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Effect of Marination on Meat Quality and Food Safety – a Review

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ABSTRACT

Marination, infusing meat with savoury elements like spices and herbs, enhances flavour, texture and shelf life. Marinated meat offers health benefits like antibacterial and anti-inflammatory properties, satisfying consumer preference for natural ingredients over chemical preservatives. Marination boosts sensory quality, making it vital in the meat industry for flavour, softness, and extended shelf life. Acidic marinades, like citrus and vinegar, tenderize by breaking protein bonds. Fermented dairy products improve meat quality and safety. Enzyme marinades, from fruits like kiwi, papaya and pineapple, tenderize by breaking down meat proteins. Originating in the Mediterranean, marination improves taste, tenderness and shelf life, reducing waste, increasing profits, and meeting consumer expectations in modern markets. Marination encompasses wet, dry and paste methods and marinades composition affects meat microflora. Acidic marinades suppress microbial growth with weak organic acids, while Lactic Acid Bacteria (LAB) dominate Modified Atmosphere Packaging (MAP) packed meat. *Pseudomonas* spoilage in marinated poultry is countered by LAB presence, and sodium lactate inhibits *Salmonella*. Weak organic acids are effective against *Listeria monocytogenes*, while combinations of organic acids and sodium chloride counter *E. coli* O157:H7. Marinades with lactic acid or sodium lactate inhibit Enterobacteriaceae and Staphylococcus aureus. Natural antioxidants, like vitamins, flavonoids and phenolic compounds from plants, inhibit oxidation and improve sensory properties. Honey, wine, garlic, carotenoids, tocopherols and spices such as clove, black pepper, thyme and oregano provide antioxidative and antimicrobial benefits. Charcoal cooking of meat can generate carcinogenic polycyclic aromatic hydrocarbons (PAHs). Control involves optimizing cooking methods, minimizing fat drippings, using marinades with phenolic compounds and pairing with anti-carcinogenic foods.

INTRODUCTION

India is the fourth largest broiler producing country in the world with an estimated annual production of 4.78 million tons of broiler meat out of 8.68 tons of total meat produced (BAHS, 2022). Total meat production in the world is about 337.3 million tonnes, of which 40.6 percent belongs to the

poultry group (FAO 2021). The poultry meat production, which was 127.3 million tonnes in 2018, reached 133.6 million tonnes in 2019 (FAO, 2021). The poultry industry in India represents a major success story today with a growth rate of more than 12 % among other meat industry (NSSO, 2014). Chicken has nutritional characteristics such as low lipid content and a high concentration of polyunsaturated fatty acids (Bourre, 2005). Raw meat can be spoiled by microbial activity or by oxidative processes due to high content of PUFA and high peroxidation index (Sebranek *et al.,* 2005; Dal Bosco *et al.,* 2016). So, to overcome the spoilage of meat, marination of meat is being done by addition of antioxidants and antimicrobial agents along with the marinade to improve the shelf life of the meat.

The practise of infusing meat with savoury substances to increase flavour, texture and juiciness is referred to as marination (Yusop *et al.,* 2012). Marination is a method of soaking meat in various marinade solutions comprising varying amounts of salt, spices, organic acids and herbs. Marination is known to improve the look of the meat, the quality of the product, the performance of the product and also the shelf life of the meat (Sheard and Tali, 2004; Latif, 2011). Marination involves soaking, injecting, or tumbling of meat in aqueous solutions containing various substances to enhance its functional and sensory characteristics (Latif, 2001). Marination of chicken meat has become an important part of the poultry industry because of increased consumer market, institutional food service and restaurant demand for ready-to-cook and convenience food. Meat has traditionally been marinated to enhance flavour, softness and extend the shelf life of the product.

The increase in raw meat production was necessitated marination, which can benefit both the producer and the consumers (Xargayo *et al.,* 2006). Antibacterial, anti-inflammatory, anti-allergic, hepatoprotective, antithrombotic, antiviral, anticarcinogenic, cardioprotective, and vasodilatory properties have been found in several investigations on marinated chicken (Benhammou *et al.,* 2009). In recent years, there has been a significant concern over the addition of chemical preservatives in marinated meat, thereby influencing consumers preference for natural products such as spices and plant extracts over chemical preservatives (Govaris *et al.,* 2010). A spice can be referred to as a seed, fruit, root, bark, berry or vegetable which is used in food to enhance its flavour (aroma and taste), colour or texture as well as to preserve the product from deterioration. The use of spices is very important in raw or fresh meat because it is mostly susceptible to spoilage (Thomas and Kuruvilla, 2012, Mithun *et al*, 2022). The main purpose of marination of meat is to improve the sensory quality of the raw meat by addition of different spices, condiments and novel compounds in the marinade. Apart from enhancing the sensory properties, marination is also used as a technique to increase the shelf life of meat.

HISTORY OF MARINATION

The term marination originated in the Mediterranean region (mare is sea in Latin), is a traditional process in which meat is immersed in a solution that extends its shelf life and imparts a specific flavour characteristic (Lemos et.al. 1999). Marination is a method of soaking meat in various marinade solutions comprising varying amounts of salt, spices, organic acids, and herbs (Smith and Young, 2007). The infusion of meat with such savoury substances to increase flavour, texture, and juiciness is usually practiced as marination (Yusop et al., 2012).

Meat has traditionally been marinated to enhance flavour, tenderness and extend the shelf life of the product. The increase in raw meat production made marination an essential component of meat industry, which can benefit both the producer and the consumer (Xargayo et al., 2006). Marination of chicken meat has become an important part of the poultry meat industry because of increased consumer market, institutional food service, restaurant demand for ready-to-cook and convenience foods (Kim et al., 2015). The availability of commercial marination process using the mechanical equipment has increased with increasing consumer demand for ready-to-cook marinated chicken meat products (Wong and Kitts, 2002)

TYPES OF MARINADE

Marination of meat is mainly done to enhance flavour, tenderize meat and short-term meat preservation.

