Review Article

# FURAN COMPOUNDS IN ULTRASONICATION PROCESSED CHICKEN

## ABSTRACT

Furan compounds formed during thermal processing of foods are a significant concern due to their potential carcinogenic effects. This review examines the role of Ultrasonication, an emerging non-thermal food processing technique in influencing the levels of furan compounds in processed chicken. Ultrasonication employs high-frequency sound waves to induce cavitation, which can alter chemical reactions and physical properties of food products. Furan compounds are byproducts of thermal processing in foods, formed through a number of precursors and reaction pathways, predominant of which is the Maillard reaction and poses significant health risks. Studies have shown that Ultrasonication enhances Maillard reaction resulting in the formation of Maillard reaction products such as Furan. Using high frequency sound waves to create cavitation bubbles which disrupt chemical bonds and promote free radical formation, ultrasonication formed free radicals can promote and inhibit furan formation by interacting with unsaturated fatty acids and other precursors in chicken. Factors such as sonication intensity, duration, processing conditions such as temperature, pH and chicken composition influence the formation of furan and furan levels in chicken processed by ultrasonication. By consolidating recent findings, this review aims to provide an understanding of Ultrasonication as a non-conventional, safer and healthier food processing alternative to traditional thermal processing methods.

## INTRODUCTION

Food quality and food safety is a major concern in the course of food processing and food preservation (Augustin et al., 2016). Conventional and traditional food preservation and processing methods expose food to very high temperature, which has a great reducing effect in the contamination or microbial load in the food, resulting in some unwanted changes such as loss of temperature sensitive nutritional components, changes in the organoleptic characteristics of food borne pathogens such as bacteria, viruses and parasites (Rajkovic et al., 2010), and can also result in the formation of various hazardous products, such as heterocyclic amines (HCAs), acrylamide (AA), furan and lipid and protein oxidation products.

The presence of furan in commercial food products is a great concern to quite a number of public health agencies such as the US Food and Drug Administration (FDA) and European food Safety Authority (EFSA) and has triggered research on furan and identification of risks conferred by furan by many international organizations, including the National Toxicology Program (NTP) and International Agency for Research on Cancer (IARC) (Seok et al., 2015). An FDA survey found that relatively high levels of furan were present in certain thermally processesed foods such as infant foods, soups, and meat products that underwent a retort process (FDA, 2009; Morehouse et al., 2008). The levels of furan present in those foods were as high as 100-200mg/ng. Other surveys also indicated the presence of furan in cooked or thermally processed foods (Becalski et al., 2005; Becalski & Seaman, 2005). Furan is unavoidably absorbed by the intestine and lungs; it can permeate biological membranes due to its low polarity and eventually reach various organs (Seok et al., 2015, Santonicola and Mercogliano 2016).The food industry has been improving traditional technologies and developing non-conventional technologies to meet the needs and demand of consumers with regards to the safety and quality of high nutritional value foods (Devlieghere et al., 2004). The production of furan as a result of thermal processing has been well studied and extensively addressed ( Becalski & Seaman, 2005, Crews & Castle, 2007; Mariotti et al., 2012; Owczarek-Fendor et al., 2012), however, its formation as a food contaminant in non-thermal processing methods have not been adequately addressed. The Non-thermal processing methods generally used for sterilization and inactivating enzymes in the food industry include Ultrasonication (US), high-pressure processing (HHP), Pulsed Electric Fields (PEF), High Pressure Carbon dioxide (HPCD), High-Pressure Homogenization (HPH), Ionizing Radiation (IR), and Pulsed Magnetic Field (PMF) (Devlieghere et al., 2004).

Ultrasound technology is an emerging, highly efficient and gentle non-thermal environmentally friendly technology which not only improves processing efficiency and the quality of products, but also saves cost (Shaofeng, et al., 2021). Compared with traditional thermal technology, ultrasonication can reduce processing time, save energy, improve the quality of food and extend shelf life (Chemat et al., 2011, Lagnika et al., 2013). It has been widely studied by the food industry for conditions such as drying (Da Silva et al. 2019), cleaning (Da Sao et al., 2014), tenderization (Alves et al., 2013) and sterilization (Cao et al., 2018). Ultrasound has a disinfecting effect on meat, for example, ultrasound bath (30 kHz) can reduce the number of microorganisms on the surface of fish more quickly, without significant effect on the quality of the fish (Pedros-Garrido et al., 2017). Studies conducted so far have shown that non-thermal processing methods are a cleaner alternative to thermal processing and have also shown the advantages of Ultrasonication as a non-thermal processing method, but the field lacks a comprehensive understanding of its effect on furan content due to the numerous pathways to furan production and the numerous factors that affect these reactions. Previous studies show that the reaction rates of Maillard reaction are highly dependent on various conditions, including combination of reactants, concentration of reactants, initial pH, water activity, reaction temperature, and reaction time (Martins et al., 2000).Recently, high-intensity ultrasound technique has been found to accelerate Maillard reaction (Siewe et al., 2020). A recent study has also shown that ultrasound treatment promoted the generation of more volatile compounds over thermal MR (Yu et al., 2018).

