



Volatile compounds and odor traits of dry-cured ham (Prosciutto crudo) irradiated by electron beam and gamma rays

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HIGHLIGHTS

- The effects of gamma rays and electron beam irradiation on odor traits and volatile compounds of dry-cured hams were analyzed.
- Electron beam is better in maintaining ham odor than gamma rays at same doses.
- Both gamma rays and electron beam irradiation at dose of 6 kGy lead to the development of off-odors in hams.
- Gamma rays irradiation at dose of 6 kGy results in additional volatile compounds changes and worse odor.

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Chemical compounds studied in this article:

(Z)-7-hexadecenal (PubChem CID:

5364438)

E-9-tetradecen-1-ol formate (PubChem CID:

5364715)

Undecane (PubChem CID: 14257)

Phthalic acid, 2-cyclohexylethyl butyl ester

(PubChem CID: 6423436)

1-heptadecene (PubChem CID: 23217)

Heptasiloxane, hexadecamethyl- (PubChem

CID: 10912)

Decanoic acid, ethyl ester (PubChem CID:

8048)

(E,E)-2,4-decadienal (PubChem CID:

5283349)

Octadecane (PubChem CID: 11635)

ABSTRACT

Prosciutto crudo samples were irradiated at 0, 3 and 6 kGy by gamma rays (GR) and electron beam (EB), respectively. The odor scores and volatile compounds were examined after 7 days storage at 4 °C. Volatile compounds from samples without and with irradiation at 6 kGy were analyzed by GC–MS. Fifty-nine compounds were identified, including terpenes, aldehydes, alcohols, ketones, alkanes, esters, aromatic hydrocarbons and acids. Both GR and EB irradiation resulted in formation of (Z)-7-Hexadecenal, cis-9-hexadecenal, tetradecane, E-9-tetradecen-1-ol formate, and losing of hexadecamethyl-heptasiloxane and decanoic acid-ethyl ester in hams. However, GR irradiation caused additional changes, such as formation of undecane and phthalic acid-2-cyclohexylethyl butyl ester, significantly higher level of 1-pentadecene, and losing of (E, E)-2,4-decadienal and octadecane. EB was shown to be better in maintaining ham's original odor than GR. Our results suggest that EB irradiation is a promising method for treatment of ready to eat hams as it exerts much less negative effect on the flavor of hams compared to GR irradiation.

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1. Introduction

As a “Ready-To-Eat” (RTE) product, dry-cured ham is one of the most popular foods throughout the world. It is produced in many

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countries, and a large variety of types are available. Prosciutto crudo, one of the most typical meat products in Italy, has been made and acknowledged since Roman times (Ferrentino et al., 2013; Laureati et al., 2014; Storrustlökken et al., 2015). There are two famous types of Italian prosciutto crudo: prosciutto crudo di Parma and prosciutto crudo di San Daniele. In 2006, over 9 million thighs were processed for Parma ham, and over 2.5 million for San Daniele (Pugliese et al., 2010).

The cured Prosciutto crudo is different from either bacon or pancetta. It is usually thinly sliced and eaten as is. Sometimes it is lightly cooked in order to bring out the aroma and merge flavors (Flores, 1997). The stages of producing Prosciutto includes salting with sea salt, resting, and dry-aging. The penetration of the salt, the evaporation of the water, and the variations in acidity take place during these processes, giving rise to a slow selection of the microbial flora that leads to proliferation of lactobacilli capable of determining the final sensory characteristics of the prosciutto. Salting is a crucial phase in the process because the amount of salt used has to guarantee both an adequate preservation by inactivating microbial growth and a pleasant flavor (Flores, 1997; Garcia-Gil et al., 2013). Numerous chemical reactions take place during curing due to microbial activities that gradually making the meat easy to digest. The whole curing process is very delicate because any excessive microbial proliferation could facilitates unwanted reactions, such as acid fermentation caused by acidifying microorganisms, which directly affects the shelf-life and quality of ham including meat texture, color, and flavor etc (Blesa et al., 2008; Martin et al., 2008).

The typical pH of hams ranges from 5.77 to 6.85 (Ruiz-Ramirez et al., 2005; Serra et al., 2005), and the water activity ranges from 0.6 to 0.9 (Serra et al., 2005). People used to believe that hams under these conditions are safe even in an unstable, non-refrigerated and uninspected environment. But according to the Meat and Poultry Hazards Control Guide made by the U.S. Department of Agriculture's Food Safety and Inspection Service (FSIS), meat pH should be declined to 5.3 within an acceptable time and temperature combination (FSIS, 2005).

Since these meat products do not require further treatment (such as cooking) before consumption, the absence of pathogenic microorganisms is paramount. Although the physico-chemical parameters are not propitious to the growth of the bacteria, prosciutto crudo particularly vulnerable to contamination with microorganism from environment, utensils or personnel during the manufacture process, such as cutting, slicing and packing (Galan et al., 2011).