Acidic marinades

Wine, vinegar, tomato and citrus juice containing acid work to loosen the protein bonds in the meat, making the meat more tender so that these juices can then be absorbed. Acid marinades are becoming more popular as antimicrobial ingredients particularly, for their ability to reduce *Listeria monocytogenes* in ready-to-eat meat products (Alvarado and McKee, 2007). Abida *et al.* (2014) reported that 0.25% citric acid was best acidic marinade for broiler compared to 0.25% acetic acid and 0.25% lactic acids which improved the shelf life of the meat without affecting the sensory quality. At 10°C, 25°C, and 35°C, acetic and lactic acids were more inhibitory against L. monocytogenes than citric acid. (Sorrells *et al.*, 1989; Alvarado and McKee, 2007). Atkas *et al.* (2001) reported that electrophoresis of connective tissue proteins obtained from the same muscle showed that both

lactic and citric acid increased tissue breakdown which led to tenderization of the meat compared to NaCl and $CaCl_2$ marinated muscle.

Dairy marinades

Fermented dairy products (FDP) like buttermilk, yoghurt, curd and kefir are some of the dairy marinades used widely in marinating meat. Grilling experts believe this is one of the proper ways to marinate meat. The calcium in the dairy works to age the meat by activating its enzymes, making the meat more tender. Latoch and Libera (2019) reported that marinating in FDP, especially in yogurt or buttermilk, improves the quality and safety of Sous-Vide cooked pork steaks by reducing the microbial growth and improving the physico-chemical properties of the meat. Acid whey is also used to marinate turkey meat to increase the shelf life of the meat (Prejsnar *et al.,* 2021). Zofia *et al* (2021) reported that marinating Rhode Island red breast meat with buttermilk and sour milk improved the tenderness, juiciness, and colour of roasted meat.

Enzyme Marinades

The enzymes obtained from the fruits like kiwi, papaya and pineapple contain papain or bromelain which acts as meat tenderiser. These proteins present in the fruit break down the meat to make it more tender. Kakash *et al.* (2019) reported that the kiwi protein had a significant effect on the punch force, springiness, and chewiness of the chicken meat samples and reduced the hardness. This was due to the activity of enzymes on myofibrillar proteins which led to the breakage of the connective tissues. Hydrolysis of myofibrillar proteins and release of amino acids significantly reduced the pH in the treated samples compared to control (Kakash *et al.*, 2019)

Nuraini *et al.* (2021) reported that marination using 3% young pineapple extract has a significant effect ($p<0.05$) on tenderness, juiciness and consistency, but does not have a significant effect ($p>0.05$) on colour, odour and taste. Bhaskar *et al.* (2017) reported that sensory evaluation of breast and thigh muscles injected with 100 tyrosine Units (TU) and 125 TU for 240 minutes had better appearance, flavour, tenderness and overall acceptability compared to control group.

Table 1: Different types of marinade (Mithun, 2023)

Types of marinades	Examples
Oils	Olive, peanut, sesame, coconut
Chile peppers	Chipotle, jalapeño, habanero, ancho, Thai red & green, Serrano, poblano Fresh, roasted, smoked, dried
Condiments	Ketchup, mustard, plum sauce, coconut milk
Wine	Red wine, white wine, sake
Vinegar	Rice, balsamic, white wine, red wine, sherry, raspberry
Dairy	Buttermilk, yogurt
Fruits	Citrus Juice, lemon, lime, orange, grape-fruit
Herbs & Spices	Asian - Ginger, lemongrass, galangal root, tamarind
	Mexican - Achiote, cilantro, citrus time, orange), chilies
	Indian Tandoor – Cardamom, ginger, turmeric, chilies
	Japanese - Soy sauce, sake, sugar, ginger teriyaki
	Peruvian Ceviche - Lime, lemon, cilantro, onions

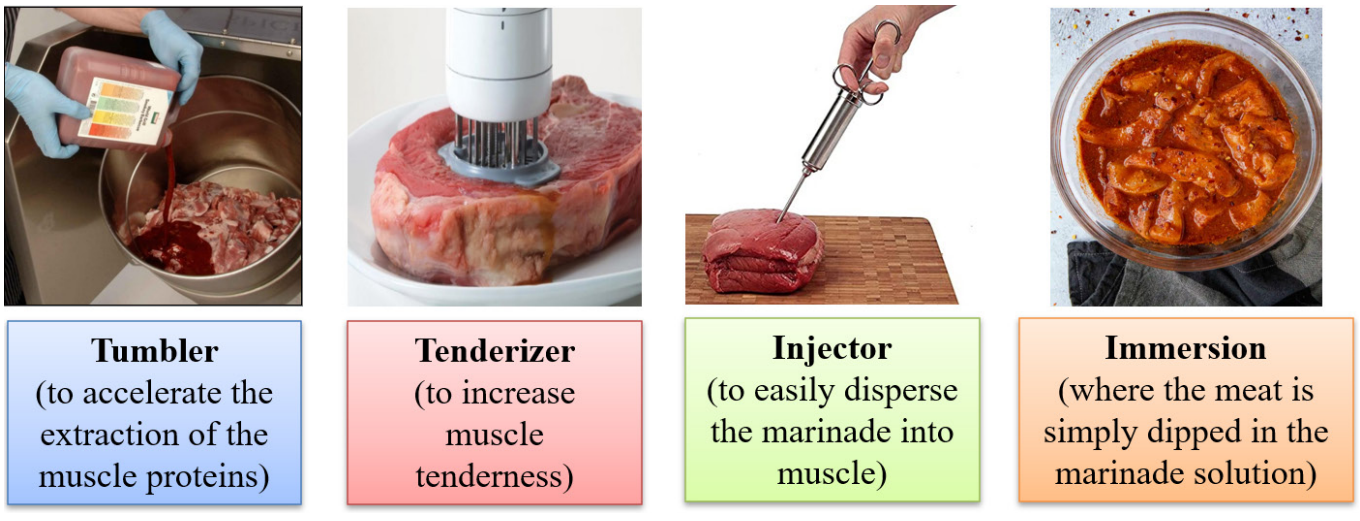

Fig. 1: Different techniques used in marination of meat

METHODS OF MARINATION

Wet marination involves covering the meat with a liquid in order to tenderize it and prevent it from spoilage. Wet marinating is done for a short period of time and should always be left to marinate in the refrigeration temperature. The pastes are basically the dry rubs, being spices and herbs, but mixed together with an oil or other liquid to make a paste.

