An Overview of Thermal and Non-Thermal Food Processing and Preservation Methods

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ABSTRACT

Thermal food processing technology had been in existence since the creation of human but recently industries are beginning to adopt the use of non-thermal food processing technology due to the challenges associated with the former like high energy consumption, degradation of food nutritive contents and high operational cost. Basically, food processing techniques are used to pasteurize, preserve taste, retain or improve nutrient contents and increase shelf life of food on storage. However, there is an increased awareness for the consumption safe and high nutritional food which has led to consumers' demand for processed food to retain natural flavour, pigment, safe, high nutritive value with an extended shelf life long enough for sales and home storage before consumption. These demands led to the continuous advancement in food processing industry to design techniques capable of retaining nutritive quality and organoleptic properties of food requiring little or no heat energy to process. In addition to the known novel processing methods like freeging, freeze-drying, ohmic heating and microwave, there is an increasing interest in developing other novel methods to achieve better food sterilization and preservation which includes high hydrostatic pressure process (HHP), pulsed electric field (PEF), cold plasma technology (CP). However, the later can lead to oxidation of lipids and loss of colour and flavour based on time of exposure. Therefore, this short review presents an overview of thermal and non-thermal food processing technologies with the underlining principles, uses and limitations of few of them.

INTRODUCTION

Food processing industry is one of the most important industry in Nigeria for its ability to create and empower populace and most importantly provide edible food for the masses to quench hunger, provide nutritional requirements and serve as supplement for some degenerative health diseases. Approaches or processes adopted in transforming raw materials to a finished product by the industry are referred to as *food processing*. Food processing techniques commonly adopted in the ancient time includes heating, sun drying, salting, soaking and fermentation. These processing techniques are required to eliminate toxins, deactivate pathogenic bacteria, prolong shelf life and make food stable and safe for consumption (Jongyingcharoen and Ahmad, 2014).

Primarily, the food industries processes food for safety, taste and stability (Jongyingcharoen and Ahmad, 2014; Chacha, *et al*., 2021). However, recently, due to modernization and awareness on the need to consume food with significant nutritive value, consumers demand for fast food, high nutritional quality, safety, satisfactory sensory properties and extended shelf life have increased (Bagchi, 2008). Meanwhile, techniques such as grilling and smoking are known to affect the nutritional physiology of food and are also linked to some health hazards like bronchitis and cancer (Oz *et al*., 2016; Oz, 2020). In a bid to meetup with consumers' demand, prevent the detrimental effects of some food processing techniques and preserve the original properties of food, researchers and processing industries have proffered new techniques referred to as non-thermal technologies (Jongyingcharoen and Ahmad, 2014).

