

The Impact of Cooling Rate on the Safety of Food Products as Affected by Food Containers

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Abstract: In recent decades, the demand for ready-to-eat (RTE) food items prepared by the food catering sector has increased together with the value of cook-serve, cook-chill, and cook-freeze food products. The technologies by which foods are cooked, chilled, refrigerated for storage, and reheated before serving are of prime importance to maintain safety. Packaging materials and food containers play an important role in influencing the cooling rate of RTE foods. Food items that are prepared using improper technologies and inappropriate packaging materials may be contaminated with foodborne pathogens. Numerous research studies have shown the impact of deficient cooling technologies on the survival and growth of foodborne pathogens, which may subsequently pose a threat to public health. The operating temperatures and cooling rates of the cooling techniques applied must be appropriate to inhibit the growth of pathogens. Food items must be stored outside the temperature danger zone, which is between 5 and 60 °C, in order to inhibit the growth of these pathogens. The cooling techniques used to prepare potentially hazardous foods, such as cooked meat, rice, and pasta, must be properly applied and controlled to ensure food safety. This paper critically reviews the effects of cooling and its relationship to food containers on the safety of RTE foods produced and sold through the food service industry.

Keywords: cooling rate, food containers, food safety, foodborne pathogens

Introduction

Catering establishments are a relatively new and major sector in the food service industry world-wide. In 2013 there were 11,781 and 6,360 caterers in the United States and the United Kingdom, respectively (Brennan, 2014; Sutton, 2015). IBISWorld market research has forecast a 2.1% annual market growth in Australia's catering service over the next 5 years that will generate approximately U.S. \$5.9 billion revenue (Gargano, 2014). The catering service industry is further segmented into several markets such as airline catering, mining industry catering, and social event food service, each of which has displayed increasing demand over the past decade (Barrie, 1996; Gargano, 2014; Meldrum, Mannion, & Garside, 2009). Catering services mainly produce convenient, ready-to-eat (RTE) food for consumers and offer a variety of food choices. Common food groups served by the catering industry include cooked meat, rice, and pasta, all of

which are classified as potentially hazardous foods (PHFs). Each of these groups has the potential to spread foodborne pathogens (FSANZ, 2017).

In the catering industry, inadequate processing control during PHF manufacture, storage, and serving prior to consumption, including improper cooling may result in significant public health hazards. Several studies have investigated improper thermal processing as a contributing factor to foodborne disease outbreaks (Dlusskaya, McMullen, & Gänzle, 2011; Murphy, Duncan, Marcy, Berrang, & Driscoll, 2002; Podolak, Enache, Stone, Black, & Elliott, 2010; Wang, Ding, & Oh, 2014). The role of cold storage in preventing the growth of many foodborne microorganisms has also been investigated (Durack, Alonso-Gomez, & Wilkinson, 2011; Eideh & Al-Qadiri, 2011; Eribo & Ashenafi, 2003; Wang et al., 2014) and has been reviewed (Gaukel, 2016). However, there is inadequate published research that investigate the impact of cooling rate of food products as influenced by food containers and its effect on food safety. Under Australian law, production of PHFs is regulated to ensure that they are cooled from 60 to 5 °C within 6 hr, the exact requirement of the Australian Food Safety Standards is that a PHF must be cooled from 60 to 21 °C within 2 hr and from 21 to 5 °C within 4 hr (FSANZ, 2017). Some food businesses are known to ignore this rule in an effort to increase work efficiency during mass production (Bennett, Walsh, & Gould, 2013). These cooling procedures should be optimized to ensure that the exposure of microorganisms to their optimum growth temperature is minimized. This is important because, for example, bacterial spores may survive heat processing and

