Review Article

FORMATION AND SAFETY OF FURAN COMPOUNDS IN ULTRASOUND PROCESSESD 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 (MRPs) such as Furan. Using high frequency sound waves to create cavitation bubbles which disrupt chemical bonds and promote free radical formation, ultrasonication 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 ultrasound processed chicken. 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.

Keyword: Furan Compounds, processed Chicken, Codex Alimentarius, food processing, food safety

INTRODUCTION

Food quality and food safety is a great concern when processing food for preservation (Jadhav et al., 2021). “Conventional food preservation processes expose food to a very high temperature which reduces the contamination or microbial load in food, but also results in some undesirable changes in food. These undesirable changes in food include loss of nutritional components that are temperature sensitive, change in the texture of food due to heat, and changes in the organoleptic characteristics of food” (Hernandez-Hernandez et al., 2019). Research has shown that foodstuffs consumed by people are often a source of food contaminants (Maher & Nowak, 2022). According to Codex Alimentarius, a contaminant is defined as “any substance not intentionally added to food or feed for food-producing animals, which is present in such food or feed as a result of the production (including operations carried out in crop husbandry, animal husbandry, and veterinary medicine), manufacture, processing, preparation, treatment, packing, packaging, transport or holding of such food or feed, or as a result of environmental contamination. This term does not include insect fragments, rodent hairs, and other extraneous matter” (Codex Alimentarius, 2019). Heating of foodstuff is a common practice that allows food preservation, avoids spoilage, develops taste and aroma and improves digestibility. During such thermal processes, process contaminants such as furan and alkylfurans can be formed. (Frank et al., 2020).

FOOD PROCESSING METHODS

"According to the heat input during processing, food processing methods are generally divided into two categories: thermal processing and non-thermal processing" (Shujun et al., 2019). "Thermal processing normally requires high temperature generated by heating, whereas non-thermal processing is often conducted by high-pressure, sonication, pulsed-electric field, microwave, infrared and cold plasma. Non-thermal processing methods utilize physical phenomena such as pressure waves, sonication, high hydrostatic pressure, and electric/electromagnetic fields" (Knoerzer 2016; Wang et al., 2019). "Innovative thermal and non-thermal technologies have displayed immense potential owing to their wide-scale application in food processing" (Taha et al., 2023). "Non-thermal processing is an emerging and innovative technology for the advancement or replacement of conventional processing technologies. Its aim is to deliver higher quality, value or better consumption-oriented food products" (Cartus and Shrenk 2017). "Rising consumer awareness has increased demands for fresh, higher quality, and microbiologically safer and stable foods and has promoted research on non-thermal methods of food preservation". (Li et al., 2021)

"Among these various emerging technologies, ultrasound is gaining popularity due to its capacity to preserve natural freshness, taste, and nutritional elements in food while consuming less energy" (Wang et al., 2019).

This review examines ultrasonication, an emerging non-thermal food processing technique, its applications, process mechanisms, shortcomings and role in the formation and levels of furan compounds in processed chicken. The goal of this review is to help researchers improve on ultrasound technology for various industrial food processing applications by highlighting its advantages and disadvantages, as well as its role in furan formation. Various studies and articles have highlighted the extensive application of ultrasound technology in the food industry but not much research have been done on the impact of ultrasound treatment on food safety and food processing contaminants such as furan. In addition, the toxicity of some transformation products generated during ultrasound treatment is often ignored by researchers, which may bring serious food safety risks.

MAILLARD REACTION

“One of the key reactions encountered in the course of food processing is the Maillard reaction. Maillard reaction (MR) is a non-enzymatic reaction that occurs when the carbonyl group of reducing sugars reacts with the amino group of amino acids, polypeptides, or proteins, resulting in the natural production of Maillard Reaction Products (MRPs) as shown in Figure 1” (Chen et al., 2019; Fu et al., 2020). “These reactions may affect the colour, flavour, and aroma of the food product, cause the formation of toxic compounds (e.g., acrylamide, furans and hydroxyl propyl furfural), and decrease its digestibility and nutritional value” (Dagostin 2017). “Maillard Reaction has been studied for over a hundred years since French Chemist Louis-Camille Maillard first reported it in 1921” (Chen et al., 2019). “This reaction takes place as a whole network of various reactions that form several early, intermediate and advanced compounds” (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 which occur during the thermal processing of Chicken” (Hang Yu et al., 2020).