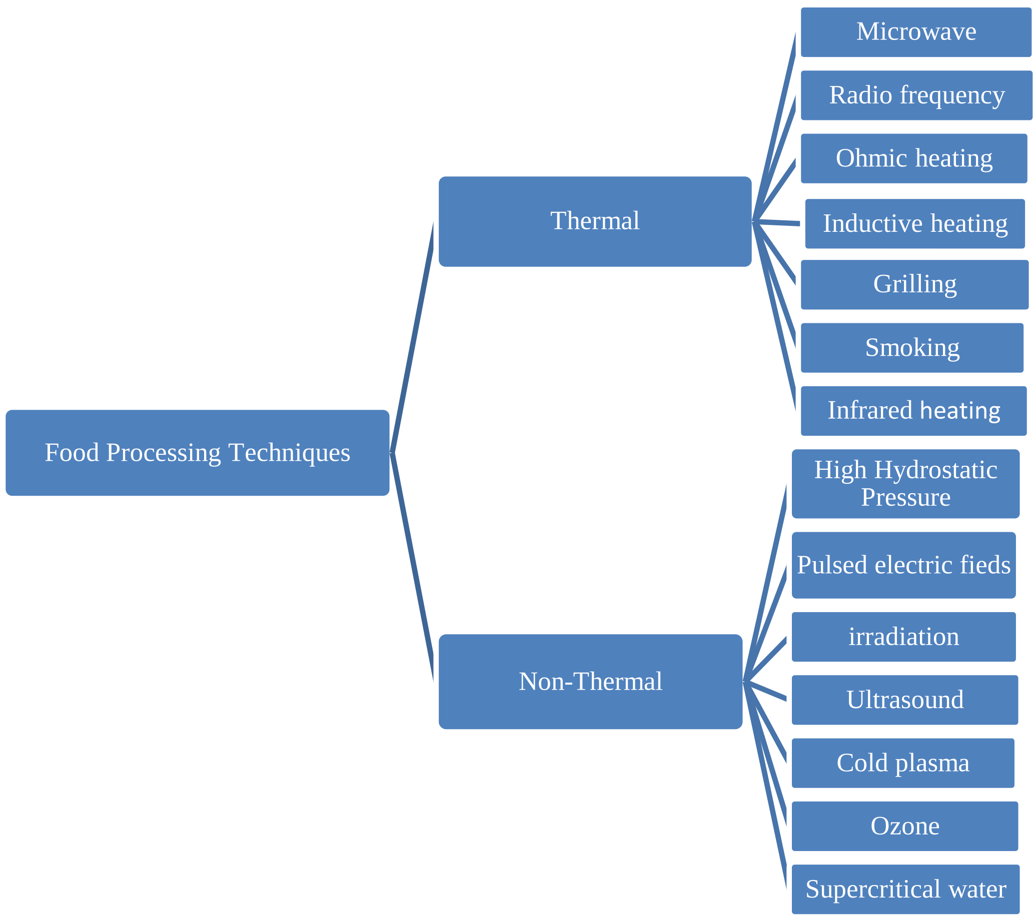

Figure 1: Food processing techniques
Source: Fozia *et al*., 2018

NOVEL TECHNOLOGIES

Before the innovation of novel technology, heating, smoking, salting and fermentation processing methods were the major techniques used in food preservation (Jongyingcharoen and Ahmad, 2014). However, these methods have their peculiarities. For instance, heating is fast and noble for its ability to retard microbial growth and prolong shelf life, but there is a limit to which this can be used in preserving fruit and vegetable products because it denatures vitamins, flavour compounds and pigments of food (Ryley and Kajda 1994; Rawson *et al*., 2011; Gao *et al*., 2016). The novel food technology is broadly divided into two (thermal and Non-thermal technologies) as presented in Figure 1.

Thermal Food Technologies

Thermal food technique is reliable and commonly adopted by food processors to minimize the microbes in food and extend the shelf life of food (Jongyingcharoen and Ahmad, 2014). These thermal processes are generally conducted at high temperatures to ensure food safety which in-turn cause detrimental effects on heat labile components like the nutrient contents, organoleptic properties and even texture of food (Knockaert *et al*., 2012; Zhong *et al*., 2019). These thermal processes can lead to the formation of carcinogenic substance which are detrimental to human health. Though, these toxicants are dependent of the kind, time and extent of heat treatment (Oz *et al*., 2016; Oz, 2020). As a result of the considerable damage caused by thermal methods, novel heating alternatives that can offer quicker heating rate to reduce damages and adverse reactions on food were devised. These techniques include microwave, radio frequency, ohmic heating and inductive heating (Fig. 1).

Effect of heat on microorganisms

Heating is a preservative technique applied during food processing to extend shelf life and increase food safety by eliminating microbes and reducing enzymatic activities of food (Tewari and Juneja, 2008) This is achieved by limiting enzymatic activities and enzyme-controlled micro-organisms. During this process, food is heated to such a temperature high enough to destroy the same percentage of contaminating micro-organism (independent of the number present initially). This is however time dependent. This time is referred to as Decimal Reduction Time (D-value) which is the time required at a giving temperature to kill 90% of contaminating micro-organism (to reduce their number by a factor of 10) (Fellows, 2000; Sebnem, *et al*., 2019). A food substance is believed to have high heat resistance when the D-value is high. Therefore, D-values of micro-organisms differ from specie to specie. z-value is the slope obtained after drawing the graph of D-value collated at different temperatures| (called Thermal Death Time-TDT) bearing in mind that the destruction of micro-organisms is time dependent and can be achieved more rapidly at higher temperature. Therefore, z-value is the relationship between an organism's resistance to different temperatures. Hence D and z-values are used to express the heat resistance of micro-organism and its temperature dependence respectively.