Dry marination, also known as dry rubs, are made using dried herbs and a variety of dried spices. The main ingredient in a dry marinade is salt which works to break down the proteins of the meat so that other flavors can be absorbed. To dry rub, it's important to first coat it with lard, oil or water so that the rub can be pressed onto the surface.

The oldest technique, immersion, involves soaking the meat in the marinade and relying on diffusion over time for the ingredients to permeate the meat. However, this method is considered unreliable in the meat industry due to its inconsistency in ingredient distribution. Additionally, it is impractical as it demands extended processing periods and imposes constraints on the amount of marinade that can be used. (Xargayo *et al.,* 2006)

The Tenderizer or multi-needle injection marination method is likely the most prevalent, as it enables precise dosing of the marinade, guaranteeing consistency in the products without the time-consuming nature of immersion. This process involves inserting needles or probes to inject the marinade, which is spread throughout the piece as the probes or needles are withdrawn (Smith and Acton, 2000).

Tumbling is a marination method used for poultry meat, creating a convenient, value-added product suitable for direct cooking. Through massaging and tumbling, protein exudates, mainly composed of salt-soluble proteins like actin and myosin, are extracted. These exudates enhance cohesion during the cooking process. As a result, tumbled products exhibit improved juiciness and are easier to slice. Studies show that this extraction of myofibrillar proteins to the meat's surface serves two crucial functions. Firstly, it aids in protein coagulation upon heating, enhancing binding properties. Secondly, it acts as a sealant during thermal processing, helping to preserve moisture within the meat tissue (Smith, 2001).

Injector marination is a culinary process employing a specialized tool to enhance flavour absorption in food. The meat injector, a syringe-like device, delivers marinade directly into tissues, promoting deeper penetration of flavour compounds. This method exploits pressure differentials to facilitate capillary flow within the food matrix, increasing the surface area in contact with the marinade. Consequently, it accelerates flavour diffusion and reduces marination time compared to traditional surface techniques. The precise control over flavour dispersion and absorption achieved through injector marination which is a versatile tool for enhancing taste and texture profiles in various dishes. (Alvarado and Saams, 2003)

Marination of meat

In India, broiler meat has become the most commonly consumed meat because of its easy availability, low cost and acceptability (Devi *et al.,* 2014). Due to increase in the production of poultry meat especially broiler, meat industry nowadays has modified their marketing strategies by introducing pre-marinated meat with the typical Indian style flavours to make it easy for the consumers to get their favourite traditional taste at maximum convenience. Marination has also become popular because of increase in the consumption of charcoal grilled or barbecued chicken consumption across all age groups. Therefore, by understanding the current scenario, marination has gained wide use in hotels, restaurants and meat industries where marinated chicken is used for cooking various meat products. The food industries are also much aware of this current trend and many new marinade mixtures are being made so that the consumer can cook meat products of their interest.

Importance of marination

Even though acquiring various meanings through history and cultures, marinated products are still a current and modern fashion adopted in large commercial markets (Meneses *et al*., 2022). The current success of marination is owing to three factors that is huge profits, reduction of wastage and satisfaction of consumer expectations. Marinated products aim to increase consumers' taste experience, enticing them to buy the product over other non-marinated products. Marinated products are less wasteful since marinades can reduce the number of spoilage bacteria present in meat, sustaining its texture and flavour for an extended time (Birk *et al.,* 2010). Marination is highly beneficial to the meat industry and retail chains since it contributes to increasing product shelf life, thus decreasing food waste. Additionally, these products are usually ready-to-cook, with no further preparation required. Besides this aspect, the lack of additional handling by the consumer, which reduces the likelihood of cross-contamination (Meneses *et al.,* 2022)

COMMONLY USED MARINADES AND THEIR EFFECTS

Pal *et al*. (2002) reported that chicken chunks marinated with 1.75% salt, 1.5% dry spice mix, 5% green curry stuff (onion: ginger: garlic: 3:1:1) and 2% sunflower oil had good

organoleptic quality indicating that marinated chicken could be stored for 9 days at 4±1°C without any appreciable loss of its quality and further reported that there was non-significant increase in standard plate count, coliform count and psychrophilic count of samples with the increase in storage period. Storage period had no significant effect on pH and moisture content of the samples. The most commonly used poultry meat marinades include salt and sodium tripolyphosphate, which have been shown to increase meat yield and water-holding capacity, as well as improve colour and texture (Alvarado and McKee, 2007). Marinating semimembranosus muscle using commercial marinades containing red pepper, garlic, pepper, onion and tomato, beneficially affected the quality of sous-vide beef by improving the eating quality including tenderness and reduced cooking loss (Tkacz *et al*., 2021).

Natural antioxidants used in marination

Meat and meat products have high biological value protein and essential nutrients required for human sustenance (Mandal and Pal, 2014). They are also associated with nutrients considered negative including high levels of saturated fatty acids, cholesterol, sodium and high fat and caloric contents (Bhat *et al.,* 2014). Development of oxidative changes in meat and meat products causes quality deterioration due to oxidation during storage. Hence, there is a trend of using natural antioxidants for arresting such oxidation process and they are also expected to give health benefits by neutralizing the negative effects (Mandal, 2021).