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germinate during cooling, especially if the product is held for an extended period under their optimum growth conditions. The longer the foods take to reach 5 °C the greater the potential for pathogen growth (FSANZ, 2017). For this reason, PHFs need to be cooled as quickly as possible. However, in practice, cooling PHFs is difficult to achieve within a specified time period due to multiple factors such as the physico-chemical characteristics of the food products and the types of container that it is held in which could influence its cooling rate. According to a study carried out by Murphy et al. (2002) product thicknesses is as important as that of the packaging material thicknesses during in-package food pasteurization as the heat transfer rate is influenced by both. These authors did not evaluate different packaging material for its cooling efficiency and only investigated one particular type of film. There are only a few published studies that have investigated the heat transfer characteristics of food packaging material. Furthermore, there are no reported studies that have evaluated the cooling rate of food products as influenced by different types of food containers. The cooling rates of heterogeneous PHFs in various containers need to be investigated in order to determine the optimum cooling conditions of products to maintain food safety. Present published literature focuses only on understanding the impact of heat processing and cold storage on food safety. However, rapid cooling also needs to be implemented in order to prevent the germination and growth of cells to achieve the required food safety standards (FSANZ, 2017). A holistic approach combining food safety issues, food spoilage characteristics, impact of food product characteristics, and the impact of the food container on heat transfer is of prime importance to food catering operations in order to consistently produce and serve safe food products. This review paper critically analyzes the present practices used in the catering industry with regard to the impact of food containers on cooling and the possible solutions that can be adopted with a view to ensuring the delivery of safe RTE foods.

Safety of RTE Foods in the Catering Industry

In Australia, the financial impact of foodborne illness was estimated to be \$1,249 million per annum (Abelson, Forbes, & Hall, 2006). In 2014, 17% of food product recalls in the United States were due to microbial contamination by either *Salmonella* spp., *Escherichia coli*, or *Listeria* spp. (USDA 2015b). Food Standards Australia and New Zealand (FSANZ) food recall statistics for Australia show that microbial contamination was ranked as the second most common recall classification (31% of all recalls) between 2006 and 2015 after allergens (FSANZ, 2014b). A growing number of food product recall cases over the last 10 yr have been due to microbiological contamination and these represent a threat to public health. There is, therefore, an urgent need to improve public health safety by minimizing the chances of the spread of foodborne disease (Crim et al., 2014), which includes not only proper handling and preparation of food, but also the cooling down of products so as to prevent the growth of microbes.

Sporadic disease outbreaks, which are defined as cases not involving more than two people or cases from only one household, are not counted by the Australian government surveillance system as foodborne disease outbreaks (OzFoodNet, 2014) due to the delayed notification associated with them (Kirk et al., 2010). A few studies have indicated that foodborne disease infections are underreported due to many reasons, including: a reluctance of those effected to seek medical help for short illness, to non-routine laboratory examination, to misdiagnosis and to the unavail-

ability of the suspected food vehicle for microbial examination (Bennett et al., 2013; Christian, Cole, & Luba, 2003; Ehling-Schulz, Fricker, & Siegfried, 2004; Moffatt, Howard, & Burns, 2011). It may be hypothesized that the socioeconomic impact of foodborne diseases may be much higher than reported. Although *Salmonella* infection cases in the United States were reported to be lower in 2013 as compared to 2012, the frequency of *Salmonella* infections still remained the highest among the confirmed foodborne disease cases (Crim et al., 2014). *Campylobacter* infection was identified as the second major foodborne disease in the United States (Crim et al., 2014). Unsurprisingly, *Salmonella* and *Campylobacter* infections were also the top two etiological agents of gastrointestinal diseases reported by National Notifiable Diseases Surveillance System (NNDSS) in Australia (NNDSS, 2015). Apart from foodborne bacterial cases, viral etiological agents, namely, Norovirus and Hepatitis A viruses were also investigated by the OzFoodNet (the Australian food borne diseases surveillance system). These viruses were identified as foodborne disease agents commonly transmitted through the consumption of raw oysters, and person-to-food-to-person transmission routes such as by food handler contaminations (Figure 1; OzFoodNet, 2014). There were 40,380 cases of 11 different types of gastrointestinal diseases reported in Australia in 2014 (NNDSS, 2015). Of these 11 different types of gastrointestinal diseases, OzFoodNet is only authorized to investigate nine foodborne diseases. These include botulism, campylobacteriosis, hemolytic uremic syndrome, hepatitis A, listeriosis, shiga toxin-producing *Escherichia coli* infection, salmonellosis, shigellosis, and typhoid fever (The OzFoodNet Working Group, 2012). Among the foodborne disease cases between years 2001 and 2013, the number of *Clostridium perfringens*, *Bacillus cereus* and *Staphylococcus aureus* are lower (Figure 1) compared to *Salmonella* and Norovirus cases, which are the two most common gastrointestinal disease agents. The reason for this could be due to the lower levels of routine tests for *C. perfringens*, *Bacillus cereus*, and *Staphylococcus aureus*. Whatever, the change in the type of pathogenic organism profile, all of these organisms can proliferate in food due to improper processing, including long cooling down periods.

