & Linsse, 1998; Hao et al., 1998; Kim, Kubota & Kobayashi, 1997; Yin & Cheng, 1998). In particular, the addition of oleoresin rosemary (Murphy, Buckley, & Gray, 1998; Stoick et al., 1991; Wong, Hashimoto, & Shibamoto, 1995), sage (Wong et al., 1995) and thyme (Hao et al., 1998) to cooked–chilled beef steaks lowered the development of WOF, decreased volatile content and increased overall sensory acceptance. In former studies, the antioxidant activities of oleoresin rosemary and sage were also demonstrated in repeated deep-fat frying of palm olein (Jaswir, Che-Man, & Kitts, 2000). Notwithstanding the antioxidant effects in foods, several investigators have also reported the health benefits of garlic, ginger and rosemary in protecting the low-density lipoprotein and the vascular endothelial cells from oxidation, as well as reducing the formation of mutagenic heterocyclic amines during cooking (Pearson, Frankel, Aeschbach, & German, 1997; Solyakov, Skog, & Jagerstad, 1999; Wei & Lau, 1998).

So far, there are few studies that have examined the combined effect of irradiation and addition of seasoning herbs on the overall quality and shelf-life of RTC pre-seasoned beef products. The objective of this study was to examine the effect of pre-seasoning with ginseng and garlic on the microbial population and oxidative stability of refrigerated stored beef sirloin steaks processed with e^- beam irradiation.

2. Materials and methods

2.1. Materials

Grade AA sirloin primal cuts were derived from *Longissimus dorsi* muscles collected from Hereford × Angus ($n = 6$) cattle raised at Lacombe Research Station (Lacombe, AB). Fresh bulbs of garlic (*Allium sativum*) and "Safeway Select" brand of honey were purchased from a local supermarket (Vancouver, BC). Purified root powder of North American Ginseng (*Panax quinquefolium*) was a gift from Chai Na Ta (Vancouver, BC). Bacto agar No.1 and peptone were purchased from Difco Laboratories (Detroit, MI). All chemicals used were of reagent grade and purchased from Sigma Chemical Company (St. Louis, MO). All solvents used for analysis were obtained from Fisher Scientific (Toronto, ON). Only distilled deionized water was used in this study.

2.2. β-Carotene bleaching test (agar diffusion method)

Antioxidant activities of fresh herbs and marinating condiments were determined by the β-carotene agar-bleaching test of Dapevicius et al. (1998). Fresh minced garlic (100 g l^{-1}) and powder ginseng (100 g l^{-1}) were both dissolved in absolute ethanol. Honey (100 g l^{-1}) was dissolved in distilled deionized water. All solutions were applied to Whatman filter paper No. 1 (1.5×1.0 cm) and the supersaturated filter papers were plated onto bacto agar containing 3.1 mg of linoleic acid and β-carotene. Bleaching of agar (i.e. oxidation of β-carotene) was carried out at ambient temperature under normal atmosphere and lighting for 24 h. The extent of the agar bleaching after incubation was quantified by the Hunterlab *L*, *a*, *b* colour system using a Hunterlab Scan 6000 model spectrocolourimeter (Hunterlab Associated Laboratories Inc., Reston, VA) and the relative antioxidant activity was derived according to a change in the Hunterlab *b* value of yellowness, Δb, between the control and samples:

$$\text{Relative antioxidant activity} = \left[\left(\Delta b_{\text{control}} - \Delta b_{\text{sample}}\right)/\Delta b_{\text{control}}\right] \times 100\%$$

2.3. Preparation of beef steaks

Grade AA sirloin primal cuts were hand-trimmed of all excess fat and connective tissue. Primal cuts were divided into individual sirloin steaks ($n = 204$) of 70–100 mm thickness using a Hobart Meat/Deli slicer (Hobart Co., Don Mills, ON), with a final weight ranging from 120.0 to 140.0 g. To all sirloin steaks was added table

salt (5 g kg^{-1}) and steaks were then randomly divided into three equal treatments ($n=68$) consisting of control, ginseng (10 g kg^{-1}) and garlic (10 g kg^{-1}). Herbs were applied topically to steaks by dry rubbing the entire surface of the steaks on both side. All sirloin steaks were individually vacuum-sealed in polyester terephthalate bags and stored for 48 h at 4 °C prior to irradiation.

