Surface decontamination - a prerequisite for safe production of muscle food: A review

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Abstract

There is paradigm shift in the acceptability of food in terms of food quality and safety in the recent past. Muscle food (meat/fish) can be source of various food-borne pathogens of significant public health concern. If sufficient control measures are not adopted for hygienic and wholesome production, the unsafe meat/fish can cause a number of food-borne illnesses. Therefore, various surface decontamination methods are used as important control measures in the meat/fish processing for ensuring the food safety by reducing the biological food hazards. Besides the conventional physical and chemical methods of decontamination, biological methods and some novel decontamination technologies like non-thermal physical methods are also being applied by the researchers/processors to ensure the muscle food safety and avoid the adverse effects of some of the conventional methods. This review is focussed on the compilation of up-to-date information related to the effectiveness of various surface decontamination methods, so that the researchers and other stakeholders can select the effective and suitable decontamination method for future research or industry application. The scope of this review is limited to the surface decontamination treatments studied for muscle food safety during the period from 2010 to 2021.

Key words: Biological, Chemical, Muscle foods, Novel decontamination, Physical

Highlights:

- Surface decontamination of muscle food as control measure improves food safety.
- Thermal physical treatments are safe, cheap, but may affect sensory quality at high temperature.
- Chemical treatments are cheap, but may have residue and affect sensory quality at high concentration.
- Novel technologies are eco-friendly, effective antimicrobial and don't affect sensory quality much.
- Hurdle technology for surface decontamination is better approach for meat/fish industry.

Introduction

Food safety is a public health priority because every year almost 1 in 10 people in the world suffers and more than 4 lakh people die every year from food borne illness after consuming the contaminated food (WHO, 2020). Some food borne illnesses are associated with food contamination with harmful chemicals, but majority of the food borne illnesses are because of the food borne pathogens like *Salmonella*, *Campylobacter*, *Enterohaemorrhagic Escherichia coli* and

Listeria. Muscle foods like meat (including poultry) and fish (fin fish and shell fish) products are great sources of these pathogens and there lies the importance of ensuring the safety of muscle foods.

Even after production of meat animals following all the good animal husbandry practices, contamination of meat carcasses during slaughter and processing is inevitable. The meat carcass surface gets microbial contamination from various sources like skin, feet, feather (in poultry), faecal contamination

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from gastro-intestinal tract during dressing of carcass etc (Das *et al.*, 2019). Similarly, fish may get contaminated with microbes from scales, skin, shell, viscera, faecal content, water etc. Pre-slaughter/pre-harvest factors like livestock/fish production practices may inadvertently result in pathogenic contamination in meat and fish. Post-slaughter/post-harvest factors that may lead to microbial contamination of meat/fish include unhygienic handling, storage, transportation and distribution of meat/fish; complex processing techniques and equipment; and inappropriate handling of meat/fish by consumers etc. There is a great chance of surface contamination of meat/fish during processing because of cross contamination from food handlers, processing equipment, unhygienic work surface, contaminated water, air, dust etc. The emerging pathogens, especially the antibiotic-resistant pathogens are new challenges in the process of ensuring food safety. All these factors lead to unsafe muscle food and ultimately food borne illnesses in the consumers.

The muscle food safety can be ensured by adopting Good Animal Husbandry Practices (GAHP), Good Aquaculture Practices (GAQP), Good Manufacturing Practices (GMP), Good Hygienic Practices (GHP), Hazard Analysis and Critical Control Points (HACCP) system and other food safety and management systems. As effective control measures in HACCP system, various intervention strategies like physical, chemical, biological surface decontamination treatments can be applied alone or in combination to reduce foodborne pathogens in muscle food. As these treatments have their own advantages and disadvantages, the processing industry has to decide their application as per the suitability of the treatment, scale of the operation, the rules and regulations of the meat producing country and requirement of the importing countries.