Natural antioxidants are known to protect cells from damage induced by oxidative stress due to the production of free radicals, which are generally considered to be the cause of ageing, degenerative diseases and cancer (Mandal and Pal, 2014, Sen and Mandal). Natural antioxidants in leaves and fruits are rich in polyphenolic compounds and possess significant 2,2-diphenyl-1- picrylhydrazyl (DPPH), 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) and superoxide anionic scavenging activity. So, this can be added in different modes such as paste, extract and powder which will have potent natural preservative effects to augment the shelf life of meat and meat products (Najeeb *et. al.,* 2014). Natural antioxidants from thyme, oregano or wine are used for inhibiting lipid oxidation in marinated meat. The similar antioxidants decrease peroxide value in marinade solutions (Istrati, 2011).

Marinade solutions rich in phenolic compounds suppress the secondary products of lipid oxidation and keep 2-thiobarbituric acid reactive substances (TBARS) almost unchanged during storage (Gray and Pearson, 1987). In meat marinated with wine, honey, garlic, black pepper and salt, the TBARS value reached after 14-day storage is low. After red meat marinating with red wine, a 20% decrease in the formed conjugated dienes after cooking was reached (Blackhurst *et al*., 2011). The addition of berry powders to marinade solutions with citric acid slowed down the linoleic acid oxidation. The authors discovered that berries were rich in polyphenolic antioxidants, with activity increasing in the following order: lingonberry, sea buckthorn, black chokeberry, bilberry and black currant (Pussa *et al.,* 2008).

After examination of seven cholesterol oxidation products in meat namely 7αhydroxycholesterol, 7β-hydroxycholesterol, 5,6 α-epoxycholesterol, 5,6 β-epoxycholesterol, 5 α-cholestane-3β, 5, 6β-triol, 5-cholesten-3β-25-diol, and 7-ketocholesterol, Lee *et al* (2007) reported that marination with soya sauce and sugar reduced their formation. In meat marinated with garlic and onion, the TBARS value is lower compared to non-marinated meat (Kim *et al.,* 2010). Addition of some spices, herbs or their extracts, wine, honey, soya sauce suppress microbial growth because of specific compounds such as polyphenols, ethanol and phenolic derivatives, garlic and vanilla or flavonoids like rutin and quercetin.

EFFECT OF MARINATION ON MICROFLORA AND PATHOGENS

The different composition of marinade solutions has different effects on meat microflora and gram-negative bacteria are more sensitive to acid conditions than gram-positive bacteria (Choi *et al.,* 2009). Marination with salt-phosphate solutions increases pH and possibly stimulates the spoilage microflora, with optimal growth in alkaline pH (Jermeiah and Gibson, 2001). The acidic marinades decrease pH and suppress microbial growth due to the presence of weak organic acids (acetic and lactic) or their salts (acetates and lactates) and NaCl (Yousup *et al.,* 2001). The growth of microorganisms depends on the meat pH after marination (Silva *et al.,* 1999). Lactic acid bacteria (LAB) are the most common microorganism in the Modified atmospheric packed (MAP) marinated poultry meat on application of proper cold storage (Schimer and Langsrud, 2010).

Lactic acid bacteria

LAB was identified as the causes of spoilage in fresh meat and MAP packed marinated meat. The isolated microorganisms included LAB dominated by *Lueconstoc, Lactobacillus sakei, Lactobacillus curvatus* and phenotypically similar to the heterofermentive *Lactobacillus* types. Excessive gas production was found which can be due to the decarboxylation

of amino acid residues. In MAP marinated poultry meat, *L. gasicomitatum, Carnobacterium divergens, L. Sakei, L. curvatus* was isolated (Bjorkroth, 2005).

Pseudomonas and psychrotropic bacteria

The spoilage in aerobically stored marinated poultry is mainly caused by gram-negative psychrotropic bacteria, *Pseudomonas* in particular (Carlos and Harrison, 1999). Growth of *Pseudomonas spp*. is highly dependent on the presence of lactic acid bacteria (Gerez *et al.,* 2009). The growth of H_2S synthesising bacteria like *Pseudomonas spp.* is largely inhibited by the presence of lactic acid – a product from the LAB (Gonzalez – Fandoz *et al.,* 2009). Addition of 1 and 3% sodium lactate to poultry meat leads to reduction of 0.2 log and 0.4 log in psychrotropic bacteria count (PTC) (Smaoui *et al.,* 2011). The antibacterial effect of a marinade solution with 1% acetic acid can be increased by the addition of 1 unit of LPS (Lactoperoxidase system: 1µg / ml LP, 5.9 ml of KSCN and 2.5 ml H_2O_2) and contribute to a significant decrease in total microbial counts and psychrotrophs (Tan and Ockerman, 2006). Pimento leaf oil of 0.5% or 0.5% clove oleoresin added to the marinade solution inhibits *Pseudomonas spp.* growth (Carlos and Harrison, 1999). Generally, the gram-negative bacteria are more sensitive to acid conditions than gram-positive bacteria (Choi *et al.,* 2009). *L. monocytogenes* survived longer in acidic conditions than *E. coli* O157: H7 or *S. enterica* (Lin *et al.,* 2000) and were more resistant than *Salmonella* strains at low pH (Tan and Ockerman, 2006).

Salmonella

The use of sodium lactate in acid marination of poultry significantly inhibits *Salmonella* development (Smaoui *et al.,* 2011). To inhibit the growth of *Salmonella*, the combination of nisin with EDTA, sodium lactate or potassium sorbate was used (Ukuku and Fett, 2004). The strong antimicrobial potential against *Salmonella* of the teriyaki sauce (soya, rice wine, sugar and spices) added to a marinade solution was also examined (Pathania *et al.,* 2010).