2.4. Electron beam irradiation

Sirloin steaks were transported to Iotron Technologies (Port Coquitlam, BC) under refrigeration, for irradiation processing using a 60 kW high capacity, high energy (10 MeV) e^{-1} beam accelerator. Steaks within each treatment (i.e. control, ginseng and garlic) were subdivided into four equal groups ($n=17$) for irradiation at 0, 2, 3 and 4 kGy, on a single layer, at room temperature. Following irradiation, sirloin steaks from all 12 subgroups were returned to 4 °C storage for a shelf-life study.

2.5. pH determination

Duplicate beef samples were periodically removed from storage and homogenized in distilled deionized water (1:10 dilution). Homogenates were then filtered through a Whatman No. 1 filter paper to obtain a clear filtrate for pH measurement.

2.6. Microbial analyses

Enumeration of psychrotrophic bacteria was conducted according to a Health Protection Branch of Canada method (MFHPB-34; Health Protection Branch, 1997). Briefly, duplicate 25-g beef samples were aseptically removed and diluted with 225 ml of peptone water (1 g l^{-1}) and homogenized in a stomacher lab blender (Seward Medical, London, UK) for 60 s. Serial dilutions of the homogenates were made with the same diluent and duplicate samples were plated onto an Aerobic 3M Petri film (St. Paul, MN) and incubated at ambient temperature for 5 days.

2.7. Lipid oxidation analysis

A modified aqueous extraction protocol of the thiobarbituric acid (TBA) method (Buege & Aust, 1978) was used to monitor the lipid oxidation of sirloin steaks. Duplicate 2.5-g samples from each steak were first homogenized with trichloroacetic acid (200 ml l^{-1}) containing *o*-phosphoric acid (16 ml l^{-1}), and then diluted with distilled deionized water. A 2-ml sample of the diluted homogenate was mixed with 1 ml TBA (5 g l^{-1}, containing 0.2 g l^{-1} of BHT all dissolved in 0.025 mM NaOH) and heated for 15 min in a boiling water bath. Absorbance values were taken at 532 nm and lipid oxidation was reported as mg malondialdehyde (MDA) g^{-1} beef.

2.8. Colour measurement

Surface colour of sirloin steaks was determined using a Hunterlab *L, a, b* colour system. All samples were "bloomed" for 1 h under normal atmosphere at 4 °C prior to taking duplicate measurements on each steak. The percentage change in Hunterlab *a* value of redness, relative to week 0 measurements prior to irradiation, was reported for all irradiated steaks during storage.

2.9. Texture analysis

Textural characteristics of sirloin steaks were analyzed by the Texture Profile Analysis (TPA) method of Bourne (1978), using a Texture Analyzer TA-XT2 model (Texture Technologies Corp., NY). Duplicate 1 cm^3 cubes were removed from each steak and sequentially compressed twice by 80% of the original height using a cylindrical plunger at a speed of 1 mm s^{-1} at room temperature (Honikel, 1998). Textural hardness was directly measured from the deformation curve obtained for each sample according to Bourne (1978).

2.10. Relative moisture loss

Moisture contents of the steaks were determined according to the official method of AOAC (AOAC, 1980) and percentage relative moisture loss (RML) was then calculated based on the initial moisture content of the individual steak samples (Wu, Rhim, Weller, Hamouoz, Cuppett, & Schnepf, 2000).

2.11. Statistical analyses

All subgroups within each treatment were prepared in triplicate and each triplicate was sampled twice for all experiments. Analysis of variance (ANOVA) was performed either by a one-way ANOVA or a two-way ANOVA according to the General Linear Model of the MiniTab Statistical Program (MiniTab Inc., PA). Comparisons of means were analyzed by Tukey's test ($\alpha=0.05$) using the same MiniTab statistical program.