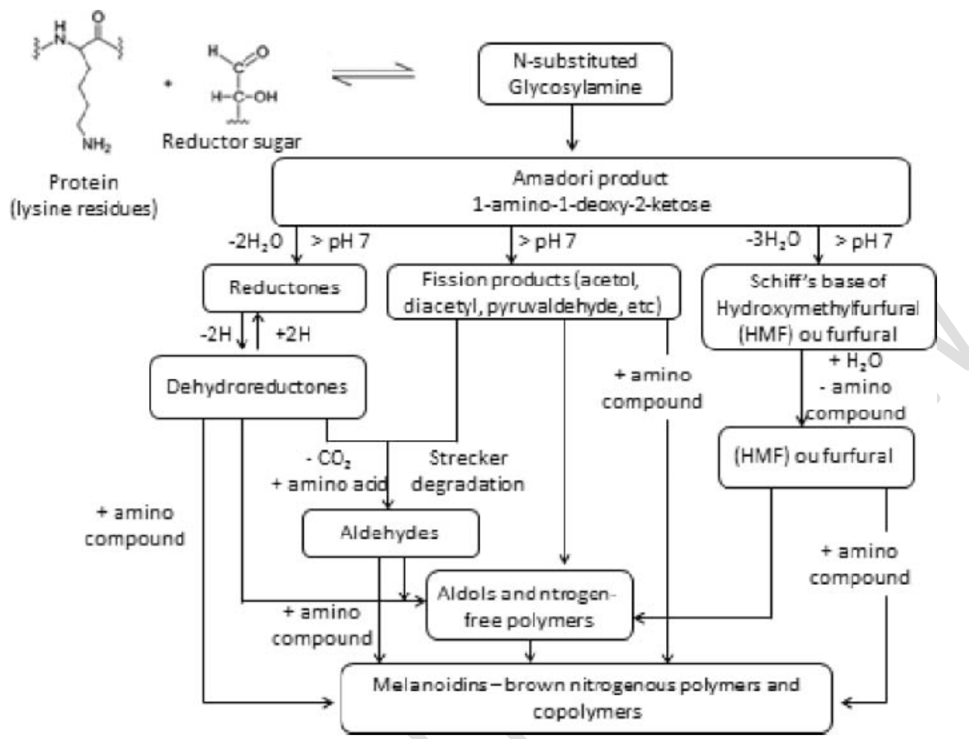

Fig. 1: Scheme of the Maillard reaction adapted from Hodge (1953), Oliveira et al., 2012

"Contrary to conventional belief however, maillard reaction can also occur at relatively low temperatures, e.g. during storage at room temperature" (Yu et al., 2020). "Previous studies on the principle and mechanism of Maillard reaction have shown 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". (Yu et al., 2020). "Among the above-mentioned conditions, the nature of reactants majorly determine the rate of the reaction. 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 chicken, but their formation is frequently accompanied by undesirable reactions that can result in various hazardous products, such as heterocyclic amines (HCAs), acrylamide (AA), furan, 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 (›150^0C) 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, these toxic substances 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). “The most reported chemical hazards contain α-dicarbonyl compounds, furan, trans fatty acids (TFAs), heterocyclic amines (HAs) and acrylamide” (Wang , S. et al., 2019).

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^oC 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 150^0C” (Koszucka& Nowak, 2019).

“Various precursors including polyunsaturated fatty acids (PUFAs), amino acids, carbohydrates, ascorbic acid, under thermal or oxidative conditions can form furan via different thermally driven mechanisms as shown in Fig. 2” (Batool et al., 2020).

