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# The feasibility of pulsed light processing in the meat industry

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**Abstract.** Today, the increasing demand for minimally processed foods that are nutritious, sensorially acceptable, and free from microbial, chemical and physical hazards, challenges research and development to establish alternative methods to reduce the level of bacterial contamination. As one of the newly developing non-thermal methods, pulsed light is a technology for the fast, mild, and residue-free surface decontamination of meat and meat contact materials in the meat processing environment. This review provides specific information on pulsed light technology and the feasibility of its application for unpackaged and packaged meat and meat products as well as meat contact materials. The advantages, limitations and achieved effects of pulsed light on microbial inactivation, lipid peroxidation, sensory quality and color of meat, seafood and meat products are illustrated and discussed in relation to its implementation on the industrial level.

## 1. Introduction

Food safety has become an essential priority for authorities and consumers worldwide, especially concerning perishable products such as those of animal origin. Considering meat as an excellent substrate for microbial growth, numerous thermal and non-thermal decontamination and preservation methods have been developed in order to sustain its safety and quality. Here, next to other food processing technologies—e.g. high pressure, pulsed electric field [1], osmotic dehydration, radio frequency electric field, ultrasound, irradiation, and chemical and biochemical hurdles (e.g. organic acids, enzymes, plant derived antimicrobials)—pulsed light (PL) application promises to reduce the likelihood of food being a vector for bacterial infection and toxin production [2]. In addition, different sources describe PL, also known as intense light pulses (ILP), pulsed white light and pulsed UV light, as a fast and mild alternative decontamination method that retains the natural appearance of the foods while being of energy saving and of environmental interest. It is based on the application of short time light pulses with an intense broad spectrum [3]. PL includes the employment of inert gas flash lamps to transform short duration as well as high power electric pulses into short duration and high-power pulses of radiation having similar spectrum to that of the sun (200–1100 nm), including infrared (IR), visible light (VL) and ultraviolet (UV). To adequately characterize the effects of PL, basic measures should be taken into consideration, including, but not limited to fluence (F) [ $\text{J m}^{-2}$ ] that describes the total radiant energy that is received from the light source by the matrix per unit area during the treatment time (in seconds) and the number of pulses (n) applied during the whole treatment [2].



These pulses inactivate the microorganisms at the surface level of food and the packaging material [4]. UV light is absorbed by the microbial DNA, which leads physico-chemical changes in its structure, damaging the genetic information and resulting in impaired replication and gene transcription as well as eventual cell death [5]. The objective of the present review is to provide current and practical information on the feasibility of PL treatments for meat and meat products in terms of bacterial inactivation. However, since non-thermal methods of food preservation are being developed to eliminate or at least minimize the quality degradation of foods that result from thermal processing, special attention will be paid to the effect of PL on sensory quality and color of different varieties of meat, meat products including game, poultry and seafood.

## 2. Microbial inactivation

In general, around 2.0 log CFU/mL reduction of the initial microbial count was achieved after PL treatments, independently of the target microorganism and the matrix. *Listeria monocytogenes* and *Salmonella enterica* were the main studied microorganisms in fish after applying PL treatments. Overall, similar values of *L. monocytogenes* decontamination were found in both meat (0.9-2.24 log CFU/mL) and fish/seafood (0.7-2.4 log CFU/mL), whereas for *S. enterica* the values were ~ 2.0 log CFU/mL [6]. Moreover, Hierro *et al.* [7] assessed the feasibility of PL treatments (0.7, 2.1, 4.2, 8.4 and 11.9 J/cm<sup>2</sup>) to enhance the safety of beef and tuna carpaccio. The results indicated a significant reduction in the initial microbial count (~1 log CFU/cm<sup>2</sup>) of the samples inoculated with *Vibrio parahaemolyticus*, *E. coli*, *L. monocytogenes* and *Salmonella* Typhimurium after applying PL treatments (8.4 and 11.9 J/cm<sup>2</sup>), and obtained a significant improvement in the food safety of these products.