3. Results and discussion

Pathogenic bacteria, such as *Escherichia coil* and *Listeria monocytogenes*, are commonly found in fresh meats and represent a safety hazard when undercooked meats are consumed. Ionizing irradiation is considered to be the most effective technology to eliminate pathogenic bacteria in raw meats (Gants, 1996). However, e^{-}

beam irradiation has a limited penetration depth in comparison to gamma rays and may, therefore, be less effective towards the pasteurization of foods of irregular shape or having a low surface-to-volume ratio. Nevertheless, the microbial quality of irradiated meats can be affected by other factors, such as initial bacteria load, storage condition, microbial quality of additives present and processing condition (Hettiarachchy, Glen, Gnanasambandam, & Honhson, 1996).

After 4 weeks, vacuum storage at 4 °C, a 2-log increase in the number of psychrotrophic bacteria in non-irradiated steaks was detected (Table 1). All irradiation dosages were effective at lowering the number of psychrotrophs in sirloin steaks during storage, although an increase in irradiation dosages beyond 2 kGy did not significantly increase the log reduction of psychrotrophic bacteria. This result was also observed at 6 and 8 weeks of storage (data not shown). Murano (1995) reported a D_{10} value of 0.4–0.6 kGy for *L. monocytogenes*, a psychrotrophic pathogen, following irradiation treatment and that a dosage of 1.5 kGy was required to reduce the population by 3 log. In the present study, we report only a moderate 2-log reduction in psychrotrophs after using an e^- beam irradiation dosage of 4 kGy. Pre-seasoning with ginseng was ineffective at reducing the psychrotroph population in both non-irradiated and irradiated steaks. A reduction in bacterial count, of both non-irradiated and irradiated garlic pre-seasoned steaks at week 2, was observed and this was due, mainly, to an synergistic antimicrobial effect between garlic pre-seasoning and e^- beam irradiation. This finding agrees with the results of previous studies that demonstrated the antimicrobial effect of garlic on selected Gram positive and Gram negative bacteria, as well as several yeast strains (Yoshida et al., 1998; Yoshida, Iwata et al., 1999; Yoshida, Katsuzaki et al., 1999). Five sulfur-containing compounds isolated from garlic were effective against the selected Gram positive, negative and yeast strains at various concentrations (Yoshida et al., 1998, 1999; Yoshida, Katsuzaki et al., 1999). Moreover, the inhibition of psychrotrophic bacteria has also been shown by other plant extracts, including bay leaf, carrot root, pimento leaf, thyme and eugenol (Hao et al., 1998).

The pH of fresh meat can be influenced by the presence of bacteria and may reflect the relative differentiation between the presence of Gram positive or Gram negative bacteria. Organic acids, produced by Gram positive bacteria, decrease the pH of meats, whereas amines produced by Gram negative bacteria increase pH (Lefebvre et al., 1994). The significant decrease in pH of non-irradiated steaks after 4 weeks of storage could be explained by the preferential proliferation of Gram positive psychrotrophic bacteria (Table 1). The significant ($P<0.05$) inverse relationship between pH and the number of psychrotrophic bacteria supports this suggestion. It has been shown that 2 kGy irradiation will alter the microflora population in anaerobically-packaged prime beef cuts from Gram negative to Gram positive bacteria (Niemands, Vab der Linds, &

Table 1
The psychrotrophic bacteria counts and pH values of sirloin steaks irradiated at 0, 2, 3 and 4 kGy as influenced by the pre-seasoning of ginseng and garlic[a]