Table 1: **Thermal properties of selected nutritional and sensory components of foods in relation to heat-resistant enzymes and bacteria**

Component	Source	pH	$^{Z}(^{0}C)$	D_{121} (min.)	Temperature range (^{0}C)
Thiamin	Carrot puree	5.9	25	158	109-149
Thiamin	Pea puree	Neutral	27	247	121-138
Thiamin	Lamb puree		25	120	109-149
Lysine	Soya bean meal	-	21	786	100-127
Chlorophyll a	Spinach	6.5	51	13.0	127-149
Chlorophyll a	Spinach	Neutral	45	34.1	100-130
Chlorophyll b	Spinach	5.5	79	14.7	127-149
Chlorophyll b	Spinach	Neutral	59	48	100-130
Anthocyanin	Grape juice	Neutral	23.2	17.8*	20-121
Betanin	Beetroot juice	5.0	58.9	46.6*	50-100
Carotenoids	Paprika	Neutral	18.9	0.038*	52-65
Peroxidase	Pea	Neutral	37.2	3.0	110-138
Peroxidase	Various	-	28-44	-	-
Clostridium botulinum	Various	>4.5	5.5-10	0.1-0.3*	104
spores type A + B Bacillus stereothermophilus	Various	> 4.5	7-12	4.0-5.0	110+

* *D* values at temperatures other than 121ºC.
Source: Fellows, 2000

The heat resistance of micro-organisms considering certain variables cannot be categorically stated as a large number of factors are responsible to their resistance. Some of these factors are listed below.

1. Specie of micro-organism: Species and strains have varying heat resistance
2. Adopted Incubation condition while growing cells or spores: For instance, spores produced at high temperatures have more resistance than those produced at lower temperatures. Age of culture is another factor affecting heat resistance and culture medium (mineral salt and fatty acids greatly affects the heat resistance of spores).

Condition of heat treatment: factors like pH, water activity, components of food and growth media and incubation conditions of food while heating are great determinants of heat resistance. Pathogenic and spoilage bacteria are more heat resistant when the pH of a food substance is around 7.0. also, the water activity influences the heat resistance of vegetative cells. Fats, proteins and high concentrations of sucrose increases the heat resistance of microbes while sodium chloride do not have significant influence on the heat resistance (Fellows, 2000).

Effects of heat on nutritional properties of food

Most nutrients and organoleptic properties are potent at low temperature. For this reason, unit operations like sorting, distilling, freezing, mixing and cleaning do not have effect on the nutritional contents of food. Conversely, unit operations that intentionally separates the component of foods affect their nutrition quality compared to its raw material. Though, some operations involving unintentional separation can lead to the loss of some water-soluble vitamins, sugars and minerals. These commonly happens during blanching, drip losses from roast or frozen foods. Heating causes major changes in the nutritional properties of foods like what is experienced in the coagulation of protein and gelatinization of starch to improve their digestibility and elimination of the phytochemicals (Fellows, 2000). For instance, the trypsin inhibitor in legumes are destroyed. However, heating also deplete the protein content of food by losing some amine compounds and destroying the heat labile vitamins and promotes the oxidation of lipids (Ryley and Kajda, 1994).

Non-thermal Technologies

Non-thermal food processing technology are techniques used for food processing which requires less heat or done without applying heat (Troy *et al*., 2016; Hernandez-Hernandez, *et al*., 2019; Bhattacharjee., *et al*., 2019). Non thermal processing techniques have shown a variety of advantages over the thermal methods for their effect on the nutritive values of food and health. Non-thermal technology has been effective in extending the shelf life of food, inactivate microbes and food growth rate. The non-thermal methods include high hydrostatic pressure (HHP), cold plasma (CP) and pulse electric field (PEF). (Barbosa-Canovas *et al*., 1998).

Table 2: **Naturally occurring pigments in foods**

			Stability to the following			
Pigment	**Typical source**	**Oil or water soluble**	**Heat**	**Light**	**Oxygen**	**PH change**
Anthocyanine	Fruits	Water soluble	High	High	High	Low
Betalaines	Beetroot	Water soluble	Moderate	High	High	High
Bixin	Seed coat of Bixa orellena	Oil soluble	Moderate	Low	High	-
Caramel	Heated sugar	Water soluble	High	High	High	High
Carotenes	Leaves	Oil soluble	Moderate-low	Low	Low	High
Chlorophylls	Leaves	Water soluble	High	High	High	Low
Curcumin	Turmeric	Water soluble	Low	Low	Low	-
Norbixin	See Bixin	Water soluble	Moderate-low	Low	High	-
Oxymyoglobin	Animal	Water soluble	Low	=-	High	Low
Polyphenols	Tea leaf	Water soluble	High	High	High	High
Quinones	Roots, bark	Water soluble		Moderate	-	Moderate
Xanthophylls	Fruits	Water soluble	Moderate	High	High	Low

Source: Zapsalis and Beck (1985); Coultate (1984).