The results obtained in the investigation of Rajkovic *et al.* [8] demonstrated that under all tested conditions, PL treatment was equally effective in inactivation of all pathogens (*E. coli* O157, *Staphylococcus aureus*, *L. monocytogenes*, and *Salmonella* spp.) inoculated on the surface of the fermented salami slices, with a maximum microbial inactivation of ~2.2 log CFU/g. The overall difference in the mean log reduction achieved, between all pathogens, was smaller than 0.2 log CFU/g, which is in agreement with the findings of Gomez-Lopez *et al.* [9] who did not observe any difference in the susceptibility among different groups of microorganisms, after studying 27 different bacterial, yeast, and mold species. In contrast, research of Ganan *et al.* [10] reported that *S. Typhimurium* showed a slightly higher resistance to PL than *L. monocytogenes*, although these differences tended to disappear at the highest fluences assayed.

The results of Rajkovic *et al.* [11] also demonstrated that under all tested conditions, PL treatment was equally effective ( $P > 0.05$ ) in inactivation of both *L. monocytogenes* and *E. coli* O157:H7 inoculated on the surface of the slicing knife. The overall difference in the mean log reduction achieved, between the two pathogens, was less than 0.1 log (N0/N), i.e. mean log reductions were 4.57 log (N0/N) for *L. monocytogenes* and 4.62 log (N0/N) for *E. coli* O157:H7.

## 3. Lipid peroxidation

In general, continuous UV light induces intensive lipid peroxidation due to the longer exposition time necessary to achieve a suitable light dose for effective inactivation of surface microorganisms in meat. By its nature, PL is a very intensive UV light, from which the lipid peroxidation in treated meat can occur. Lipid peroxidation is a very important factor because it usually causes meat deterioration [12]. However, in the investigation of Rajkovic *et al.* [8], both vacuum and modified atmosphere packed samples of sliced fermented salami were PL treated before they were packed and kept under refrigerated storage conditions for 9 weeks. The fermented salami slices, untreated (control) and PL treated, were analyzed for lipid oxidation changes after the first day and 3, 6 and 9 weeks of cold storage. Immediately after the PL treatment, on the first day of cold storage, dry fermented salami kept in vacuum showed no significant difference in the concentration of malondialdehyde (MDA) between the control (0.33mg MDA/kg), 3 J/cm<sup>2</sup> (0.31mg MDA/kg) and 15 J/cm<sup>2</sup> treated samples (0.49mg MDA/kg). Similar results were noted for the salami kept in modified atmosphere. The MDA concentration in salami kept both in vacuum and modified atmosphere, in all three salami groups (control, 3 J/cm<sup>2</sup> treated and 15 J/cm<sup>2</sup>

treated), continually increased during the cold storage, but a significant difference ( $p < 0.05$ ), compared to the values obtained after the first day of storage, was observed only after 9 weeks of storage. The highest MDA concentration (1.23mg MDA/kg) in all of the salami samples investigated for lipid oxidation was observed in ready-to-eat dry fermented salami (modified atmosphere, treated with 15 J/cm<sup>2</sup>) after a period of 9 weeks [8]. Similar results were reported for chicken meat [13], chicken frankfurters [14] and vacuum packed ham slices [15] by other researchers. Koch *et al.* [16] also did not find any association of PL treatment with lipid peroxidation, due to low oxidation level induced by PL treatments on pork skin ( $<0.12 \mu\text{g/g}$ ). When applied in pulsed form, the short duration of the pulse limits oxidative changes in lipids due to the short half-life of the p-bonds, which prevents efficient coupling with oxygen [17], and which could explain the low 2-thiobarbituric acid-reactive substance levels observed in PL treated meat and meat products.

#### 4. Sensory quality

In the research of Tomasevic [18], PL treatment did not significantly change appearance and total score values of beef. The color score also remained unchanged regardless of the level of fluence applied, which was in contrast of the findings of Hierro *et al.* [19], where the color of beef was assessed by panel members as slightly lighter after the treatment of 11.9 J/cm<sup>2</sup>. The application of 1-pulse (3.4 J/cm<sup>2</sup>) in [18] significantly decreased the score for beef odor, while this happened only after 8.4 J/cm<sup>2</sup> was applied to beef carpaccio [19]. The beef odor was, however, still assessed as acceptable in both studies even after the highest fluency rate was applied. According to the results of Tomasevic [18], the odor of beef meat is a little more sensitive to PL than the odor of pork. For poultry, the only sensory attribute affected by PL treatment was odor but not to an extent that could affect the pondered average values of the total sensory quality for the chicken and turkey meat [18]. A similar finding was published by Paskeviciute *et al.* [13], where UV light dose higher than 6 J/cm<sup>2</sup> had only a moderate effect on the odor of chicken. The odor scores significantly decreased in all game meat samples after 17 J/cm<sup>2</sup> treatment; this was most easily observable in deer meat, and essentially contributed to the significant change of its pondered average value of total sensory quality. The effect of the treatment on odor was the least pronounced in kangaroo meat [18].