Sample	Dose (kGy)	Week storage			
		2	4	2	4
		Psychrotroph count (log cfu g^{-1} beef)		pH	
Control	0	4.42±0.03b	4.49±0.46b	5.3±0.1b	4.9±0.1c
(3.19±0.08a)[b]	2	2.74±0.16a	3.45±0.03a	5.5±0.1a	5.1±0.1b
(5.5±0.1a)[c]	3	2.81±0.19a	3.42±0.05a	5.5±0.1a	5.2±0.1b
	4	2.66±0.13c	3.40±0.02a	5.6±0.1a	5.3±0.1b
Ginseng	0	4.40±0.05b	TNTC[c]	5.4±0.1b	4.9±0.1c
(3.09±0.06a)	2	2.98±0.09a	TNTC[d]	5.7±0.1a	4.7±0.1c
(5.6±0.1a)	3	2.83±0.17a	TNTC[e]	5.7±0.1a	4.8±0.1c
	4	2.55±0.13c	TNTC[e]	5.7±0.1a	4.8±0.1c
Garlic	0	3.41±0.02a	TNTC[c]	5.6±0.1a	5.0±0.1b
(3.16±0.09a)	2	2.59±0.11c	3.42±0.01a	5.7±0.1a	4.8±0.1c
(5.6±0.1a)	3	2.65±0.25c	3.40±0.02a	5.6±0.1a	4.8±0.1c
	4	2.46±0.04c	3.44±0.04a	5.7±0.1a	4.9±0.1c

[a] Values represent the average of six measurements±S.E.M. at dilutions of 1:10 to 1:1000. a–d Values with different letters are significantly different ($P<0.05$).
[b] An average psychrotroph count of all samples prior to irradiation.
[c] An average pH value of all samples prior to irradiation.
[d] TNTC denotes too numerous to count at a dilution of 1:1000.
[e] TNTC denotes too numerous to count at a dilution of 1:100.

Holzapel 1981). A moderate decrease in pH during storage was also observed for all irradiated control sirloin steaks, thereby suggesting that Gram negative bacteria were eliminated by irradiation. Moreover, the microflora shift from Gram negative bacteria to Gram positive bacteria, after irradiation, increased drastically when the dosage was increased from 1 to 5 kGy, possibly due to the greater radiosensitivities of Gram negative bacteria to ionizing radiation (Lefebvre, Thibault, Charbonneau, & Piette, 1992). In addition to the effects of e^- beam irradiation, it was also noted that both ginseng and garlic herbs significantly decreased meat pH by week 4 of storage, regardless of the dosage of irradiation used. It is conceivable that, in these steaks, an accelerated breakdown of the ginseng and garlic herbs, possibly by the microorganism present, occurred during storage following irradiation and these products in turn may have affected pH of all pre-seasoned steaks when exposed to prolonged (e.g. 4 week) storage.

Oxidation of unsaturated fatty acids in meats is an important process that limits the shelf-life of fresh beef by producing unfavourable flavour and texture changes (Ladikos & Lougovois, 1990). There is increasing interest in the use of herbs and plants as natural antioxidants for ready-to-serve meat products (Karpinska, Borowski, & Danowska-Oziewicz, 2001). Phenolic compounds in herbs are generally recognized as the active components eliciting an antioxidant effect. Based on characteristic differences in chemical structure, different phenolic compounds exhibit different antioxidant activity affinities (Pekkarimen et al., 1999). Moreover, the interfacial dispersion of phenolic compounds in a multiphasic food system can greatly affect antioxidant activity (Huang et al., 1997).

In the present study, both ginseng and garlic were initially assessed using the β-carotene agar assay for antioxidant activity (Table 2). In this assay, active constituents were applied topically in an attempt to prevent linoleic acid oxidation by scavenging lipid peroxides in and on the agar before the initiation of oxidation of β-carotene and bleaching of the agar. Visual assessment of the agar showed that BHT, ginseng and garlic were able to retain surface colour to the area of agar applied only. Subsurfaces immediately beneath the applied area, were observed to be colourless, suggesting the inability of the herbs to diffuse into the solid agar and inhibit lipid oxidation. This was confirmed by the Hunterlab colourimetry results (Fig. 1), where ginseng at a concentration of 100 g l^{-1} was most effective at minimizing the bleaching of the agar, followed by BHT and garlic at 100 g l^{-1}. Honey, which was the most viscous sample, did not prevent the bleaching of the agar, thus ruling out the indirect effect of altering water activity on lipid oxidation in this model system

In muscle foods, oxidative damage can occur in either polar or non-polar phases. For example, oxidation of phospholipids will occur at the muscle fibre lipid bilayer membrane, whereas oxidation of oxymyoglobin is associated with the sarcoplasm (Ahn, Sell, Chen, Wu, & Lee, 1998; Schaefer, Liu, Faustman, & Yin, 1985). Therefore, the degree of protection offered by ginseng and garlic against surface lipid and oxymyoglobin oxidation could depend on the characteristic physical partitioning of both herbs. The results obtained with the β-carotene model study support this suggestion.