Pathogens of food safety concern in muscle food

The most prevalent and emerging

pathogens of meat and poultry products are *Campylobacter jejuni*, *Salmonella typhimurium*, *E. coli* O157:H7, other Enterohemorrhagic *E. coli* (EHEC), *Listeria monocytogenes*, *Bacillus cereus*, *Clostridium botulinum*, *Staphylococcus aureus*, *Yersinia enterocolitica*, *Mycobacterium paratuberculosis*, Hepatitis E virus, Avian influenza virus, *Toxoplasma gondi* etc. Fish can also be source of pathogens like *Listeria monocytogenes*, multiple drug resistant *Salmonella* Newport, *Vibrio* spp., *E. coli*, *Yersinia* spp., *Brucella* spp., *Shigella* spp., *Streptococcus iniae*, *Klebsiella* spp., *Clostridium botulinum*, *Piscirickettsia salmonis*, *Edwardsiella piscicida*, *Lactococcus garvieae*, reovirus, norovirus, herpesvirus etc. (Novoslavskij *et al.*, 2016).

In the USA during 2017, 360 food borne disease outbreaks were reported and most common food categories associated with these outbreaks were molluscs (19% of outbreaks), fish (17%), chicken (11%), and beef (9%). The most common pathogens associated with these outbreaks were norovirus, *salmonella* (*Enteritidis*, *Typhimurium*, *Newport*, *Heidelberg*, *Braenderup* serotypes), and Shiga toxin-producing *E. coli* (STEC) (CDC, 2017). During 2017-18, 1060 cases of listeriosis and 216 deaths were reported in South Africa due to contamination of ready-to-eat meat with *L. monocytogenes* (WHO, 2020).

Regulatory requirements for microbiological safety of muscle foods

To ensure the supply of safe food to the domestic consumers, all the meat and fish producers/processors/sellers in India have to follow the Food Safety and Standard Act and Regulations implemented by the Food Safety and Standards Authority of India (FSSAI). For hygienic production of meat/fish products, the producers have to comply with the microbiological standard requirements for these products. As per the Food Safety and Standard Regulations (FSSR), the fresh or chilled meat should not have more than 10^6 log CFU/g aerobic plate count (APC), 10^4 log CFU/g yeast

and mould count, 10^3 log CFU/g *E. coli* and *Staph. aureus*; and the *Salmonella* should be absent in 25 g sample (FSSR, 2011). The chilled and frozen fin fish and crustacean should not contain more than 10^7 CFU/g APC, 500/g *E. coli*; and their *Salmonella* and *Vibrio cholerae* count should be nil in 25 g sample (2011). Likewise, other countries also have their own food standards, hence exporting meat to other countries becomes challenging sometimes, especially when the importing countries have very stringent criteria of zero or near zero tolerance standard for some of the pathogens (example, *Salmonella*). Therefore, the control measures, like, surface decontamination of carcass may be adopted by the meat/fish industry to meet the national and international microbiological standards. In some countries where the consumers prefer consumption of raw fish (molluscs), surface decontamination is the prime step for ensuring the food safety.

The food safety authorities of various countries like United States Department of Agriculture-Food Safety and Inspection Services (USDA-FSIS), European Food Safety Authority (EFSA), Food Standards Australia New Zealand (FSANZ) etc. have guidelines for approving the surface decontamination treatments and set criteria like, these treatments should significantly reduce the target pathogens and should not pose any substantial public health risk. For example, USDA-FSIS has approved the application of hot water, steam, lactic acid, citric acid, acetic acid, ozone etc. and EFSA has approved lactic acid as carcass surface decontaminant.

Thermal physical methods for surface decontamination of muscle foods

The principle of all the following physical methods is the thermal destruction of microbes on the meat/fish surface:

Hot water washing / pasteurization: Hot water washing/pasteurization (74-82 °C) results in reduction of *E. coli* and *Enterobacteriaceae* on lamb, beef and poultry carcass (Hauge *et al.*,

2011; Barco *et al.*, 2015; Belluco *et al.*, 2016). Hot water pasteurization (82 °C for 8 sec) significantly reduces the aerobic plate count, *B. cereus*, and reduces almost 99.5% of generic *E. coli* and thereby STEC on lamb carcass (Hauge *et al.*, 2011). Though this treatment can cause discolouration of meat initially, but the colour is acceptable after 24hrs of storage (Hauge *et al.*, 2011). The adverse effect on meat quality can be avoided by application of lower temperature for shorter time (few seconds).