Tomasevic [20] also reported that the 17 J/cm<sup>2</sup> treatment resulted in significant quality degradation in two ready-to-eat cooked meat products evaluated. The sensory quality of Parisian sausage and cooked ham deteriorated after the 17 J/cm<sup>2</sup> treatment to such an extent that they were assessed as unacceptable products, with unpleasant odor similar to the one found in scalding facilities in slaughterhouses, terrible taste (regardless of smell), atypical yellowish and brownish color, strong aftertaste and poor texture [20]. These findings are quite the opposite of what was previously reported by Hierro *et al.* [21], where the test panelists did not find significant differences in any of the parameters evaluated among PL and non-PL ham slices. According to [20], dry-cured meat products, Parma ham and bacon, showed greater resistance to the effects of PL than the cooked meat products examined. There were no statistically significant differences in any of the attributes evaluated between 1-pulse treated and untreated samples of Parma ham [20]. In the case of bacon, the same treatment caused significant difference only in odor, although assessors noted that the odor of both, treated and control bacon, was not so pronounced. When the higher fluence of 17 J/cm<sup>2</sup> was applied to Parma ham and bacon, their odor and taste significantly decreased to the level of neither good nor poor, as assessed by the panelists. However, the was accompanied by negative changes to their texture and juiciness [20]. These observations are in agreement with the previously reported changes in dry cured loin immediately after the PL treatment of 11.9 J/cm<sup>2</sup>, when odor and flavor also significantly decreased [22].

Tomasevic [20] also noted that the sensory quality of 1-pulse treated fermented sausage was not significantly different to the untreated fermented sausage, which is in concurrence with the findings of Ganan *et al.* [22] where also no significant differences were observed in salchichón treated with different fluences. When the fermented sausage was exposed to a 5-pulse treatment, its temperature raised by 12°C and the texture and juiciness was significantly affected. In another investigation of Tomasevic [23], all of the seafood samples were assessed as very acceptable, with the total score value greater than

4.5, no matter if they were PL treated or not. Even though significant changes in odor were assessed after the 5-pulse treatment, it was still described as pleasant and acceptable. Tomasevic [23] could not confirm the development of sulfur notes in tuna induced by the fluences higher than  $8.4 \text{ J/cm}^2$ , as Hierro *et al.* did [19]. All the other sensory attributes evaluated remained unaffected by the PL treatments [23]. Ozer and Demirci [24] also noticed that PL treatment of  $5.6 \text{ J/cm}^2$  did not affect the quality of salmon fillets.

The latest study carried out by Koch *et al.* [16] associated the most intense PL treatments ( $4.96$  and  $12.81 \text{ J/cm}^2$ ) with unpleasant, ozoneous, pungent, ammoniacal, and off-odor perception in pork skin and loin. Conversely, the samples subjected to  $0.52 \text{ J/cm}^2$  were perceived as “less porky” and “slightly chemical”, which supports the indications of Tomasevic [18,20] that excessive PL treatment can seriously affect the sensory quality of certain types of meat and meat products.