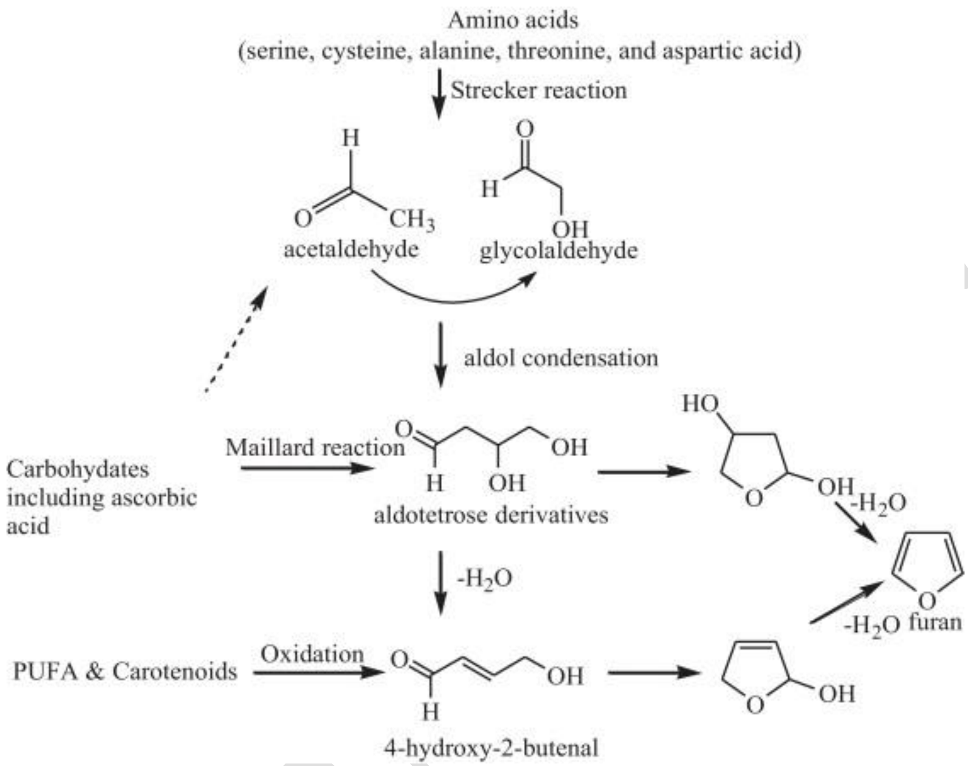

Fig. 2. Different stages of furan formation. Adapted from Perez Locas, C., &Yaylayan, V. A. (2004). Origin and mechanistic pathways of formation of the parent Furan , A food toxicant.

“Furan can be formed in foods from various naturally occurring precursors via chemical reactions including the thermal decomposition of carbohydrates, thermal oxidation of polyunsaturated fatty acids (PUFAs), thermal decomposition of ascorbic acids and reducing sugars” (EFSA, 2017; Gill et al., 2016). “Dietary intake is the main route of exposure to furan and its derivatives” (Minorczyk et al., 2023)

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 2017;FSA, 2018). "However, diminishing its content in foods using different strategies would be considered challenging due to its different precursors and formation pathways" (Batool et al., 2020). Hence, there is great need to optimize the methods and find some reasonable solution to problems related to furan formation in food processing.

Studies carried out by Batool et al (2020) show that during food 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). "In industrial processes, at temperature around 200^0C, the furan levels increases with increase in temperature" (Santonicola and Mercogliano 2016). However, when it exceeds the value of 200^0C the concentration of furan is no longer dependent on the temperature values. On the other hand, in domestic cooking, furan formation is dependent on the type of cooking as reported by Santonicola and Mercogliano (2016), where frying at 150^0-200^0C generated higher levels of furan, compared to baking. Furan seems likely to form in browned products, especially if the water activity is low as high levels of furan were found in bread toasted from brown to a very dark colour. So it is therefore safe to assume that a combination of higher temperatures and lower water content leads to a higher furan content (Santonicola and Mercogliano 2016).