As one of the few non-thermal processing techniques that can reduce processing time, Ultrasound Technology can save energy and improve the quality of chicken when compared to traditional thermal technology (Minju & Kwang-Geun 2023).Conventional processing methods have been extensively investigated to reduce contaminants in chicken but none of them are completely satisfactory (Alister et al., 2018). Such methods cannot effectively remove harmful substances or may cause secondary pollution (Yigit & Velioglu, 2019). Besides, some extreme treatment conditions may affect the sensory quality of food or cause food contamination. Ultrasound has been widely reported to be able to degrade organic pollutants in the field of environmental science (Debabrata & Sivakumar, 2018; Kida et al., 2018). The free radicals produced by the cavitation effect were proved to be the main reason for contaminant degradation by ultrasound and the degradation efficiency is related to ultrasonic frequency, power and other parameters (Yang et al., 2019).In recent years, ultrasound has been widely used in meat processing because of environmental friendliness, safety, and energy conservation (Zhao et al., 2022). Studies carried out by Zhao et al., (2022) showed that the ability of Myofibrillar protein to bind furan compounds was increased with increasing ultrasound power levels. This binding ability first increased and then decreased. Among the ultrasound power levels tested, 500 W could promote the disaggregation and unfolding of the MP to the maximum extent, expose more hydrophobic bonding sites and hydrogen bonding sites, and increase electrostatic effects, thus clearly improving the affinity of MP to furan compounds (Zhao et al., 2022).Studies also showed that the internal structure of the furan compounds also influenced the interactions of the protein-furan compounds (Zhao et al., 2022).

It has been known for a long time that formation of certain chemicals during food processing or preparation may pose a risk to human health. Technological developments and the use of various industrial, as well as home-cooking methods have led to a great number of different ways on how to use thermal treatments to achieve specific food qualities (Cartus & Schrenk 2017). Thermal treatments change the physical and chemical structure of macronutrients, e.g., starches and proteins (Cartus & Schrenk 2017). However, thermal processing of food is known to generate potentially mutagenic and carcinogenic by-products in addition to desirable aromas, colours and flavor of active compounds. It has been reported to accelerate oxidative processes not only in lipids, but also in proteins due to its increasing effect on free radical production and decreasing effect on food antioxidant protection. Numerous studies have been conducted on thermally generated food toxicants, ranging from identification, formation, toxicology and analysis (Wenzl et al., 2007, Sante-Lhoutellier et al. 2008).

Food preservation and food processing techniques involve the application of heat, based on this, food processing methods are categorized into Thermal and Non-thermal processing methods (Shujun et al., 2019). Thermal processing normally involves high temperature generated by heating, whereas non-thermal processing is often induced by high-pressure, sonication, pulsed electric field, infrared, and cool plasma utilizing physical phenomena such as pressure waves, sonication, high hydrostatic pressure, and electric/electromagnetic fields (Knoerzer 2016).

Non-thermal processing is an emerging and innovative technology for the advancement or replacement of conventional processing technologies, with the aim of delivering higher quality, value or better consumption-oriented food products (Cartus and Shrenk 2017). Traditional thermal processing techniques are widely applied to improve food safety and stability, but can also cause extensive chemical changes in foods. Beyond that, thermal treatment also changes the physical and chemical structure of macronutrients, e.g., starches and proteins with the generalized effect of better gastrointestinal digestion. They have been reported to fast track oxidative processes not only in lipids, but also in proteins (Cartus and Shrenk 2017). This acceleration of oxidative process is due to their increasing effect on free radical production and their decreasing effect on the food antioxidant protection. The acceleration of the development of lipid oxidation through the generation of free radicals results in rancid odour, off-flavour development, discolouration, loss of nutritional values, decrease in shelf-life and generation of compounds that may pose risks to human health. Chicken meat is particularly susceptible to oxidative damage owing to its high degree of lipid unsaturation. Comparatively, non-thermal food processing is in line with the trend of food safety.