Steam pasteurization and vacuuming: Steam pasteurization (above 82 °C) is commercially used for decontamination of whole carcass (Chen *et al.*, 2012). It is more effective, but more expensive than hot water washing and can raise the surface temperature of carcass and affects meat colour and texture. Whereas, steam vacuuming is effective only for spot treatment (where steam is applied on the specific area, but not on entire carcass). In this process, first steam is applied and then vacuum is used to remove the condensed moisture and contamination from the carcass. It reduces total viable count (TVC) by 0.4- 0.9 log CFU/cm² at different parts of beef carcass (Hochreutener *et al.*, 2017). It also significantly reduces the Enterobacteriaceae and TVC on lamb carcass (Sandra Da Silva and Farag, 2020). It is costlier than hot water washing and can also have adverse effect on the meat appearance and tenderness, if the temperature is too high or applied for longer duration.

Chemical methods for surface decontamination of muscle foods

Various chemicals have been in use for surface decontamination of the meat carcass or fish for long. Though their uses started long back, but they are still useful because of various reasons like their antimicrobial effect, cost effectiveness, ease of application etc. Some of the studies conducted in the last decade are reviewed here (Table 1).

Organic acids: The researchers have evaluated

Table 1. Overview of chemical surface decontamination treatments

Decontamination treatment	Application	Microbial reduction	Reference
Organic acids	Lactic acid (2%) and acetic acid (2%) sprays for 30 seconds on beef surface	0.9 to 2.2 log CFU in APC and complete inhibition of enterococci	Sallam <i>et al.</i> , 2020
	Acetic acid spray (2%, for 60 seconds) on beef carcass	0.8-log CFU, 1.54-log CFU and 1.4-log CFU in TPC, total coliform and faecal coliform counts respectively	Carranza <i>et al.</i> , 2013
	Peracetic acid (50 ppm) on <i>Pangasius</i> fish	0.4–1.4 log CFU/g, in <i>E. coli</i>	Thi <i>et al.</i> , 2015
	Lactic acid (2.5%) and acetic acid (2.5%) on rainbow trout fish	1 and 0.5 log CFU/g in APC, 1.2 and 1 log CFU/g in lactic acid bacteria (LAB) respectively	Dikici <i>et al.</i> , 2021
Chlorine based productsCPC	ClO ₂ solution wash (200 ppm for 5 minutes) on chicken carcass	1.07 log CFU /cm ² in total viable count and 1.15 log CFU /cm ² in coliform count	Sefna <i>et al.</i> , 2019
	Chlorinated water (50 ppm) on <i>Pangasius</i> fish	0–1.0 log CFU/g in <i>E. coli</i>	Thi <i>et al.</i> , 2015
	ASC by DAR method (10 ppm for 5 min)	Completely inactivated <i>E. coli</i> O157:H7, <i>L. monocytogenes</i> , <i>S. typhimurium</i> and <i>Staph. aureus</i>	Kim <i>et al.</i> , 2014
	ASC (1200 ppm) on chicken skin	1.2-1.8 log ₁₀ CFU/mL in <i>S. typhimurium</i>	Ilhak <i>et al.</i> , 2018
	ASC(1200 ppm) on rainbow trout	1.4 log CFU/g in APC, 1.2 log CFU/g in LAB and 1.56 log CFU/g in Enterobacteriaceae	Dikici <i>et al.</i> , 2021
	CPC (0.5%) on chicken skin	2.2-3.2 log ₁₀ CFU/mL in <i>L. monocytogenes</i>	Ilhak <i>et al.</i> , 2018
Ozone	Ozone (0.4 ppm) on chilled poultry	Significant reduction in Total Aerobic Counts and Enterobacteriaceae	Cortesi <i>et al.</i> , 2011
Tripolyphosphate	TSP (12% for 30 seconds) on beef carcass	0.88 log in APC, 1.2 log in Enterobacteriaceae, 1.51 log in enterococci count	Sallam <i>et al.</i> , 2020
	TSP (10%) on rainbow trout	0.8 and 0.9 log CFU/g in APC and Lactic acid bacteria respectively	Dikici <i>et al.</i> , 2021

the effect of various organic acids like lactic, acetic, citric, propionic, ascorbic, formic, and peracetic acid etc. as meat/fish surface decontaminants. Acetic acid, citric acid and lactic acid are generally recognized as safe (GRAS as per Codes of Federal Regulation,

USFDA) and their solutions at 1.5-2.5% are approved by USDA-FSIS as carcass decontaminants. The application of lactic acid and acetic acid spray significantly reduce microbial population on beef surfaces and trout fish (Carranza *et al.*, 2013; Sallam *et al.*, 2020;

Dikici *et al.*, 2021). The application of peracetic acid (PAA) is more effective than chlorine water in reducing the *E.coli* in fish as the PAA does not get affected by organic matter rapidly (Thi *et al.*, 2015). These are inexpensive, easy to apply and generally do not affect the sensory qualities of meat/fish, if applied at low concentration.