Since maximum lipid oxidation is known to occur mainly on the surface (due to maximum exposure to oxygen), topical application of herbs was thought to be adequate in preventing lipid oxidation of sirloin steak. However, earlier results, from the β-carotene agar, demonstrated that lipid oxidation in a solid medium can occur on both the surface and subsurface location, and herbs applied topically may therefore be ineffective in preventing subsurface lipid oxidation due to the low

Table 2
Relative antioxidant activity of common herbs and condiment as determined by the β-carotene agar bleaching test[a]

Sample	Relative antioxidant activity (%)	S.E.M
Ginseng[b]	80.8	0.28
Garlic[c]	9.98	0.60
Honey[c]	0.10	0.10
BHT	78.9	0.22

[a] Values represent the average of six measurements ±S.E.M.
[b] Ginseng at a concentration of 100 g l^{-1}.
[c] Garlic and Honey at a concentration of 100 g l^{-1}.

Table 3
The malondialdehyde concentration in sirloin steaks irradiated at 0, 2, 3 and 4 kGy as influenced by the pre-seasoning of ginseng and garlic[a]

Sample[b]	Dose (kGy)	MDA[c] concentration (mg MDA g^{-1}beef)	
		Week of storage	
		2	4
Control (1.33±0.17a)	0	1.69±0.24a	1.51±0.15a
	2	1.89±0.30b	1.75±0.15a
	3	2.01±0.40c	2.23±0.20c
	4	2.01±0.26c	2.77±0.18d
Ginseng (0.98±0.04a)	0	1.63±0.43a	1.69±0.23a
	2	1.62±0.34a	1.59±0.10a
	3	1.68±0.13a	2.13±0.19c
	4	1.50±0.23a	2.65±0.31d
Garlic (1.23±0.11a)	0	1.59±0.14a	1.92±0.19c
	2	1.83±0.39b	1.85±0.11a
	3	1.95±0.16c	3.36±0.41e
	4	2.05±0.47c	2.82±0.39d

[a] Values represent the average of 6 measurements ±S.E.M. a–e Values with different letters are significantly different ($P<0.05$).
[b] An average MDA concentration of all samples prior to irradiation.
[c] MDA denotes malondialdehyde.

rate of diffusion. As a result, it was considered necessary to examine lipid oxidation of the entire steak, and not just the surface of the steak where the herbs were applied.

The relative effect of ginseng and garlic to limit lipid oxidation in sirloin steaks is presented in Table 3. Addition of garlic had no effect after 2 weeks storage and significantly increased the MDA concentration of irradiated steaks after 4 weeks of storage. This apparent prooxidant activity result may be due to the participation of allium reducing constituents and the oxidation of hydrogen peroxide generated from irradiation, as described in the Fenton reaction. Furthermore, Whitburn, Shieh, Sellars, Hoffman, and Taub (1982) observed the generation of hydrogen peroxide by γ-radiolysis of an aqueous ferrimyoglobin solution that resulted from the union of two hydroxyl radicals produced from oxidized proteins. Our previous findings confirmed the increased production of hydroxyl radical in the presence of myoglobin after irradiation by high-intensity ultraviolet radiation (Wong & Kitts, 2001). It is conceivable that the reducing capacity of allium constituents maintained the heme iron in the ferrous form and therefore, the decomposition of the preformed hydrogen peroxide to hydroxyl radicals would catalyze lipid oxidation. Ginseng, on the other hand, appeared to inhibit lipid oxidation in irradiated sirloin steaks by lowering MDA concentration after 2 weeks storage. However, this effect was lost after 4 weeks of storage. The active components in ginseng (e.g. alcohol-soluble ginsenosides) have very little reducing capacity, a high radical-scavenging activity and a higher affinity towards the lipid phase (Hu & Kitts, 2001; Kitts, Wijewickreme, & Hu, 2000). Thus, ginseng was not a prooxidant and its lipophilic characteristic increased the effectiveness of ginseng at lowering lipid-based oxidative damage more than garlic after irradiation processing and storage.