One of the key reactions encountered in the course of food processing is the Maillard reaction, involving reducing sugars and amino acids, which are responsible for 330 known volatile compounds associated with cooked food (Bravo et al, 2012). These reactions may affect the colour, flavor, and aroma of the food product, cause the formation of toxic compounds (e.g., acrylamide, furans and hydroxyl propyl furfural), and decrease the digestibility and nutritional value (Dagostin 2017). Maillard Reaction, a non-enzymatic browning reaction between reducing sugars and amino acids, peptides or proteins has been studied for over a hundred years since French Chemist Louis-Camille Maillard first reported it in 1921 (Chen et al., 2019). Also called non-enzymatic glycation, Maillard reaction (MR) is a spontaneous reaction between amino groups (including amino acids, peptides, or proteins) and reducing compounds (containing reducing saccharides) (Chen et al., 2019). This reaction is a complex reaction of amino compounds (proteins, peptides, amino acids or amines) and reducing sugars which takes place as a whole network of various reactions that form several early, intermediate and advanced compounds, known as MR products (MRPs) (Chasataporn et al., 2019). It is commonly found in food processing and storage, contributing to the formation of food flavour and colour and many bioactivities such as antibacterial, antihypertensive, and antitumour activities (Fu et al., 2019). In general, Maillard reaction is one of the major food protein-modifying reactions occurring during thermal processing of Chicken (Hang Yu et al., 2020). Contrary to conventional belief however, it can also occur at relatively low temperatures, e.g. during storage at room temperature (Martins et al., 2000). Previous studies on the principle and mechanism of Maillard reaction have demonstrated that its reaction rate is dependent on various conditions, e.g. combination and types of reactants, concentration of reactants, initial pH, water activity, reaction temperature, reaction time, etc. (Martins et al., 2000). Among the above-mentioned conditions, the nature of reactants is a major determinant. For example, the rate of Maillard reaction is inversely proportional to the size of reducing sugar molecule. It therefore means that the rate of Maillard reaction in some processes increase with a decrease in the size of the reducing sugar molecule (Hang Yu et al., 2020).

On the reverse however, Maillard reaction also generates negative products and food contaminants (Hang Y. et al., 2020), meaning that there are some negative effects associated with it. Maillard reaction produces flavour and aroma compounds in thermally produced chicken. Unfortunately their formation is frequently accompanied by undesirable reactions that can result in various hazardous Maillard products, such as heterocyclic amines (HCAs), acrylamide (AA), furan and lipid and protein oxidation products (Khan et al., 2022). These toxic substances can be produced in industrial food processes and during ordinary household cooking as both high temperatures (›$150^0$C) and prolonged heating promote their formation. It therefore means that avoiding dietary exposure to them is near impossible for the general public. As a result, they may pose serious health risks, and inhibiting their formation has been a long-term strategy for developing safe and healthy foods (Khan et al., 2022).

## FURAN

Furan and its derivatives, one of the naturally occurring compounds formed in many heat-processed foods is a heterocyclic organic compound consisting of a five- membered aromatic ring with four carbon atoms and one oxygen. It is a cyclic dienyl ether with a low boiling point of 31.4$^o$C and is poorly soluble in water. These compounds have low odour thresholds and significantly contribute to the sensory properties of heated foods and beverages above $150^0$C (Koszucka & Nowak, 2019). Furan and methylfurans are lipophilic oxygen heterocycles of high volatility occurring in a wide range of cooked and/or heat processed foods. They are formed through diverse chemical reaction pathways involving mainly oxidative or thermally driven mechanisms (Crews & Castle, 2007). Some of the many precursors that can be envisaged are the polyunsaturated fatty acids (PUFAs), carotenoids, carbohydrates/sugars, amino acids, and ascorbic acid/dehydroascorbic acid (Becalski & Seaman, 2005; Crews & Castle, 2007). The diversity of foods which contains furan suggests that multiple pathways are likely to be involved in the formation of furan in chicken (Owczarek-Fendor et al, 2011). Studies performed in model systems have shown that furan and methylfuran can be generated from heating ascorbic acid, polyunsaturated fatty acids, unsaturated aldehydes, sugars and amino acids ( Anese & Suman 2013).