“Furan levels may form at various pH and temperatures in experimental model systems and pH has a significant effect on thermally induced furan formation when temperature is greater than 110^{0}C” (Santonicola and Mercogliano 2016). “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 temperature” (Santonicola and Mercogliano 2016). “For instance, after heating for 30 minutes at 150^{0}C in experimental model, the furan concentration at pH 7.00, 9.40 and 4.18 was found at 304, 238 and 40ng/mL, respectively” (Santonicola and Mercogliano 2016).

“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” (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).

“According to reports, the main fatty acids (FAs) in chicken are palmitic acid, oleic acid and linoleic acid, and the contents of unsaturated fatty acids (UFAs) in chicken fat are higher than those in other animal fats” (Pena-Saldarriaga et al., 2020). “Chicken fat plays a crucial role in forming species-specific flavours, and the oxidation of lipid during heating is the main factor responsible for the production of volatile organic compounds” (Han et al., 2023).

ULTRASONICATION

“As one of the few non-thermal processing techniques that can reduce processing time, ultrasonication is the process of using ultrasound technology in food processing. It is the application of ultrasound itself at low temperatures to heat sensitive products” (Prasad et al., 2022). “Ultrasonication 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) as such methods cannot effectively remove harmful substances or may cause secondary pollution (Yigit &Velioglu, 2019). “Also, some extreme treatment conditions may affect the sensory quality of food or cause food contamination. In recent years, ultrasound has been widely used in meat processing because of its environmental friendliness, safety, and energy conservation” (Zhao et al., 2022). “It has also been widely reported to be able to degrade organic pollutants in the field of environmental science” (Debabrata & Sivakumar, 2018; Kida et al., 2018)

“Ultrasonication is an emerging technology that uses sound waves of above 20kHz for a wide range of applications in the food industry. It has numerous advantages, proffering energy efficiency and economic feasibility” (Bhat et al., 2021). “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). It has been widely studied by the food industry for conditions such as drying (Da Silva et al. 2019), 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).

APPLICATION OF ULTRASOUND IN FOOD PROCESSING

“In the field of food science, ultrasound has been extensively applied in many processes such as emulsification, drying, freezing, and microbial inactivation as a very effective and highly efficient technique of food processing (Table 1). At present however, the application of ultrasound technology is in the primary stage of evaluation, and some challenges in the field of food processing need to be solved to improve its application” (Yuan et al., 2021)

Table 1: Applications of ultrasound for food products

Applications	Conventional methods	Advantages	Products	References
Extraction	Maceration Percolation	Less time Higher yields, lower temperatures	Aromas Polyphenols minerals	Zmanipooor et al., (2020) Umana et al., (2020)
Marinating	Brine	Less time, Improving organoleptic quality, product stability	Vegetables, Meat	Shi et al., (2020)
Drying	Hot gas stream, freezing	Less time, Improving heat transfer and organoleptic quality	Fruits, vegetables	Guo et al(2020)
Freezing	Freezer	Less time	Meat	Tian et al (2020)
Emulsification	Mechanical treatment	Less time, better stability	Emulsions (Ketchup,	Li et al (2020)

			mayonnaise...)	
Fermentation	Microorganisms	Improving rhelogical properties Improving organoleptic quality	Wine	Zhang et al., (2020)
Enzymatic and Microbial inactivation	Pasteurization Sterilization Sanitizers	Improving organoleptic quality Retaining bioactive substances	Milk Vegetables Fruits	Wang et al., (2020)
Cooking	Fryer Stove	Less time Improving heat transfer and organoleptic quality	Meat Vegetables	Miano et al., (2018)

ULTRASOUND: MECHANISM AND SYSTEM

"Ultrasound is defined as a soundwave at a frequency that exceeds the hearing limit of the human ear" (20kHz) (Yu et al., 2020). "The alternating speed of this wave depends on the ultrasonic frequency" (Yuan et al., 2021). "When acting on a liquid medium, the ultrasound wave generates positive and negative pressure which produces periodic compression and expansion on the liquid medium molecules. In the stage of negative pressure expansion, the ultrasonic wave will produce tiny bubbles or cavities in the liquid medium. These cavities keep absorbing acoustic energy until they reach a critical size and break violently, releasing high energy as shown in Figure 3. This phenomenon is called cavitation effect" (Yuan et al., 2021). "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).