A loss of surface redness of non-irradiated control steaks (i.e. spontaneous oxidation of oxymyoglobin to metmyoglobin) can be attributed to a decrease in dissolved oxygen, due in part to the utilization of oxygen by psychrotrophic bacteria, and the participation in oxidative reactions such as lipid oxidation. Oxidation of oxymyoglobin, as measured by the change in surface redness on the sirloin steaks, was reduced by the presence of ginseng during storage (Fig. 2). Garlic was less effective at maintaining surface redness of sirloin steaks than ginseng. Since the production of water-soluble lipid peroxide can induce oxymyoglobin oxidation (Schaefer et al., 1985), the possibility that ginseng was more effective at inhibiting lipid oxidation, due to greater partitioning with the lipid phase, would also result in protection against peroxyl radical-induced oxymyoglobin oxidation. In addition, the exposure of meat to irradiation can increase the production of water-soluble free radicals (e.g. hydroxyl radical), which would increase oxidation of oxymyoglobin (Renerre, 1990). This effect was particularly noted in irradiated and garlic pre-seasoned steaks.

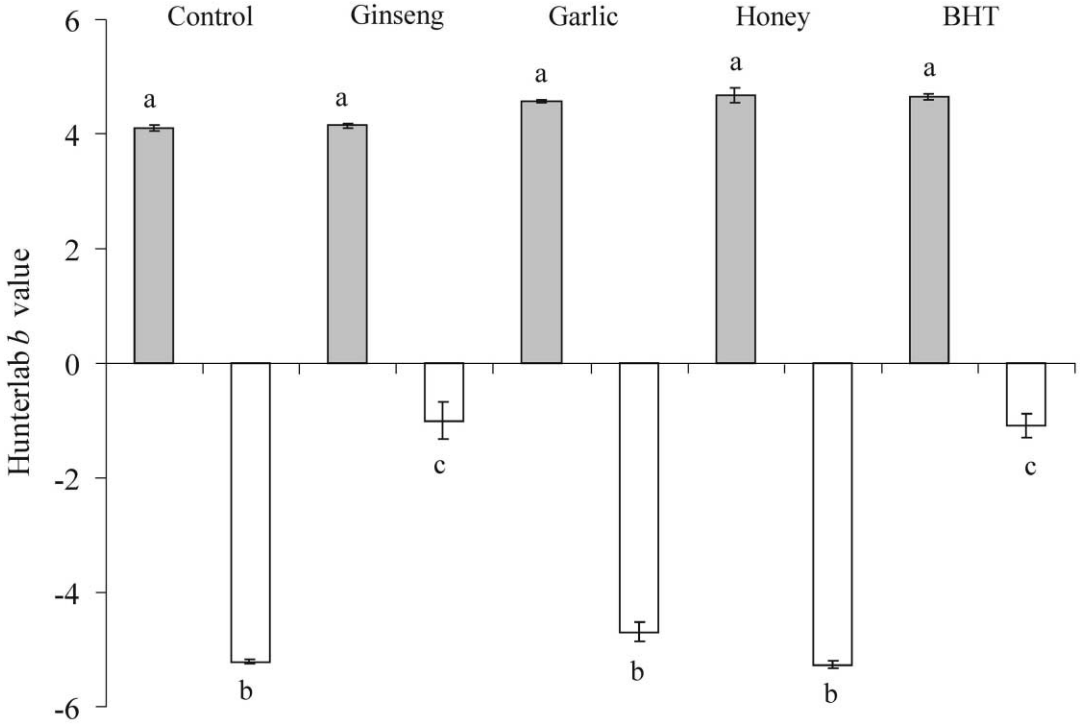

Fig. 1. Oxidation of β-carotene agar as measured by Hunterlab *b* value for yellowness. The colour of agar before incubation (open) and after incubation (shaded) are presented as the average of six measurements ±S.E.M. Columns with different letters are significantly different ($P < 0.05$).