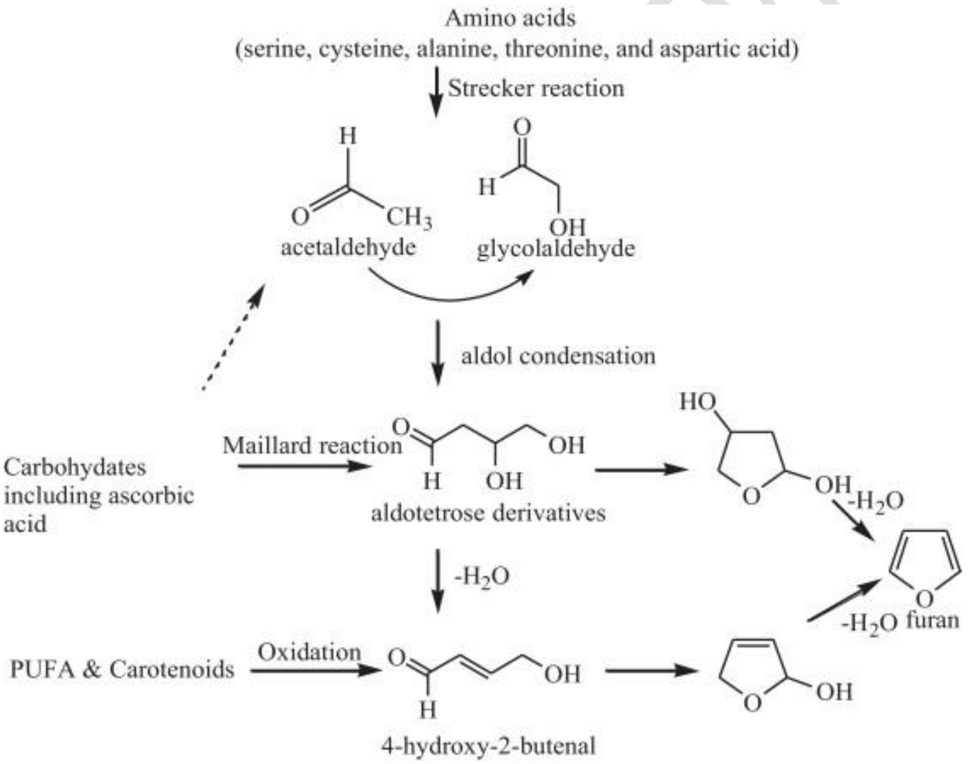

Fig. 1. Different stages of furan formation. Adapted from Perez Locas, C., & Yaylayan, V. A. (2004). Origin and mechanistic pathways of formation of the parent Furan , A food toxicant.

Furan can be found in chicken processed using different techniques because the molecule can be formed from many different precursors (Crews and Castle 2007). Various precursors including polyunsaturated fatty acids (PUFAs), amino acids, carbohydrates, and ascorbic acid, under thermal or oxidative conditions can form furan via different classically thermally driven mechanisms. To date, four most important mechanisms featuring the major routes of furan formation have been revealed by different literature studies (Crews and Castle 2007). They are as follows:

(1) The oxidation of polyunsaturated fatty acids.

(2) Thermal degradation of amino acids under thermal conditions.

(3) Thermal degradation or rearrangement of carbohydrates such as glucose, fructose and lactose or reaction with amino acids (Maillard reaction).

(4) Ascorbic acid decomposition including its derivatives as precursors (Crews and Castle 2007).

## FURAN COMPOUNDS IN PROCESSED FOOD

Furan containing compounds are plenty in food, perfumes, synthetic pharmaceuticals, natural herbal medicines, and environmental pollutants (Knutsen et al., 2017; Delost et al., 2018). Furan has attracted worldwide attention due to its carcinogenity and frequent occurrence in a variety of thermally driven foods, such as different coffees, baby foods, cereals and meat products (EFSA (European Food Safety Authority, 2017; FSA (Food Standard Agency United Kingdom, 2018). However, the main risks associated with furan consumption still remains unclear. (Batool et al., 2020). Diminishing furan content in foods using different strategies would be considered as challenging for prevention for from human diseases (Batool et al., 2020). Hence, there is great need to optimize the methods and find some reasonable solution of problems related to furan formation in food while processing.

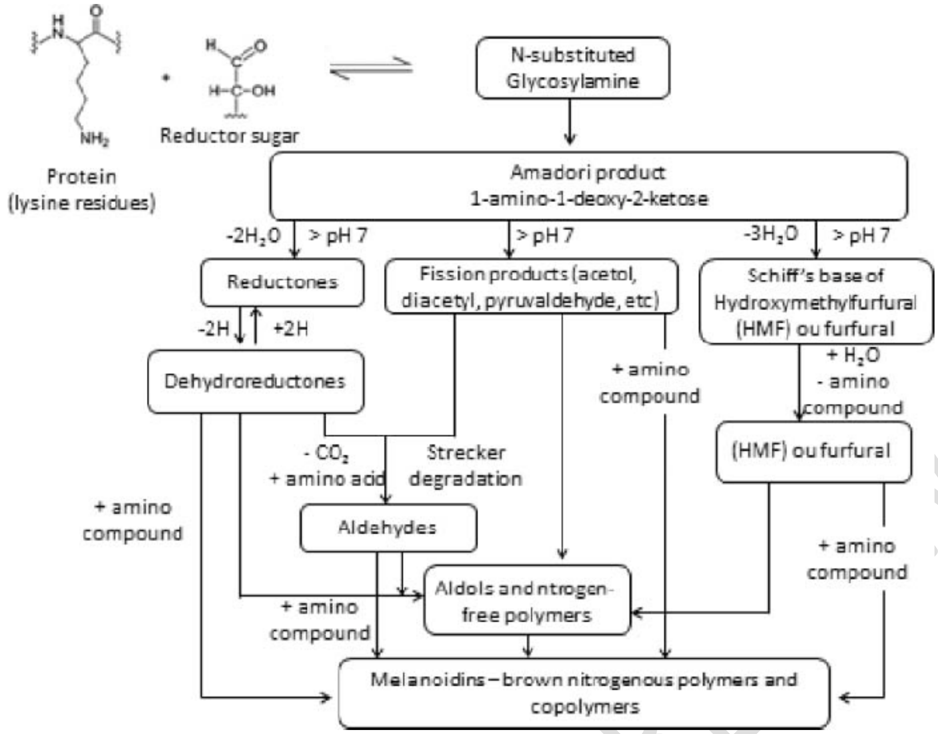

Fig. 2: Scheme of the Maillard reaction adapted from Hodge (1953), Oliveira et al., 2012