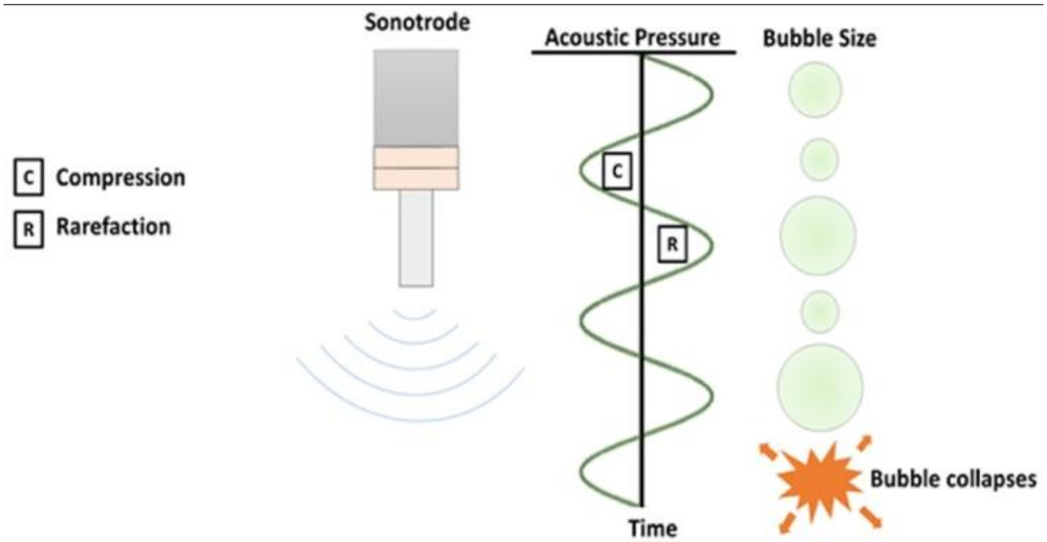

Figure 3: Acoustic cavitation generated by ultrasound devices. (Taha et al., 2020).

“Ultrasonic wave-producing systems consist of a generator, a transducer, and an application system as shown if figure 4. A generator produces mechanical or electrical energy while a transducer converts this energy into sound energy at ultrasonic frequencies”. (Bhargava et al., 2021).

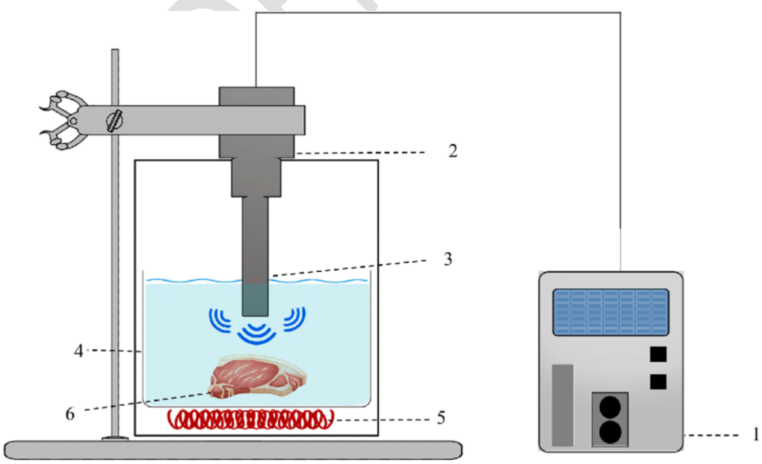

Fig: 4: Probe-based HIUS-assisted cooking system.

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)

CLASSIFICATION OF ULTRASOUND

“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).