Table 4
The effects of ginseng and garlic on the hardness, chewiness and relative moisture loss of sirloin steaks irradiated at 0, 2, 3 and 4 kGy as on week 2 and 4 of 4 °C storage[a]

Sample	Dose (kGy)	Week of storage			
		2	4	2	4
		Hardness (g)		Relative moisture loss (%)	
Control (1420±119a)[b]	0	343±142a	1510±257b	2.1±0.9a	4.5±2.4a
	2	1370±494c	1610±250b	4.2±0.8b	6.4±1.7b
	3	1420±439b	1910±382b	5.9±2.7b	6.9±1.1b
	4	1440±322b	2780±949g	6.5±1.6b	7.1±2.9b
Ginseng (1630±123a)	0	909±158d	1450±187b	2.7±1.2a	2.0±0.9a
	2	1690±556b	2500±768g	2.4±1.4a	3.9±2.3b
	3	1270±167b	2340±536g	2.8±1.6a	6.9±2.1b
	4	3680±994e	3650±709e	3.8±1.8b	6.8±2.6b
Garlic (1580±167a)	0	1390±219b	3250±521d	ND[c]	ND
	2	1050±390b	2030±492g	ND	ND
	3	924±255f	1500±696b	ND	ND
	4	754±166f	928±164f	ND	ND

[a] Values represent the average of 6 measurements ±S.E.M. a–g Values with different letters are signifcantly different ($P<0.05$).
[b] An average hardness value of all samples prior to irradiation.
[c] ND denotes not detected.