Chlorine based products: Chlorine is widely used as antimicrobial agent. When chlorine is added to water, it forms hydrochloric acid, hypochlorous acid and hypochlorite ions which disrupt the bacterial cell wall, damage the bacterial enzymes and DNA. Chlorine dioxide is less toxic and more stable than chlorinated water, so it can replace chlorinated water for chicken processing (Sefna *et al.*, 2019). Though chlorine is effective, inexpensive and easy to apply, but it gets inactivated rapidly when comes in contact with meat. It may also produce harmful chemical residues and by-products, affects sensory qualities, and promote chlorine-resistant strains of *Salmonella*, if used at high concentration.

Acidified sodium chlorite (ASC) can be used as an efficient alternative to chlorine. The use of ASC at <1200 ppm has been approved for decontamination of meat and in countries, like Canada, European Union and New Zealand, ASC at a level of 1200 ppm is also reported to be effective in surface decontamination of trout fish (Dikici *et al.*, 2021). ASC generates chlorous acid which penetrates the bacterial cell wall and disrupts protein synthesis. It is effective in reducing *S. typhimurium* on meat surface (Ilhak *et al.*, 2018). Its bactericidal effect depends on preparation procedure and initial reactants concentrations. ASC prepared by DAR method *i.e.* premixing of sodium chlorite and acid, followed by dilution after reaction (DAR), is more effective than the conventional ASC preparation (mixing equal volume of SC and acid). The ASC-DAR (10 ppm, 5 min) completely inactivated all the test pathogens (Kim *et al.*, 2014). Therefore, this can be used to maximize the bactericidal action of ASC.

Another chlorine-based compound, Cetylpyridinium chloride (CPC) is also effective in reducing *L.monocytogenes*, *Campylobacter* Spp. and *S. Typhimurium* on meat surface without affecting the quality (Zhang *et al.*, 2018). CPC (0.5%) is more effective than 1200 ppm ASC in reducing *Listeria*. (Ilhak *et al.*, 2018). CPC reduces microbial load of rainbow trout without affecting its texture adversely (Dikici *et al.*, 2021).

Tri sodium phosphate: Tri sodium phosphate (TSP) is as an antimicrobial treatment approved by USDA-FSIS for beef and poultry carcass. It is able to inactivate enterococci, enterobacteriaceae, coliforms and *Staph. Aureus* and also minimizes adherence of microorganisms to carcass. 12% TSP is less effective than 2% lactic acid or acetic acid treatment (Sallam *et al.*, 2020). 10% TSP is effective as surface decontaminant but, it causes whitening in trout fish (Dikici *et al.*, 2021). So, it is inexpensive and easy to apply, but it can affect colour and flavour of the muscle food when used at higher concentration.

Ozone: Ozone is produced by passing the electric charges or ionizing radiation through air or oxygen. It is a powerful oxidizing agent used to inactivate bacteria like *E. coli* O157:H7, *S. typhimurium*, *Pseudomonas fluorescens* on several muscle foods. Ozone treated chilled poultry showed better control of aerobic bacteria and Enterobacteriaceae during storage (Cortesi *et al.*, 2011).

Biological treatment for surface decontamination of muscle foods

Not many researches have been done to explore the efficacy of the biological treatments for surface decontamination of muscle food. Bacteriophages and bacteriocins have the potential for use as surface decontaminants, but it is important to establish their sufficient antimicrobial activity under industrial conditions and eliminate the challenge of potential resistance development. Bacteriophage reduces *Salmonella* and

Campylobacter count on chicken surface, but there is a need for more studies at commercial level (Zweifel and Stephan, 2012). The *V. parahaemolyticus* - specific phage OMN (vB_VpaS_OMN) can inactivate 90-99% of *V. parahaemolyticus* on oyster surface when applied for 48-72 hrs (Zhang *et al.*, 2018).