“The application of ultrasound in the food industry is further categorized into two approaches; low energy and high energy approaches depending upon the sound power (W), sound intensity (W/m^2), or sound energy density (Ws/m^3) used” (Prasad et al., 2022). “An ultrasound frequency higher than 100kHz and intensity below 1W/cm^2 is preferred for low-energy applications that normally do not change the physical or chemical properties of the material through which they propagate” (Bhargava et al., 2021). “On the other hand, high energy (power ultrasound) applications use frequencies between 20 and 100kHz, and higher intensities, within the range of 10-1000W/cm^2 which can alter physicochemical properties or the structure of a material” (Charoux et al., 2021). Today ultrasound is most efficiently applied in various forms of food processing (Charoux et al., 2021, Chew et al., 2021) as it provides several benefits, such as more efficient mixing, faster energy transfer, easier cleaning and operation process, small equipment size, selective extraction, and faster response to extraction control (Boateng and Nasiru 2019).

EFFECT OF ULTRASOUND ON FOOD QUALITY

"Although ultrasonication can achieve microbial safety and decontamination, the nutritional and sensorial quality of the final product must be ensured" (Yuan et al., 2021). 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. For example, ultrasound can have a positive effect on the textural properties of meat (Shi et al., 2020), but a negative effect on other food properties including colour, flavour, or nutritional value at high power levels (Yuan et al., 2021).

While Ultrasonication has demonstrated efficacy in diverse applications, its specific impact on furan content in chicken remains an intriguing area of exploration.

FURAN AND ULTRASOUND PROCESSED CHICKEN

"Ultrasound-assisted cooking can increase the type and amount of volatile compounds in chicken 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. For chicken, due to its lipid content, ultrasound induced lipid degradation will not only produce unpleasant odors, but also secondary reaction products which will reduce the nutritional quality and safety of the chicken (Cao et al., 2018). Considering the seemingly inevitable release of toxic compounds such as Furan in the course of processing chicken for consumption, ultrasound processed chicken is therefore a risk for humans, especially for infants, the elderly and immune-suppressed persons.

“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 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).

“Studies conducted so far have shown that Ultrasonication as a processing method is a cleaner alternative to thermal processing and have also shown the advantages of ultrasonication as a non-thermal processing method as shown in Table 2. There is however a lack of comprehensive understanding of its effect on furan content due to the numerous pathways to furan production and the numerous factors that affect these reactions” (Siewe et al., 2020).

Table 2: Advantages and disadvantages of Ultrasonication for chicken treatment.

S/No	Advantages	Disadvantages
1.	High energy efficiency	The large-scale implementation is still a challenge
2.	Ultrasonic devices are easy to clean and operate.	It is still complicated to find the optimum ultrasound condition (power, duration, volume of treated sample, frequency, etc.) for various

			applications.
3.	Ultrasound treatment is considered green technology as it can induce chemical reactions without external chemical reagents.	Ultrasound devices could release traces of toxic substances, thus more toxicological studies are required when using ultrasound with food products.
4.	The induction of both chemical and physical effects makes sonication an ideal method for specific application such as emulsion polymerization	Ultrasound probes are easily damaged, thus maintenance is recommended annually.

(Zhang et al., 2018; Taha et al., 2020; Yuan et al., 2021)

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 promotes 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 ultrasound processed chicken (Hang Yu et al., 2020). The MR during ultrasound 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, off-flavours(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 influence of ultrasound pretreatment on the extent of Maillard reaction (MR) and the properties of Maillard Reaction 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 more 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. However, a combination approach has advantages when the prolonged treatment of a single technology may result in adverse effects. This is 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. Hydroxyl radical is generated through the various formation pathways of furan including the breakdown of water during ultrasound induced cavitation. These hydroxyl radicals generated contribute 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 and enhancing the formation of furan compounds” (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)

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).

CONCLUSION

It is important to note that the US-MR is a double-edged sword for the final products as furan and its derivatives are very likely to be formed through the US-MR. Although there are very limited studies concerning the formation of Furan in ultrasound processed chicken, it is strongly recommended to carry out a safety assessment of final products when maillard reaction is extensively involved. It is also necessary to adopt the proper ultrasonication 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 ultrasonication on processed chicken and the formation of furan through kinetic study. Although some maillard reaction steps have been proved to be promoted and inhibited by ultrasonication, 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. 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. 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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