Different furan precursors triggering furan production in the course of the processing of chicken via heat and pressure induced pathways have been identified as shown in figure 2. (Oliveira et al., 2012, Batool et al, 2020). However, during processing several factors could have played significant roles in influencing furan formation from these precursor systems. These key factors include heating time, water, sugar to amino acid ratio, temperature, pressure, metals, oxidation conditions, pH, reaction types and irradiations (Charkraborty et al. 2015; Dhakal et al. 2017; Hu et al. 2016 ; Shen et al. 2015). Among these factors, oxidation conditions, pH, temperature, time, and irradiation might have played crucial roles in furan formation (Nie et al. 2013, Cho &Lee, 2014).

In industrial processes, at temperature around 200$^0$C, the furan levels increases with increasing temperature (Santonicola and Mercogliano 2016). However, when it exceeds the value of 200$^0$C the concentration of furan is no longer dependent on the temperature values. In domestic cooking, furan formation is dependent on the type of cooking. Frying at $150^0$-$200^0$C generates higher levels of furan, compared with baking (Santonicola and Mercogliano 2016). The combination of higher temperatures and lower water content leads to a higher furan content. Furan seems likely to form in browned products, especially if the water activity is low. In particular, high levels of furan were found in bread toasted from a brown to very dark colour. (Santonicola and Mercogliano 2016).

Furan levels may form at various pH and temperatures in experimental model systems (Nie et al., 2013), and pH has a significant effect on thermally induced furan formation If temperature is greater than $110^0$C. At pH 7.00 higher levels of furan were observed than at pH 9.40 and 4.18, suggesting that pH is an important factor influencing furan formation as a function of thermal treatment and temperature (Santonicola and Mercogliano 2016). For instance, after heating for 30 minutes at $150^0$C in experimental model at pH 7.00, 9.40 and 4.18, the furan concentration was found at 304, 238 and 40ng/mL, respectively (Santonicola and Mercogliano 2016). Also Fan, (2005a) reported that less furan is formed at pH 3.00 than at pH 7.00 for glucose solution. At pH 7.00 furan content increased rapidly from 34 to 304ng/mL with temperature increasing from $120^0$C to $150^0$C. These data suggests that temperature is also a major factor affecting furan formation in model system (Nie et al., 2013).Time and temperature are process variables that have been shown to have certain impacts on furan formation. Higher temperature can trigger thermal degradation of carbohydrates, further producing furan precursors. Furan formation increases with increase in heating time during processing due to enhanced Malliard reaction or thermal degradation of chicken constituents an (Zahra et al., 2020).

Lipids oxidation is most likely one of the most studied pathways of furan formation in Ultrasound processesed chicken. This study was carried out by simulating different model systems. The (E)4-hydroxybut-2-enal formed as the resulting intermediate degradation product, cyclised to 2,3-dihydro-2- furanol, triggering furan formation after water removal (Batool et al., 2020). Moreover, linolenic acid has been shown to be an efficient furan precursor among PUFA mixtures (Shen et al. 2015) particularly in the presence of transition metals, accelerating lipid oxidation with the subsequent formation of conjugated dienes. Furan formation from fatty acids also happens due to the formation of 4-hydroxyalk-2-enals, probably including (E)4-hydroxybut-2-enal, produced by oxidation of but-2-enal (Owczarek et al. 2010). Thermal degradation of amino acids such as serine and cysteine also induce furan formation (Locas and Yaylayan 2004). The formation of acetaldehyde and glycolaldehyde during thermally driven degradation of serine gives rise to an intermediate 2-deoxyaldotetrose, whose cyclization and dehydration yield furan moiety. Certain other amino acids can also form furan, such as alanine, aspartic acid and threonine can furnish furan backbone by producing 2-deoxyaldotetrose, depending on amino acids condensation into acetaldehyde only with involvement of glycoaldehyde. Thus, reducing sugar, serine or cysteine are required to form glycoaldehyde formed during strecker degradation, and further produces 2-deoxyaldotetrose, acting as an intermediate toward furan formation (Locas and Yaylayan 2004). Amino acids subjected toward oxidation reaction may also procure reactive carbon-2 units such as glycolaldehyde and acetaldehyde (Locas and Yaylayan 2004).