### 5. Instrumental color measurements

Tomasevic [18] found the instrumental color values of beef meat were not affected by 1-pulse treatment. Treatment of 5 pulses significantly decreased redness in beef, while no significant differences were observed for lightness and yellowness. The changes in redness, although significant, were not sufficient to be noted by the sensory panel [18]. In beef carpaccio subjected to PL, Hierro *et al.* [19] also observed decreases in  $a^*$  (redness) values but they were accompanied by significant differences in  $b^*$  (yellowness) value when the samples were treated with fluences equal to or higher than  $8.4 \text{ J/cm}^2$ . Tomasevic reported [18] that pork  $a^*$  and  $b^*$  values significantly decreased after the treatment of  $17 \text{ J/cm}^2$ , while chicken color values were not significantly changed, irrespective of the level of treatment. This is in agreement with the results of Keklik *et al.* [25], also indicating that mild and moderate pulsed light treatments did not affect the color of chicken samples, although extreme PL treatment did increase the lightness ( $L^*$ ),  $a^*$ , and  $b^*$  values of samples significantly. The  $a^*$  value of treated turkey samples were significantly lower than that of the untreated samples with significant differences observed among the fluences assayed by Tomasevic [20]. The redness gradually decreased as fluence increased. Similar PL color resistances as were observed in chicken meat were noted only in rabbit meat samples. Venison suffered significant decrease in  $a^*$  value after 5-pulse treatment, while kangaroo meat had significantly lower  $L^*$  (after 1-pulse) and  $b^*$  (after 5 pulses) [18].

In the investigation of Tomasevic [20], PL lightened the color of cooked ham after the  $17 \text{ J/cm}^2$  treatment was applied. The  $a^*$  value gradually decreased as fluence increased, while only the highest fluences significantly affected the  $b^*$  value, similar to observations by Hierro *et al.* [21]. The lightness of Parisian sausage remained unaffected during the Tomasevic [20] investigation, while redness and yellowness suffered significantly, with observed differences among the fluences assayed. The significant increase in  $b^*$  values of cooked ham after PL treatment was previously reported [26], as it was in other cooked-meat products like bologna [21] and chicken frankfurters [14].

As reported by Tomasevic [20], Parma ham  $L^*$  was significantly lower in ham treated with  $17 \text{ J/cm}^2$  compared to control and ham treated with  $3.4 \text{ J/cm}^2$ , while in fermented sausage and bacon,  $L^*$  remained unaffected by PL. The lightness of dry-cured loin also endured, while it was significantly higher in salchichón (fermented sausage) treated with  $11.9 \text{ J/cm}^2$  as reported by Ganán *et al.* [22]. The  $a^*$  value significantly decreased after the 5-pulse treatment in Parma ham, fermented sausage and bacon, while the  $b^*$  value significantly increased only in bacon [20]. It has been reported that when cured meat products are exposed to light, discoloration appears as a decrease in  $a^*$  values and an increase in  $b^*$  values, with or without a change in  $L^*$  [27].

Pulsed light darkened tuna when examined by Tomasevic [23], but only after the fluence of  $17 \text{ J/cm}^2$  was applied, while  $a^*$  and  $b^*$  values were not significantly different to the control. This is contradictory to [19], where  $8.4 \text{ J/cm}^2$  significantly increased  $L^*$  and decreased  $a^*$  and  $b^*$  values in tuna carpaccio. The lower dose of  $3.4 \text{ J/cm}^2$  significantly affected none of the color values in tuna [23], similar to the results of Figueroa-García *et al.* [28] for catfish and of Cheigh *et al.* [29] for flatfish where no changes were observed in the CIE  $L^*$ ,  $a^*$  and  $b^*$  at fluences lower than  $2 \text{ J/cm}^2$ . The color of flounder and crab was not significantly affected [23] by PL.

## 6. Conclusion

PL increases the shelf life of meat, fish and derivate products as well as achieving decontaminating effects on meat contact surfaces. In general, around 2.0 log CFU/mL reduction of the initial count of microorganisms was achieved after PL treatments, independently of the target microorganism and the matrix. However, it is still necessary to optimize the treatment conditions and take into account that the effectiveness of PL depends on the time among contamination, PL treatment parameters and food matrix. According to the evidence provided so far, it seems convincing that because of the short duration of the pulse, PL does not encourage oxidative changes in lipids.

The meat sensory quality changes induced by PL are varied and depend on animal species, type of meat and PL dose applied. Instrumental color values remained unaffected in chicken and rabbit meat while higher doses of PL significantly compromised both redness and yellowness only in pork and turkey meat. The sensory quality changes induced in meat products by PL are also varied and depend on type of meat product and PL dose applied. PL caused minimum changes in the sensory properties and instrumental color values of dry cured and fermented meat products. There is a lot of potential for the commercial application of PL for the decontamination of seafood products because the sensory quality of seafood induced by PL is almost unaffected and independent of type of seafood and PL dose applied. Only the odor of the majority of investigated seafood samples suffered significant changes after PL treatment.

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