The choice of non-thermal processes is preferred over processes like fermentation because they can be used for the preservation and modification of liquids and semi-liquid rather than transforming foods in order to preserve or modify them (Mertens and Knorr, 1992). Using high hydrostatic pressure or high-intensity electric-field pulses, whole foods, micro- and/or macro-ingredients can be modified, for example gelatinization can be improved. High hydrostatic pressure and high-intensity electric-field impulses can also be used to induce stress, for example to increase the biosynthetic activities of micro-organisms, cell cultures or algae.

High hydrostatic pressure (HHP)

High Hydrostatic Pressure is a food processing technique done at ultra-high pressure to preserve and sterilize food (Rendueles 2011; Rastogi 2013). During this process, a pressure ranging from 100 and 600MPa is applied uniformly and instantly with a little variation in temperature. The temperature increases at 3^0C per 100MPa. to sterilize food substances, inactivate microorganisms without altering the flavour and nutrient with increased shelf-life (Rendueles, 2011). This method is considered safe as chemical reactions or carcinogens are not formed, ensures the inactivation of pathogenic bacteria and it does not affect the structure of protein and fat molecules. The pressure depletes the microbial cells while the existing covalent bond remains intact (Considine *et al*., 2008; Rastogi 2013).

Pulsed electric field process (PEF)

This is a non-thermal process where microorganisms are inactivated while the main nutrient of the food is retained. It is used for the sterilization of heat labile fluids and semisolids like juice, milk and liquid eggs in food industry (Ohlsso and Bengtson, 2002; Donsi *et al*., 2010; Mathys etal., 2013). This method is universally acceptable because it saves time, consume less energy, flexible, extends shelf life and retain nutritional contents more than novel thermal method (Arroyo, 2012). In principle, the electroporation may be reversible or irreversible- what happens in the reversible case is that the temporary pores formed traps desired constituents on the cell membranes while the irreversible causes permanent destruction to (distort the osmotic equilibrium of) the cell membrane which is often employed in the process of microbial inactivation and increase yield (Dukic-Vukovic *et al*, 2017). Pulse electric operates by exposing the tissue to an electric field for short high voltage pulses in the range of 10-80KV/cm to render the cell membranes more permeable (through a process called electroporation) (Sale and Hamilton, 1967; Zimmermann, 1986; Zhang *et al*., 1995; Pal, 2017; La Pena, 2019)**.**

The limitation of this method is that bacteria and moulds are resistant to it even at high intensity. This limitation may result in serious food hazard because it may alter the sterilization process. Since dielectric breakdown may occur when this method is applied on foods having bubbles, it is advised to apply it to food without air bubbles and low electrical conductivity (Arrayo *et al*., 2012).

Cold plasma technique (CP)

Cold plasma technique is a non-thermal technology which uses energetic, reactive gases to inactivate contaminating microbes on food and packaging material with minimal processing. It is the high-energy gas created when an electric current passes through a gas. This food processing technology unique for its surface sterilization and disinfection. Therefore, it is commonly used for the preservation of agricultural products in recent years (Misra *et al*., 2014). This method is simple, consumes less time, environmental friendly, economical and can be used for a wide range of food processing (Pankaj *et al*., 2018). Pigments of food may be affected during this process due to chemical reactions (Ali *et al*., 2021). However, original colour of food can be retained if the time of exposure to treatment is reduced (Pankaj *et al*., 2018).

Cold plasma process has to do with the combination of ions, UV photons, electrons, reactive species which constitute plasma state including those generated from oxygen. The cold plasma reaction does produce chemically active compounds like active nitrides and oxides cleavage some bonds and causes chemical modification on the side chains. These modifications include those of tryptophan, tyrosine, aromatic ring of phenylalanine and cysteine which may cause changes in protein structure (Surosky *et al*., 2019). Food substances are exposed to the oxygen generated reactive species to destroy the structural component of the microbial cells.

CONCLUSION

There is no doubt that heating is still the most commonly used technique for food preservation and sterilization. However, human must come to terms that the nutritional component of food must be retained rather than the benefit of preservation alone. Therefore, there is the need for the adoption of novel preservation technologies with options to produce high quality food with and lengthened shelf life. The introduction of non-thermal technologies is expected to produce better products than those of the conventional methods. The likelihood of adopting these novel technologies will be higher if the safety of their product are guaranteed with high quality product. The application of a combination of these technologies would not be a bad idea because it will broaden the application of novel technologies especially when the operation is done at about room temperature.

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