Listeria monocytogenes

Greater inhibition in *L. monocytogenes* growth was reached with the use of weak organic acids compared to strong hydrochloric acid (Vasseur *et al.,* 1999). The growth and development of Listeria monocytogenes under acidic circumstances were greatly slowed and reached a stationary phase at pH levels that were different from the final value (Buchanan *et al.,* 1993). Acetic and lactic acids proved to be more effective against *L. monocytogenes*, while citric acids had the weakest effect (Alvarado and McKee, 2007). Bacteriophages are generally considered as safe for use in food which is highly host specific and are more frequently used for inactivation of *L. monocytogenes* (Greer *et. al.,* 2006).

Escherichia coli

The combination of organic acid (having antimicrobial action) and sodium chloride in marinade solutions may effectively inactivate *E. coli* O157: H7. The growth of *Listeria monocytogenes*, *Salmonella typhimurium* and *E. coli* O157:H7 was inhibited using supercritical carbon dioxide (SC-CO_2) in marinade solutions with soya sauce and hot-pepper paste (Choi *et al.,* 2009). Antimicrobial effect of natural spices on the microbial growth of *E. coli* and that marinating in garlic juice could decrease total bacteria and total coliforms count. Significant inhibition of the microbial growth of *E. coli* O157:H7 were achieved when the meat was marinated by a solution containing 0.2 % citric and 0.3 % acetic acid.

Enterobacteriaceae

To suppress the growth of *Enterobacteriaceae*, marinade solutions containing lactic acid or sodium lactate was used. Moreover, 1% lactic acid was a stronger inhibitor (1.31 log cfu/g), than 3% sodium lactate (1.74 log cfu/g) (Smaoui *et al.,* 2011)

Staphylococcus aureus

S aureus strains produced enterotoxin and could cause food poisoning (HPA, 2009). *S. aureus* growth was slower than that of other microorganisms and never exceeded the limit of 4 log cfu / g in non-marinated meat (Smaoui *et al.,* 2011). The addition of lactic acid to poultry marinade solutions significantly inhibited the growth of *Staphylococcus aureus* until the 15th day of storage. Similar results were achieved when using sodium lactate. The inhibiting effect of lactic acid on *Staphylococcus aureus* is mainly due to the low pH (Koutsoumanis *et al.,* 2006).

Campylobacter jejuni

No significant difference in the growth of *Campylobacter jejuni* in marinated and non-marinated meat was found during microbiological analysis (PerkoMäkelä, 2000). Marinating could not be an effective method for suppressing the development of enteric pathogens. The buffering capacity of meat causes fast pH neutralization during acid marination (Björkroth, 2005). Changes in pH to a neutral level probably led to dissociation of lipophilic acids and their antimicrobial effect decreased quickly in the marinades.

Clostridium perfringens

The *Clostridium perfringens* spores are widely spread in the soil and water and the possibility for post-mortem contamination exists. *C. perfringens* may also be found in

processed food after inappropriate thermal processing. The sodium salts of organic acids used in marinade solutions reduced the risk of *Clostridium perfringens* (Vangelova and Dragoev, 2014)

EFFECT OF MARINATION ON LIPID OXIDATION

Lipid oxidation in meats is a process whereby polyunsaturated fatty acid react with reactive oxygen species leading to degradation of lipids and development of oxidative rancidity. This process is one of the major factors responsible for the gradual reduction of sensory and nutritional quality of meats, thus affecting consumer acceptance (Sen and Mandal, 2017). Antioxidants are compounds that inhibit oxidation which prevent free radicals and chain reactions that may damage the cells of organisms. Natural antioxidants are an emerging alternative to conventional antioxidants. They are generally more expensive and less efficient. These components are better accepted by consumers and are considered safer. Some natural compounds have higher antioxidant capacity than synthetic compounds and some also have other positive effects on the sensory properties of meat products (Velasco and Williams, 2011, Kumar *et al.,* 2015;)

Natural antioxidants include various substances with different chemical characteristics, found in any plant part such as grains, fruits, kernels, seeds, leaves, roots, peels, and barks. The antioxidant capacity of natural extracts is related to the presence of compounds such as vitamins A, C and E, flavonoids and other phenolic compounds. Natural antioxidants from thyme, oregano or wine are used for inhibiting lipid oxidation in marinated meat. The similar antioxidants decrease peroxide value (POV) in marinade solutions. This is due to the rich content of phenolic compounds. Horseradish contains isothiocyanate and allyl isothiocyanate which inhibits lipid oxidation (Istrati *et al.,* 2011). There is plenty of evidence for antioxidative effect of the honey components (Mundo *et al.,* 2004). The key role of sulphureted organic compounds and their precursors (allicin, diallyl sulphide and diallyl trisulphide) in garlic antioxidant activity is studied (Kumar and Berwal, 1998)

Ascorbic acid (AA) is a chelating agent that binds metal ions; it also scavenges free radicals and act as a reducing agent (Ismail *et al.*, 2013). Carotenoid compounds are widely used as natural pigments and also have antioxidant properties (Domenech-Asensi *et al.,* 2013). They can act as singlet oxygen (E1) quenchers, react with free radicals (E2), or act as chain-breaking agents under specific conditions (Faria *et al.*, 2010). Carotenoids such as norbixin, lycopene, zeaxanthin, and β-carotene have good antioxidant activity in food (Kiokias *et al.,* 2009). Tocopherols are effective natural fat-soluble antioxidants. α-tocopherol is commonly used in animal feed to increase the oxidative stability of meat (Velasco and Williams, 2011).