The EFSA evaluated the safety and efficacy of Listex™ P100 as spray or dip to reduce *L. monocytogenes* contamination on raw fish surface. Listex™ P100 contains bacteriophage (P100) which kills only *Listeria*. Also, it is not considered as harmful to the consumers. The EFSA considered two studies conducted under laboratory condition on artificially contaminated raw fish and Listex™ P100 was effective against *L. monocytogenes*. But the future study has to be conducted to establish the listericidal effect of bacteriophage in naturally contaminated fish, at industrial level and also to prove the reduction of potential human listeriosis risk by this bacteriophage treatment of raw fish (EFSA, 2012).

Novel technologies for surface decontamination of muscle foods

To avoid the adverse effects of thermal physical decontamination methods and the chemical decontaminants, the researchers have been exploring the efficacies of various non thermal physical methods. Some of these novel technologies for meat/fish carcass decontamination are reviewed here (Table 2).

Ultrasound: It is a form of energy generated by a sound wave with a frequency (20 kHz or more) greater than the upper limit of the human hearing range. The high power ultrasound inactivates microorganisms by generating intracellular cavitation which ultimately results in thinning of cell membranes, heating and production of free radicals. As ultrasonic waves are safe and non-toxic, ultrasound can be used as a “green technology” to improve the muscle food quality and safety (Turantas *et al.*, 2015). But the ultrasound cannot always give the desired results when applied alone. The combination of ultrasound with other methods (steam, chlorine,

ethanol, lactic acid, plasma) contributes to the enhancement of microbial inactivation (Morild *et al.*, 2011; Lee *et al.*, 2014; Musavian *et al.*, 2014; Seo *et al.*, 2019). The ultrasound treatment on fish (salmon, mackerel, cod, hake) can reduce the mesophilic and Psychrophilic bacteria, Enterobacteriaceae and *pseudomonas* spp. significantly without much affecting the colour of fish; it is faster and more cost effective than conventional decontamination methods (Pedros-Garrido *et al.*, 2017).

Irradiation: It is suitable for the decontamination of fresh meat/fish as it can be used as bactericidal and it does not substantially increase the product temperature or affect the sensory quality. The Joint Expert Committee of FAO, WHO and IAEA (International Atomic Energy Agency) has established that there is no threat of toxicological, microbiological or nutritional hazard if irradiation up to 10 k Gy dose is applied in food. The USFDA approved a maximum dose of 4.5 k Gy irradiation to treat unrefrigerated uncooked meat and certain meat products for reducing the foodborne pathogens (USFDA, 2020). Ionizing radiation may be either in the form of gamma and X-rays or electron beam (E-beam). It damages or kills bacteria by destroying DNA, RNA and protein. Irradiation of meat with high doses may lead to off-odours in meat, primarily due to lipid oxidation. But, low-dose, low-penetration E-beam irradiation can be used as an antimicrobial on beef carcass without affecting much its sensory qualities (Arthur *et al.*, 2005). E-beam irradiation at 1 k Gy reduces *E. coli* O157:H7 and *Salmonella* on beef surface (Kundu *et al.*, 2014). Low penetration E-beam with uniform dose distribution on rabbit carcass surface significantly reduced *E. coli* O157:H7 (Maxim *et al.*, 2014). The gamma radiation (1 to 3 k Gy) inactivates psychrophiles and Enterococcus bacteria on turkey breast samples (Henry *et al.*, 2010).

Ultraviolet (UV-C): Light UV-C (200-280 nm wave length) inactivates the bacteria, viruses, and other pathogens by disrupting their DNA