## ULTRASONICATION OF CHICKEN

An emerging technology that uses sound waves of above 20kHz for a wide range of applications in the food industry, Ultrasonication is a technology that has numerous advantages, proffering energy efficiency and economic feasibility (Bhat et al., 2021). Sound waves are considered as safe, non-toxic, and environmentally friendly, which gives the use of Ultrasonication a major advantage over other emerging techniques (Feng H. et al., 2011). Ultrasonication technology uses sound waves above the human audible range from 20kHz to 10MHz, and based on this, treatments are categorized into low intensity(100kHz-10MHz, ‹1W/cm$^2$) and high intensity (20-100kHz, ›1W/cm$^2$) (Bhat et al, 2021b). The energy can be delivered at a single frequency or as a more efficient multi-frequency process. Frequencies less than 100kHz and power intensity in the range of 1-1000W/cm$^2$ are generally used for food and protein related applications (Bhat et al., 2021). Ultrasound is divided into two types based on their frequency range: low intensity ultrasound (0-1W. cm$^2$, >100kHz) and high intensity ultrasound ( >1Wcm$^2$, 20-100kHz) (Nowacka and Wedzik 2016). Both types of ultrasound treatments have practical applications in various disciplines, most notably in food processing and food-safety related sectors. As a nondestructive method, low-intensity ultrasound is utilized to monitor the changes in physicochemical properties during food preparation. In comparison, high-intensity ultrasound is used for many applications, including emulsification, and inactivation of enzymes and bacteria that leads to the extension of the shelf life of food product (Nowacka and Wedzik, 2016). While Ultrasonication has demonstrated efficacy in diverse applications, its specific impact on furan content in chicken remains an intriguing area of exploration.

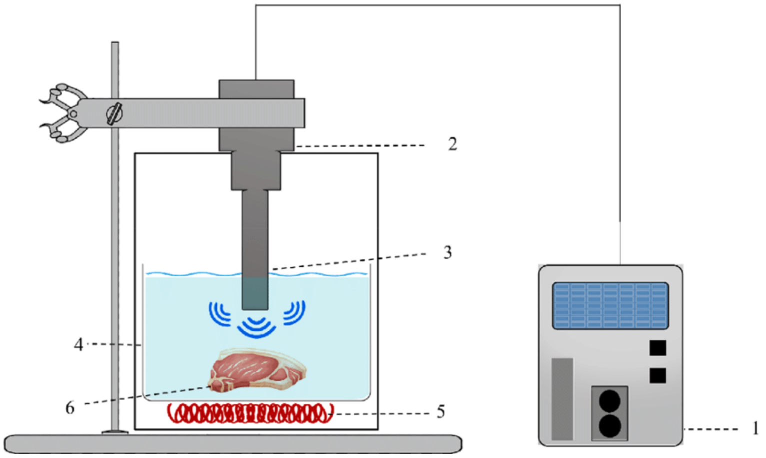

Fig: 3: Probe-based HIUS-assisted cooking system.

1) Ultrasound generator and control panel; 2) Ultrasonic probe; 3) Horn; 4) Container; 5) Heat generator; 6) Meat sample (Mahmoud S.F, et al., 2022)

In Ultrasonication, passing Ultrasound wave through the targeted media results in a continuous wave-type motion. The motion creates two types of alternative cycles, namely compression and expansion. In a liquid, cavities are generated during the expansion cycle due to a large negative pressure overcoming the liquid's tensile strength; the compression cycle generates positive pressure which can push molecules together (Hang yu, et al., 2020). The cavities keep growing with the adsorption of acoustic energy; upon reaching a critical size, the cavities would implode, release energy and heat to the surroundings reaching up to an extraordinarily high temperature of about 5,500$^{0}$C, followed by a flash cooling at the rate of more than a billion$^{0}$C per second. Hence, the cavitation generated by high-intensity ultrasound brings a unique environment for chemical reactions (Hang yu, et al., 2020). Stable cavitation is produced in the process of continuous low-intensity ultrasound (‹1 W/cm$^{2}$), the volume of the cavitation bubble gradually expands, but remains smaller than the critical fracture size during the compression cycle. Transient cavitation refers to the rapid expansion of the cavitation bubble in the process of continuous high intensity sound (‹1 W/cm$^{2}$), which breaks and releases a lot of energy after reaching a critical size. Such a unique environment generated by ultrasound can fragment water and other molecules into free radicals (Yuan et al, 2021). It is worth noting that high-intensity Ultrasound (from 1 to 1000W/cm$^2$) is able to expand the cavities much faster than low intensity US, which has drawn much attention in the food science domain. Currently, high-intensity US with the lower frequency range of 20 -100kHz has been treated as an alternative to conventionally thermal processing due to its low energy consumption, as well as the reduction of processing time and thermal effects (Rastogi, 2011).