The antioxidant and antimicrobial capacities of spices like clove, cinnamon, nutmeg, and black pepper are examples of commonly used spices with antioxidant activity, mainly due to the presence of phenolic compounds such as coumaric, ferulic, gallic acids, volatile oils, and flavonoids. Spices and herbs have similar chemical composition and roles (Radha *et al.,* 2014). Herbs of the Lamiaceae family, like oregano, rosemary, sage, and thyme have shown their significant antioxidant capacity, primarily due to phenolic -OH groups. Herbs with high levels of phenolic compounds, such as phenolic acids (e.g., gallic, caffeic, and rosamarinic acids) have strong H-donating acitivity and are effective scavengers of H_2O_2 and superoxide radicals (Velasco & Williams, 2011). Apart from these, many other fruit extracts, fruit powder, seed powder, flower extracts, flower powder, leaf oils/extracts and leaf powders from natural sources are being experimented as anti-oxidants in marinated meat products.

Effect of marination on oxidation

Marinade solutions rich in phenolic compounds suppress the secondary products of lipid oxidation and keep 2-thiobarbituric acid reactive substances (TBARS) almost unchanged during storage (Gray and Pearson, 1987). In meat marinated with wine, honey, garlic, black pepper and salt, the TBARS value reached after 14-days storage is low. Thyme, oregano and horseradish have high antioxidant activity and decrease the formation of TBARS. In meat marinated with garlic/onion, the TBARS value is lower compared to non-marinated meat (Kim *et al.,* 2010). After red meat marinating with red wine, a 20% decrease in the formed conjugated dienes after cooking was reached (Blackhurst *et al.,* 2011).

EFFECT OF MARINATION ON PHYSICO-CHEMICAL AND SENSORY PROPERTIES

Meat products such as beef, pork, and poultry are commonly marinated using tumbling, tenderizer, injector and immersion method.

Proximate composition

The proximate composition of meat was differently affected by the marination method due to different dispersibility of

components contained in the marinade. Dietary fiber provides high water retention, so that the moisture content in meat will be high (Choi *et al.* 2009). The water content of the injected chicken breast was significantly higher than that of the tumbled and tenderized chicken breast samples. The protein and fat content of the injected chicken breast was the lowest among all the samples. The ash content was higher in the tenderized and injected chicken breast samples than in the tumbled chicken breast (Kim *et al.,* 2012; Lee *et al.,* 2008) represented in table 2.

Table 2: Proximate composition of marinated chicken breast manufactured with tumbler, tenderizer and injector (Kim et al., 2012)

Properties	Treatment		
	Tumbler	Tenderizer	Injector
Water content (%)	71.54 ± 0.11^{b}	70.88 ± 0.12^{c}	73.77 ± 0.48^{a}
Protein content (%)	26.85 ± 0.08^{a}	26.60 ± 0.13^{b}	22.86 ± 0.09^{c}
Fat content (%)	1.11 ± 0.18^{ab}	1.46 ± 0.22^{a}	0.98 ± 0.17^{b}
Ash content (%)	1.77 ± 0.03^{b}	1.99 ± 0.77^{a}	2.04 ± 0.01^{a}

pH

The pH values of marinated uncooked chicken breast ranged from 6.00 to 6.09, after cooking the marinated chicken breast samples ranged from 6.16 to 6.31. The pH of marinated uncooked chicken breast was lower than that of marinated cooked chicken breast. Studies also reported that the increase in pH value of several meat products was noticed after thermal processing (Kim *et al.,* 2010; Morin *et al.,* 2002). This may be due to the exposure to imidazolium, the basic R group of the amino acid such as histidine, during heating, increased the pH of the marinated chicken breast (Choi *et al.,* 2009). Both the marination method and holding time significantly affected on meat pH. The highest pH value was reported from the meat samples marinated using immersion, injection and tumbling methods hold at 8 hours.

Rise of pH in marinated meat samples may be due to the presence of salt and phosphates in the marinade mixture (Gamage *et al.,* 2017). The chloride ions of the marinade solution which bind to the protein filaments in muscle fibers in turn increase the ionic charge forming a repulsive force inside of the muscle fibers. This repulsive force is believed to increase the pH value of meat (Cheng and Sun, 2008). Tumbling marination stimulates the activity of various proteolytic enzymes. These proteolytic enzymes are known to facilitate the protein degradation of the meat further increasing the pH value of muscle protein (Lawrie and Ledward, 2006). Increasing holding time (4 h to 12 h), allows more marinade solution to penetrate into the meat resulting increased pH. Increasing holding time (4 to 10 h) has increased pH in pork chops marinated by tumbling (Gao *et al.,* 2015).

Texture and tenderness

Tenderness is a quality of meat determining how easily it is chewed or cut. Tenderness is a desirable quality, as tender meat is softer, easier to chew, and generally more palatable than harder meat. Texture is used to describe meat tenderness and also describes the firmness or coarseness of a meat surface (Purchas, 2014). The term tenderness is often used interchangeably with "sensory-tenderness" and objective tenderness measurements. Tenderness of the cooked meat samples can be determined by obtaining Warner Bratzler shearing force values (SFV) using Warner Bratzler Meat shearer. Allo-Kramer method and Muellenet-Owens razor shear method also can be used to obtain SFV. The SFV is a useful indicator related to the meat tenderness where lower SFV indicate more tender meat (Herring *et al.,* 1967).

Marination improved the meat quality by decreasing the SFV while enhancing the meat tenderness. Tumbling of marinated meat is also known to lower the SFV by loosening muscle structures by destructing the connections between myofibrils and collagen (Hayes *et al.,* 2006; Gao *et al.,* 2014). Low shear force values resulted from tumbling marination had direct effects on parameters like increased pH values, low cooking loss and low drip loss. In tumbling method salt soluble proteins extracted after cooking may lead to formation of gel-rigid microstructures which can retain more water and fat in the meat which in turn lubricates muscle fibers when chewing (Gao *et al.,* 2015). SFV of a tenderized chicken breast was significantly lower than those for the tumbled and injected chicken breast samples due to many knives of a tenderizer effectively breaks muscle fibre (Kim *et.al.,* 2015).