Table 2. Overview of novel surface decontamination technologies

Decontamination treatment	Application	Microbial reduction	Reference
Irradiation	E-beam irradiation (1 k Gray) on beef surface	≤ 4.5 log CFU/g in VTEC, ≤ 4.0 log CFU/g in <i>E. coli</i> O157:H7 and ≤ 1.9 log CFU/g in <i>Salmonella</i>	Kundu <i>et al.</i> , 2014
	E-beam irradiation (10 Me V) on inoculated rabbit carcass	5 log in <i>E. coli</i> O157:H7	Maxim <i>et al.</i> , 2014
	Gamma radiation (1 to 3 k Gy) on turkey breast	Significant reduction in psychrophiles and Enterococcus bacteria	Henry <i>et al.</i> , 2010
Ultrasound	Ultrasound + steam (30–40 kHz, 2 sec. + 130 °C, 3.5–5 atm) on pork	2.5 log CFU/cm ² , 2 log CFU /cm ² and 2.1 log CFU /cm ² in <i>E. coli</i> , <i>S. typhimurium</i> , <i>Y. enterocolitica</i> respectively	Morild <i>et al.</i> , 2011
	Ultrasound + Lactic acid (40 kHz, 1% LA) on Chicken wing skin	≤ 4.0 /cm ² in Gram-negative bacteria	Kordowska-Wiater and Stasiak (2011)
	Ultrasound (5-45 minutes) on salmon, mackerel, cod and hake fish	0.5-1.1 log CFU/g in mesophilic count, 0.6-1.5 log CFU/g in psychrophilic count, 0.7-0.8 log CFU/g in Enterobacteriaceae, 0.6-1.3 in <i>Pseudomonas</i> spp.	Pedros-Garrido <i>et al.</i> , 2017
UV light	UV-C light (590 mJ/cm ²) on beef	1.19 log CFU/cm ² in <i>E. coli</i> , 1.08 log CFU/cm ² in <i>Salmonella</i> strains and 0.89 log CFU/cm ² in <i>Listeria monocytogenes</i>	Kalchayanand <i>et al.</i> , 2020
	UV -C light (2040 mJ/cm ²) on pork	0.56 log CFU/g in <i>Yersinia enterocolitica</i>	Reichel <i>et al.</i> , 2019
Pulsed UV light	Pulsed UV light (3 pulses/second, pulse duration of 360 μ s, for 30 s to 180 s) on whole chicken carcass	0.87 to 1.43 log CFU/ml in <i>E. coli</i> K12 after 30-s 180 s treatments	Keklik <i>et al.</i> , 2011
	Pulsed UV light (0.52–19.11 J/cm ²) on Pork skin	3.16 log CFU/cm ² in <i>Salmonella typhimurium</i> and 4.37 log CFU/cm ² in <i>Yersinia enterocolitica</i>	Koch <i>et al.</i> , 2018
	Pulsed UV light (5 to 30 J/cm ²) on chicken thigh and breast	0.29 and 1.04 in <i>E. coli</i> on breast, 0.34 and 0.94 on thigh	Cassar <i>et al.</i> , 2021

Cont. Table 2.

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Decontamination treatment	Application	Microbial reduction	Reference
Cold plasma	i. Dielectric barrier discharge (DBD) plasma (N ₂ and O ₂ , 2 W, 15 kHz, for 10 min) on Beef	1.90 log CFU/g in <i>Listeria monocytogenes</i> , 2.57 log CFU/g in <i>E.coli</i> O157:H7 2.58 log CFU/g in <i>Salmonella typhimurium</i>	Jayasena <i>et al.</i> , 2015
	ii. DBD plasma (2–100 W, 15 kHz, 10 min) on chicken breast	2.14 log CFU/g in <i>Listeria monocytogenes</i> , 2.73 log CFU/g in <i>E. coli</i> , and 2.71 log CFU/g in <i>Salmonella typhimurium</i>	Lee <i>et al.</i> , 2016
	iii. Atmospheric pressure plasma jet (1 MHz, 2–3 kV, 180 s) on chicken skin and breast.	2.5 log CFU/cm ² in <i>Campylobacter jejuni</i>	Rossow <i>et al.</i> , 2018
	iv. Plasma-activated water and ultrasound (1.5 MHz, 6.8 kV, 40 Hz, 60 min, 40 °C) on chicken skin	1.12 log CFU/mL in <i>E. coli</i> K12 and 0.86 log CFU/mL in <i>Staphylococcus aureus</i>	Royintarat <i>et al.</i> , 2020

and multiplication. Several researchers observed significant microbial reduction on the meat surface (chicken, beef, pork) and reported that there was minimal to zero adverse effect on colour or texture (Oh *et al.*, 2014; Reichel *et al.*, 2019; Kalchayanand *et al.*, 2020). Though UV-C alone can reduce microbe numbers, but cannot eliminate them completely. It improves the microbial safety of food in a better way when used in combination with other decontamination treatments.