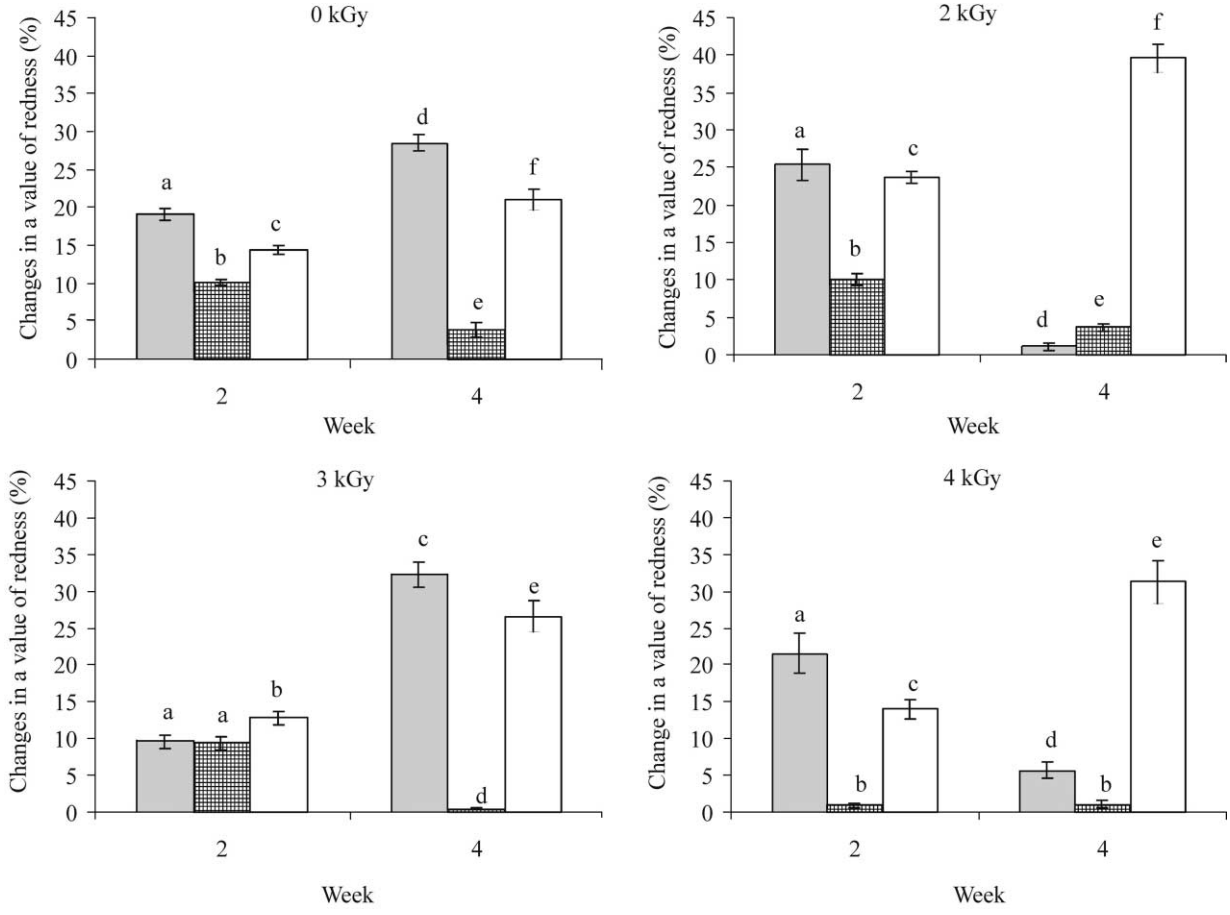

Fig. 2. The effects of control (shaded), ginseng (checkerboard) and garlic (open) on the percentage changes in Hunterlab *a* value for redness of sirloin steaks after irradiation at 0, 2, 3 and 4 kGy. All values represent the average of six measurements ±S.E.M. Columns with different letters are significantly different ($P<0.05$).

Oxidative damages to the sarcoplasm may also involve changes in moisture loss and texture (Ladikos & Lougovois, 1990; Mitsumoto, Arnold, Schaefer, & Cassens, 1995). For all practical purposes, RTE and RTC meats will not likely be marketed for more than 4 weeks, and therefore only textural changes up to 4 weeks of storage are of importance. The hardness and relative moisture loss of all sirloin steaks at weeks 2 and 4 are shown in Table 4. Hardness value was significantly ($P < 0.05$) increased by the seasoning of steaks with ginseng. Since bioactive ginseng constituents most likely partitioned with the lipid phase, it is conceivable that the antioxidant properties of this herb were not effective at protecting the more polar sarcoplasm. Irradiation of sirloin steaks further increased the hardness values of both control and ginseng pre-seasoned steaks, but the opposite trend was observed with the irradiation of garlic pre-seasoned steaks (Table 4). Nevertheless, relative moisture loss was reduced in the presence of ginseng after 2 weeks, storage and no relative moisture loss was observed in the presence of garlic after 4 weeks, storage. One possible explanation for the observed effect with the ginseng herb could be that the sugar-containing ginsenoides (Kitts, 2000) provided a hygroscopic effect, thereby reducing moisture loss from the inter- and intramuscular fibres. In addition, the protection of muscle membrane from lipid oxidation by applying lipid-soluble antioxidants can also maintain membrane integrity of muscle fibres and reduce moisture loss (Mistumoto et al., 1995).

4. Conclusion

Electron beam irradiation of sirloin steaks at all dosages tested was effective at reducing the number of psychrotrophic bacteria, to a maximum of 2-log cycles. The pre-seasoning of garlic worked synergistically with e^- beam irradiation in decreasing the psychrotophic bacteria count of sirloin steaks. Significant increases in both MDA concentration and hardness, as well as a decrease in surface redness, were observed at both 3 and 4 kGy dosages of irradiation. A decrease in muscle pH during storage indicated the presence of Gram positive bacteria. Ginseng exhibited a greater antioxidant effect than garlic, as evaluated by the β-carotene agar assay and reduced lipid oxidation in irradiated steaks. The greater affinity of ginseng to diffuse through a solid medium to the site of lipid oxidation could explain the greater antioxidant activity observed in both instances. The reduction in lipid oxidation by ginseng also corresponded to a maintenance of surface redness of sirloin steaks during storage. Hardness value of sirloin steaks was minimized in the presence of garlic, a possible reflection of the lower relative moisture loss in pre-seasoned steak attributed to the protection of sarcoplasmic protein.

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