Water holding capacity (WHC)

Water holding capacity is another important quality parameter of meat. In most of the studies, WHC is usually expressed as drip loss and cooking loss. Drip loss of chicken thigh meat samples was measured using the bag method. Chicken thigh was hung in a plastic bag and allowed to stand for 2 days at 4°C. Drip loss was calculated by the weight difference before and after hanging (Otto, 2004). The loosening of microstructures of muscle fibers and increase in the pH value of the meat with the extraction of myosin, actin, and actomyosin like salt soluble proteins involve in reducing drip loss and cooking loss (Detienne and Wicker, 1999). The mechanical tumbling could support the marinade effects and improve the WHC and cooking yield (Alvarado and McKee, 2007). In injection method, definite quantity of marinade mixture is directly inserted into the meat, comparatively a lower

WHC was observed for thigh meat marinated by injection method than those marinated by tumbling method. One possibility is that injection might have resulted in excessive water losses due to created holes in the meat surface during the injection process. These holes may act as channels to evaporate water during thermal processing (Gamage *et al.,* 2017). The increase in WHC results in a reduction of cook loss, increase of tenderness and juiciness of the meat product as well as moisture retention (Desmond, 2006).

Colour

Myoglobin is the sarcoplasmic heme protein primarily responsible for the meat color and the chemistry of myoglobin is species specific. The mechanistic interactions between myoglobin and multiple extrinsic and intrinsic factors govern the color of raw as well as cooked meats (Suman and Joseph, 2013). Myoglobin has three natural colors depending on its exposure to oxygen and the chemical state of the iron. Surface meat color in terms of CIE L*, a*, and b* values were measured using a colorimeter. L* - degrees of lightness, a* - degrees of redness and b* - degrees of yellowness. Cooking increases the lightness values and decreases the redness value of meat products. The lightness and yellowness values of marinated cooked chicken breast were higher than those of uncooked sample (Kim *et al.,* 2015). The color index of the marinated meat was particularly resulted from the marinade mixture. Among immersion, tumbling and injection, the immersion method of marination was effective in increasing the surface meat color (Gamage *et al.,* 2017). Saturation of meat surface with the marinade mixture during immersion process may lead to the development of high color intensity which could be easily observed. The lower L*, a*, and b* values resulted from injection method was mainly due to direct insertion of marinade mixture inside the meat during injection process.

Uptake of marinade

The uptake of marinade will be calculated by obtaining the difference between weights of the meat sample before and just after marination.

$$\text{Marinating yield}(\%) = \frac{\text{Final weight}(\text{g})}{\text{Initial weight}(\text{g})} \times 100$$

Cooking and marinating yield are important measurements related to WHC of meat product. The marinating and cooking yields of chicken meat could be related to the components in the brine and the marinating method. Chicken thigh meat samples marinated using injection and tumbling methods resulted a higher marination uptake than immersion method (Gamage *et al.,* 2017). The marinating and cooking yields of the injected chicken breast was significantly higher than those of the tumbled and tenderized chicken breast samples (Kim *et al.,* 2015). In injection, the marinade is inserted into meat by forcing and penetrating into the meat where a definite quantity of marinade is moved resulting in a higher marinade uptake (Xargayo *et al.,* 2001). In tumbling marination method, massaging effect forces water to move into the muscle (Alvarado and McKee, 2007).

Uptake of marinade in immersion method is largely affected by the surface area contact with the marinade and the dipping time. The driving force of the marinade into the meat is mainly due to the pressure gradient. When the pressure gradient becomes zero or the surface of the meat is fully saturated with the marinade the uptake of the marinade will be reduced. (Yusop *et al.,* 2012)

Cooking yield

Thigh samples marinated using tumbling method resulted comparatively a higher cooking yield because the massaging effect exert during tumbling leads to extraction of the myofibrillar protein into meat surface. Extracted muscle proteins are known to provide two functions

i. Coagulation when the meat is subjected to heat
ii. Acting as a sealer when the meat is cooked. Sealing effect facilitates the moisture retention inside of the meat while increasing the cooking yield of the meat (Smith and Acton, 2000)

$$\text{Cooking yield}(\%) = \frac{\text{W1} - \text{W2}}{\text{W1}} \times 100$$

Whereas W1 is weight of sample before cooking and W2 is weight of sample after cooking

Sensory quality

Marinated chicken meat was evaluated for sensory properties by untrained panelists using a pre-designed 6, 8 or 9 point hedonic scale. Each sample was evaluated in terms of colour, flavor, juiciness, tenderness, and overall acceptability. Increased toughness in meat when increasing holding time is because of the disruption of myofibrils as a result of biochemical and physicochemical reactions causing the tenderness of meat to be reduced (Gamage *et al.,* 2017). Prolong holding time is known to cause much more damage to the micro-structure of the meat resulting poor sensory properties. Marinade penetration, colour penetration and the overall acceptability were the highest in meat hold for 8 h after injecting marinade into meat. Tenderizing method of marination is more effective in

enhancing the tenderness of meat compared to tumbling and injection (Kim *et al.,* 2015). Chicken meat marinated by immersion method best contributes to the development of physicochemical parameters but the sensory panelist preferred meat marinated by injection method (Gamage *et al.,* 2017).

REDUCING CARCINOGENIC COMPOUNDS IN CHARCOAL GRILLED MEAT AND MEAT PRODUCTS

The meat and meat products when subjected to high temperature charcoal cooking or barbecuing, there is a high risk of deposition of carcinogenic compounds on the meat surface namely polycyclic aromatic hydrocarbon (PAH).