Listeria monocytogenes is considered as the major pathogen affecting safety of RTE meat, causing high mortality rate up to 20%. In USA, zero-tolerance policy for *L. monocytogenes* in RTE meat is adopted, which requires a Food Safety Objective (FSO) value below 0.04 CFU/g at the retailer stage. In Europe, the FSO value is 100 CFU/g for RTE meats, or the criterion "not detected in 25 g" is applied before the product leaves the production plant if the manufacturer cannot demonstrate the achievement of FSO value (Sara et al., 2014).

L. monocytogenes is widely distributed in the environment, and has been often isolated from wet and cool food processing environment. It is a compulsory step to eliminate *L. monocytogenes* for RTE meat products before marketing. But *L. monocytogenes* is psychrotrophic and can survive during refrigeration and storage. It can grow at pH levels between 4.4 and 9.4 (FAO/WHO, 2004). Traditional heat treatment can inactivate *L. monocytogenes*, the D-values at 61 °C and 65 °C were 124 s and 16.2 s, respectively. The effectiveness of inactivation by pasteurization depends upon package size and characteristics of products (Meijun et al., 2005). But heat treatment may involve undesirable changes of the quality characteristics of the product. Like any other RTE foods, prosciutto

crudo requires additional non-thermal treatment to control the microbiological quality without modifying the sensory quality.

Irradiation is a safe and effective method among the existing technologies for meat preservation (Alfaia et al., 2007), and is proven to be one of the best technologies in eliminating pathogens from raw meat and extending shelf life (Bari et al., 2006; Trindade et al., 2010). When irradiation is applied for packaged foods, it also protects food from environmental recontamination. Food irradiation is a "cold treatment", used at bactericidal levels which do not substantially raise the internal temperature, leaving the food closer to its original texture and nutritional state. According to IAEA NTR 2008 (IAEA, 2008), applications of irradiation doses may be grouped into three categories: low dose (up to 1 kGy) for sprout inhibition, delay ripening, and insect disinfestation; medium dose (1 kGy to 10 kGy) for reduction of spoilage and pathogenic microbes in meat, poultry, seafood, and spice; high dose (above 10 kGy) for sterilization of packaged food and improved rehydration. The US has approved using irradiation for reduction of bacterial contamination in foods, such as beef, poultry, pork, molluscan shellfish, eggs, fresh fruit and vegetables, spices and seasonings, lettuce and spinach, and seed sprouting. The maximum doses for poultry, refrigerated meat, and frozen meat are 3.0, 4.5 and 7.0 kGy, respectively (Kundu et al., 2014; Li et al., 2015).

Irradiation has been used at as many as 40 different foods to control microbial contamination and prevent sprouting or insect pest disinfestations in about 60 countries. Currently, gamma sources, electron beam generators, and X-ray accelerators are most commonly used for food irradiation (Kundu et al., 2014; Li et al., 2015). Electron beam irradiation is a promising method with a potential to reduce the burden of foodborne illness, and could become an alternative when thermal treatment is not an option. Electron beam irradiation inspires greater consumer confidence because of its radioisotope-free nature. Electron beam also has higher dose rate (10^3 – 10^5 Gy/s) than gamma rays (0.01–1 Gy/s), thus less time is required for equivalent pasteurization treatment (Li et al., 2015). So far, fresh and dry-fermented meat products have been developed and prepared as RTE using electron beam irradiation (Galan et al., 2011).

Meat products are rich in fat. Lipid oxidation, as a secondary effect of ionizing radiation, is a major cause of flavor development (Kundu et al., 2014; Trindade et al., 2010). The flavor of hams is produced by a complex mixture of volatile compounds, which are formed from chemical or enzymatic oxidation of unsaturated fatty acids and further interaction with proteins, peptides and free amino acids, or from spices added in the production process, such as garlic or pepper (Marusic et al., 2011; Marusic et al., 2014). Volatile compounds are markedly affected by production aspects (rearing, salting and curing), geographical origin and ripening process of raw meat (Pham et al., 2008). Fatty acids, esters and some sulfur and nitrogen containing compounds are potent odor-active compounds with a low odor threshold. For instance, propyl and amyl formates are the most abundant esters present in San Daniele hams whereas butanoates and hexanoates are the most important esters in Iberian and Parma hams (Del Pulgar et al., 2011).

For meat irradiation, the major concerns of effects on nutritional value and sensory characteristics are lipid oxidation, meat color fading and off-odor production (Alfaia et al., 2007). Gamma rays irradiation of meat often led to the development of off-odors, color and rancid flavors in beef (Chen et al., 2007; Park et al., 2010).

However, few studies have compared the influence of gamma rays to electron beam irradiation on the odor and volatile compounds of hams. Previous research from our laboratory demonstrated that electron beam irradiation was superior to the gamma irradiation in keeping sensory traits of meats. The purpose of this

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