## FURAN AND ULTRASONICATION

The cavitation effect of ultrasound enables water molecules to generate hydroxyl radicals and produce hydrogen peroxide with strong oxidative properties, which leads to oxidation of proteins and lipids in meat (Antti et al., 2008). Ultrasound-assisted cooking can increase the type and amount of volatiles in meat products by promoting lipid and protein oxidation (Cao et al., 2018). Studies carried out by Cao et al. (2018) showed that, the physical and chemical effects caused by ultrasound may have negative effects on food, because hydroxyl radicals produced by the “cavitation” effect caused degradation of ascorbic acid and a decrease in total phenol content. Especially for lipid foods, ultrasound induced lipid degradation will not only produce unpleasant odors, but also the secondary reaction products will reduce the nutritional quality and safety of the food (Cao et al., 2018). Considering the seemingly inevitable release of toxic compounds such as Furan in the course of processing chicken for consumption, it is therefore a risk for humans, especially for infants, the elderly and immune-suppressed persons (Lineback and Stadler, 2009). The introduction of other technologies and further research is needed to find mitigation strategies which lead to the same quality without affecting the safety of the product.

The efficiency of ultrasound in the processing of chicken depends on the ultrasound characteristics (e.g., frequency and intensity), ambient conditions (e.g., pH and temperature) and molecular properties of the reactants (Zhu et al., 2019). Therefore, extrinsic control parameters such as frequency, ultrasonic intensity, treatment time and temperature play important roles in the chemical effects of ultrasound (Yuan et.al, 2021). In recent decade, effects of Ultrasonication on Maillard reaction (MR) have gradually drawn attention in the food science domain. As one of the most important chemical reactions in the food systems, the MR generates important and distinctive Maillard Reaction Products (MRPs) during food processing. Ultrasonication as an emerging technology is therefore expected to promote positive but inhibit negative attributes brought by the MR (Hang et al., 2020).

In an ultrasound system, the electrical energy is transformed into vibrational energy, which is mechanical energy that has been transmitted through a sonicated medium (Mahmoud et al., 2022). Part of the input energy is lost through conversion to heat, and the rest can produce cavitation. A fraction of the cavitation energy produces chemical, physical, or biological effects while other fractions are reflected and consumed in the re-emission of sound. Studies have found that the cavitation effect of the ultrasound could crack the water molecules to produce the hydroxyl radicals to produce the hydrogen peroxide with strong oxidizing properties leading to the protein and lipid oxidation of chicken (Antti et al., 2008). Carbohydrates and lipids are the primary precursors of furans, however, alkylfurans, mainly those with longer alkyl side chains are derived from lipid degradation (Parker 2015). Two furans, including 2-pentylfuran and 2-ethyl-furan were detected in higher concentrations in the ultrasound treated flavourings compared to the control sample. The increase in the concentration of the 2-pentyl-furan, and 2-ethyl-furan in ultrasound treated samples might be due to the formation of α,β-unsaturated aldehydes like 2,4-alkadienals or 2-alkenals at greater extent during ultrasound pretreatment (Adams et al.,2011)

Ultrasonication devices range from cylindrical probes and tanks to cooking stew pots. The ultrasound frequency is not highly variable, 20 to 40 kHz, however, intensities are vary from 2.39 to 109.7 W/cm$^2$, as well as treatment times from 1 to 120 minutes (Alarcon-Rojo et. al., 2018). Despite recent advances made in the field, research results still vary. Some findings seem to position High Intensity Ultrasonication (HIU) as a promising technology for the processing of chicken in the food industry, especially with regards to the release of MRPs such as furan and its derivatives, others on the other hand stress the need for more research particularly when the effect interacts with other variables in the tissue (Alarcon-Rojo et. al., 2018).

So far, Ultrasonication has been adopted as an alternative technology for food processing. However, studies on Maillard reaction model systems show that Ultrasonication plays an important role in promoting the intermediate stage and final stages of Maillard reactions. Ultrasonication promote the generation of coloured and volatile MRPs, as well as MRPs with higher antioxidant capacity (Hang Yu et al., 2020). One significance of Ultrasonication is its ability to partially replace conventionally thermal treatment, therefore leading to a decrease of processing time and temperature. As a result of decreasing treatment duration, higher content of nutrients and functional ingredients would be preserved in the ultrasonicated processed chicken (Hang Yu et al., 2020). The MR during ultrasonication treatment is inhibited to a certain level as well, preventing loss of essential components in the final products. As a result of the inhibited MR, less content of coloured MRPs, offflavours(e.g. HMF, 2-FM-Lys, 2-FM-Arg, etc.) are formed in the processed chicken with the assistance of US. It is important to state that US-MR is a double-edge sword for the final products (Hang Yu et al., 2020).

The speed of an ultrasonic pulse depends on the acoustic properties of the medium, and the speed of sound propagation is greater in solids than in liquids and higher in liquids than in gases (Kasaai 2013). This therefore means that the speed of sound propagation in chicken is great, thereby enhancing cavitation, transforming electrical energy into vibrational energy, which is mechanical energy that has been transmitted through a sonicated medium. Part of the input energy is lost through conversion to heat, and the rest can produce cavitation (Alarcon-Rojo et. al., 2018).