Fig. 2: Charcoal grilling of marinated chicken chunks

Risk of polycyclic aromatic hydrocarbons (PAH) in meat and meat products

The processing of meat and meat products is aimed at improving its quality, imparting desired sensory properties, improving digestibility, and extending shelf life. Thermal processes to which meat is subjected may carry a risk of generating harmful by-products, which include polycyclic aromatic hydrocarbons (PAHs) and Heterocyclic aromatic amine (HAA). These are products of incomplete organic matter combustion (pyrolysis process) (Singh *et al.,* 2016). PAHs have a lipophilic nature, where their octanol-water partition coefficients are quite high, which significantly impacts their accumulation in living organisms (Pimentel *et al.,* 2015). Human exposure to PAHs is common and absorption takes place in several ways like inhalation, skin, and gastrointestinal tract. Among them the highest exposure to PAHs is related to consumption of contaminated meat (Hamidi *et al.,* 2016). The three possible mechanisms of PAH formation in smoked or grilled meat products are first, the pyrolysis of organic matter, mainly fat and protein (PAH formation through pyrosynthesis reaction). The second relates to the leakage of cellular sap onto the heat source (Hamidi *et al*., 2016; Mologni *et al.,* 2019). The third is the incomplete combustion of organic matter used for cooking (e.g., charcoal, wood) (Hamidi *et al.,* 2016). PAHs are transported together with smoke upfront and settle on the surface of the product and then may migrate inside (Hamidi *et al.,* 2016; Mologni *et al*., 2019). Furthermore, they are formed within the temperature range of 350–900°C. Benzo(a)pyrene is most common PAH formed at temperatures exceeding 500°C (Hamidi *et al.,* 2016; Singh *et al.,* 2016).

PAHs exhibit toxic, genotoxic, mutagenic, and carcinogenic effects on living organisms, including humans (Singh *et al.,* 2016; Wang *et al.,* 2018). High PAH exposure may increase the risk of oesophageal, stomach, and colorectal cancer (Hamidi *et al.,* 2016). DNA-PAH adducts can lead to replication errors and mutations, initiating and promoting carcinogenesis (Hamidi *et al.,* 2016; Wang *et al.,* 2018). Additionally, PAHs may disrupt the hormone system (Pimentel et al., 2015) and negatively impact fertility by affecting estrogen receptor expression in ovaries (Hamidi *et al.,* 2016; Wang *et al*., 2018).

EFSA (2008) states that PAH4 (benzo(a)pyrene, chrysene, benzo(a)anthracene, and benzo(b)fluoranthene) is a significant indicator of PAH content in food, with a permissible limit of 12 µg/kg (Regulation 1881/2006). Muthukumar *et al.* (2019) assessed PAH levels in tandoor and smoked chicken, finding 2 out of 3 tandoor chicken samples had pyrene at 0.01 ppm, while smoked chicken had pyrene and anthracene at 0.01 to 0.02 ppm (1 ppm = 0.001 µg/mg). These findings raise concerns about PAH contamination in these foods.

Reduction of PAH in meat and meat products during charcoal grill cooking

Due to the wide spread exposition of the human on PAHs, the control of their content in food products is necessary. Optimization of the technological process through relevant methods, fuel type and thermal processing in possibly the lowest temperature and the shortest time are very

Table 3. Effect of using different marinades on meat which reduced the formation of PAH

Sample	Ingredients used	Reference
Fried pork	Spices, garlic, and onion	Da Paz et al., (2017)
Chicken	Oil containing lemon juice or tamarind	Farhadian et al., (2012)
Charcoal grilled chicken wings	Beer marinade	Wang et al. (2019)
Charcoal grilled chicken wings	Green tea marinade	Wang et al. (2018)
Chicken	Pretreatment with garlic	El Badry (2010)
Pork loin steaks	Vinegar	Cordeiro et al. (2020)
Chicken breasts	Palm oil and sunflower oil	Wongmaneepratip and Vangnai (2017)
Grilled pork belly	Green tea marinades	Park et al., (2017)
Beef patties	Red wine pomace	Lomillo et al., (2017)
Pork patties	4% Vegetable oil Olive oil, sunflower oil, grape seed oil	Lu et al. (2017)
Pork meat	Onion (30%), Garlic (15%)	Janoszka (2010)

important in controlling the PAH level in meat and meat products (Onopiuk *et al.,* 2021).

It is crucial to minimize the pyrolysis of fat-containing "juices" since the resulting PAH-containing smoke will adhere to the product's surface and increase contamination. Minimized fat dripping can be obtained by keeping the fat content of the meat as low as possible, through the use of a pan or tray for the meat, wrapping the meat, or using a grill constructed in a way that fat cannot drip down (e.g., indirect heating), or by moving the heat source laterally, such as with vertical barbecues. (Mithun, 2023)

Mitigation of PAH can also be done by using marinades as pre-treatment before barbecuing. Marinades of garlic and onions, tea marinades, beer, and especially acidic marinades with high phenolic content can reduce PAH concentrations considrably (Onopiuk *et al.,* 2021). Correct pairing of ingredients of a meal with e.g., anti-carcinogenic vegetables, can counterbalance the adverse health effects of PAH formed during the process of barbecuing (Olesen and Lonas, 2021). Pre-burn charcoals to avoid flames, and in general, for other heating materials, the consumer should make sure that the combustion is complete to reduce the PAH concentrations of the barbecued products. Reheating of charcoal should be avoided. Appropriate distance should be maintained during barbecuing (>25 cm) between charcoal and the meat. (Olesen and Lonas, 2021).

CONCLUSION

Marination enhances the colour, flavour, texture, tenderness and sensory quality of meat. It also improves the physio-chemical properties of meat. Marinated meat with added spices and herbs act as both anti-oxidant and anti-bacterial agent, in turn helps in improving the shelf life of meat. Marination helps in the birth of variety of new meat products and creates convenience in meat storage and usability. Moreover, marination of meat was reported to reduce the amount of polycyclic aromatic hydrocarbon (PAH) in charcoal grilled meat.

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