Pulsed UV light: It can be used to inactivate microorganisms on surfaces in very short time. The decontamination efficiency of pulses of light is higher than the continuous application of UV-light. It inactivates the microbes by damaging DNA, thermal stress, and pulse disturbance effects (Krishnamurthy *et al.*, 2010). Generally, very short (μ s) high power pulses of UV light are generated by using inert gas flash lamps. The treatment of chicken carcass and pork skin with pulsed UV light resulted in the significant microbial reductions (Keklik *et al.*, 2011; Koch *et al.*, 2018; Cassar *et al.*, 2021). Chicken meat temperatures increased with longer treatment times. The

optimum treatment time was 45 s and it caused 1 log microbial reduction without affecting meat colour or increasing the temperature too high. The effectiveness of the pulsed UV light treatment may be increased by optimizing the system design and/or combining it with other antimicrobial treatment (Keklik *et al.*, 2011).

Cold atmospheric plasma: This non-thermal emerging technology is being used for food safety in recent years. This can reduce food-borne pathogens effectively without affecting much the product quality (Lee *et al.*, 2016). The cold plasma can kill microbes because it consists of excited atoms and molecules, UV photons, electrons, ions, free radicals and reactive species (Baek *et al.*, 2020). These kill microbes by damaging cell membrane, cell wall, RNA, DNA and denaturing proteins (Misra and Jo, 2017; Baek *et al.*, 2020). The researchers have used various forms of cold plasma, like dielectric-barrier discharge (DBD) cold plasma, direct treatment with plasma jet, plasma-activated water, combining atmospheric cold plasma treatment with peracetic acid application, combining plasma-activated water with ultrasound etc. (Royintarat *et al.*, 2020). All the

studies reported successful minimization in microbial load and combination treatments improved the antibacterial effects. The plasma treatment causes no changes or very little changes in meat quality (Jayasena *et al.*, 2015) and leaves no harmful residue in meat. Therefore, this environment friendly treatment has great potential to decontaminate muscle food.

Hurdle technology for surface decontamination of muscle foods

Majority of the decontamination treatments cannot give desired results when applied alone, but when they combine with other treatments, they are very effective in microbial inactivation. As steam/hot water decontamination treatment of broiler carcasses is hindered due to adverse effects on broiler skin, a combination of steam with ultrasound treatment can significantly reduce numbers of *Campylobacter* without affecting the sensory quality (Musavian *et al.*, 2014). The steam-ultrasound treatment (130 °C/3.5-5 atm. steam and 30-40 kHz ultrasound) on meat surfaces significantly reduces *Salmonella typhimurium*, *Y. enterocolitica* and *E. coli* (Morild *et al.*, 2011). For microbial inactivation on chicken skin, ultrasound treatment in lactic acid solution is more effective than ultrasound in water; and the effectiveness increases with increase in sonication time (Kordowska-Wiater and Stasiak, 2011). The cold plasma treatment combined with peracetic acid, plasma-activated water treatment with ultrasound (Royintarat *et al.*, 2020) also give better antimicrobial results in comparison to the application of cold plasma alone.

Conclusion

The antimicrobial effect of the surface decontaminants on muscle food depends on variety of conditions, like contamination levels, physical/chemical nature of decontaminants, concentration/dose, application modes, temperatures, pressures, exposure times etc. All the thermal physical methods are safer as they don't leave harmful chemical residues and they are environment-friendly, but may have adverse effect on the food quality if the temperature is too

high or exposure time is more. The chemical decontaminants are effective antimicrobial, low cost and easy to apply, but they may leave harmful residues, affect sensory qualities adversely and may also result in resistant microbial strains, if used in high concentrations. Biological treatments showed effective surface decontamination effect, but their applicability in commercial level is not well established. All the non-thermal novel technologies are environment-friendly, do not leave harmful residue, and usually sufficient alone to significantly reduce the pathogenic load on carcass surface. Though these are mostly being used in the laboratory conditions, further researches may be conducted to optimize individual treatment and also explore the synergistic effect of combination of treatments for providing best surface decontaminants while maintaining the food quality. Combination of decontamination treatments (hurdle technology) may be a unique approach to achieve the reduced microbial risk by balancing the adverse effects of one treatment and taking the advantages of additive effects of multiple treatments. Therefore, meat/fish industries can apply the above mentioned decontamination methods as per their choice/suitability, provided the method is approved by the regulatory authority of that country and also the importing countries. It can be concluded that the surface decontamination of muscle foods is an important control measure in the meat/fish processing for ensuring the safety, but it should always be accompanied with other good food manufacturing, hygienic and sanitary practices.

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