The quantity and quality of furan and its derivatives in Ultrasound processesed chicken depend on the precursors, thermal processing parameters, pH, and quantitative ratio of amino nitrogen to reducing sugar. This therefore shows that the Maillard reaction is actually a complex network of various reactions involving reactants and products with high reactivity. Its mechanism is still a controversial issue; therefore the reaction is difficult to control and its study is still a challenge (Martins et al., 2000; Nursten, 2005).

The influence of ultrasound pretreatment on the extent of Maillard reaction (MR) and the properties of MR products (MRPs) of chicken liver protein (CLP) and its hydrolysate (CLPH) were investigated by Chen et al., (2020). The result showed that the extent of Maillard reaction of Ultrasound processesed chicken liver protein hydrolysate was morr than that of the other two Maillard reaction products; chicken liver protein hydoxylate and sonicated chicken liver protein hydroxylate. Ultrasound processing increased the utilization of amino acids and enriched the variety of volatile compounds in all groups. Furfural was the major heterocyclic compound in the MRPs. The study reported the contents of furfural in CLPMs, and CLPHMs, and SCLPHMs as 627.97mg/mL, 649.78mg/mL and 668.51mg/mL respectively, indicating higher furfural content in the sonicated chicken liver protein hydroxylate (Chen et al., 2020).

So far, Ultrasound-alone treatment has been seen to be effective in removing chemical contaminants, but a combination approach has advantages when the prolonged treatment of a single technology may result in adverse effects as seen in recent studies documenting the synergistic effects of ultrasound with other techniques such as ultraviolet (Wang et al., 2020), and thermal treatment (Kida et al., 2018). In most cases, combining two or more approaches enhances the production of hydroxyl radical, the most powerful reactive specie generated through the various formation pathways of furan, including the breakdown of water during Ultrasound induced cavitation. During cavitation, hydroxyl radicals are produced, contributing to the initiation of chemical reactions including those involved in furan formation (Wang et al., 2020). Hydroxyl radicals react with various precursors in the chicken such as amino acids and sugars, facilitating a series of complex reactions that lead to the formation of furan compounds. It therefore means that in order to control the intensity, duration, and the resultant effect of ultrasound processing, it is important to optimize processing conditions in managing the formation of reactive species like hydroxyl radicals. A detailed understanding of these mechanisms will aid in tailoring ultrasound processing of chicken to minimize undesired reaction formation and food contaminants such as furan, while still maintaining the benefits of this non-thermal technique in the processing of chicken. Studies carried out by Lee & Lee (2023) showed that ultrasonication greatly increased ($p‹0.05$) the furan compounds in black soymilk. The highest total concentration of furan was in the black soymilk sample ultrasound treated at 90%

amplitude for 5 minutes. This increase may be due to the increased efficiency of the Maillard reaction (Lee & Lee, 2023). Studies on Maillard reaction Model systems have shown that ultrasound promotes Maillard reaction (Yu et al., 2020). During ultrasound treatment, molecular mobility increases and protein structures change, exposing reactive groups on the surface, thereby promoting Maillard reactions (Zhao et al., 2022).

Many researchers have evaluated the effect of Ultrasound on food quality, and it was found that Ultrasound may have positive or negative effects on food quality depending on the processing conditions employed. Processing conditions such as frequency, output power, temperature, pH and crucial time have a crucial impact on the Ultrasound process and the concentration of furan produced (Shi et al., 2020). Therefore reporting promoted/inhibited Maillard reaction products such as furan in the US-MR is not enough at this stage, and more studies should be carried out accordingly considering the result of the complexities of the MR mechanisms (Hang et al., 2019)

## CONCLUSION

It is important to note that the US-MR is a double-edged sword for the final products as furans are very likely to be formed through the US-MR. Although there are very limited studies concerning the formation of Furan in US processed chicken, it is strongly recommended to carry out a safety assessment of final products when MR is extensively involved. It is also necessary to adopt the proper US processing conditions for balancing both positive and negative aspects brought by the US-MR thereby inhibiting the formation of Furan and other food processing contaminants. It is also important to further explore effects of US on processed chicken and the formation of Furan through kinetic study. Although some

MR steps have been proved to be promoted and inhibited by US, there are still uncertainties especially with the formation of furan.

This review indicates that Ultrasonication may have a dual role in influencing furan levels in processed chicken, a role that is contingent on parameters such as intensity, duration, and temperature of the Ultrasonication process. Further studies are necessary to fully understand the mechanisms involved in the Ultrasonication of chicken and the subsequent production of furan in order to establish safe industrial processing guidelines for the effective use of Ultrasonication. With continued research and advancements, Ultrasonication could become a standard method for enhancing food safety and quality in the poultry industry, offering a healthier option for consumers.

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