Investigation of foodborne disease cases is carried out by identifying the etiological agents, common settings, and the responsible food vehicle (The OzFoodNet Working Group, 2012). Numerous studies have shown that mass-catered PHF suppliers, including street-vended-food, were the most common settings for foodborne illness outbreaks (Asiegbu, Lebelo, & Tabit, 2016; Bennett et al., 2013; Dalton et al., 2004; Moffatt et al., 2011; OzFoodNet, 2014). These outbreaks could substantially affect the economic viability of the affected food industry and the reputation of the implicated catering service. However, the outbreak of foodborne illnesses and its negative impact on the nation's economy can be reduced by proper food processing and handling practices such as by cooling products rapidly, cooking food under controlled time, and temperature conditions and packaging food under hygienic conditions.

Risk Factors Associated with Foodborne Disease Transmission

Inadequate temperature control is considered to be the main factor associated with the transmission of foodborne diseases (NSW Food Authority, 2013), this includes not only the heating of products but also its proper cooling down. A survey of 420 restaurants that served cook-serve products by Brown et al. (2012) showed that 86% of the respondents did not follow the cooling

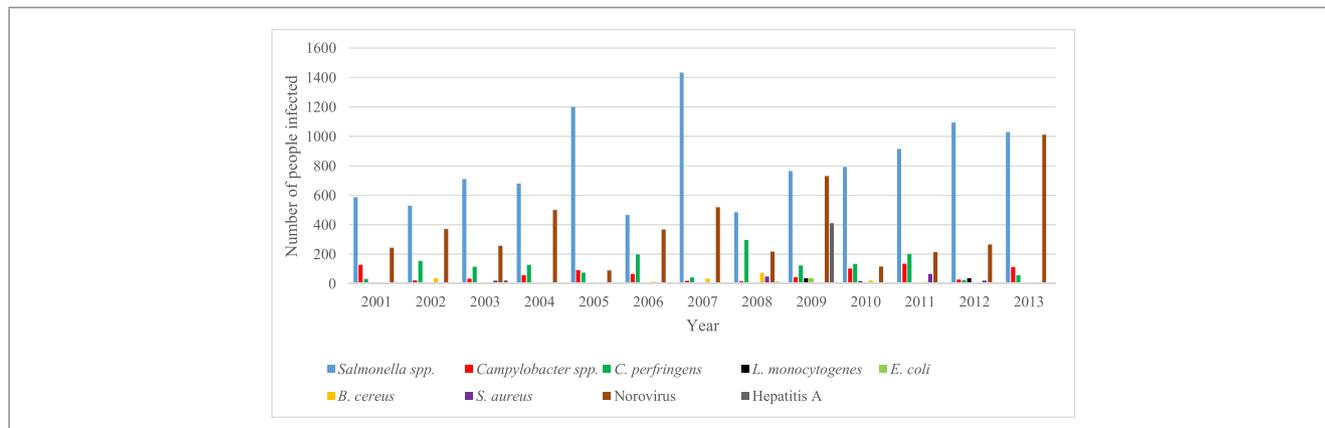


Figure 1–Number of people infected by specific foodborne pathogens, Australia (Sources adapted from OzFoodNet annual and quarterly reports from 2001 to 2013; OzFoodNet, 2014).

procedures required by regulation. The results suggest that the issues associated with PHF cooling are commonly neglected by the food industry (Barrie, 1996; Brown et al., 2012; NSW Food Authority, 2013). Control measures need to focus on regulating not only the cooking but also the cooling of foods so that microbial growth and germination of spores can be prevented in post-processing storage (Fazil et al., 2002; Rybka-Rodgers, 2001), which ultimately prevent the spread of foodborne disease.

There have been several studies that have shown the importance and impact of cooling practice on food safety (Fazil et al., 2002; Juneja & Marks, 2002). A predictive growth model studied by Juneja and Marks (2002) showed that the microbial count of *C. perfringens* in cured chicken with higher salt content and faster cooling rate (51 to 12 °C within 6 hr) after cooking to 60 °C inhibited the germination of *C. perfringens* spores for 21 days. In a similar study, Fazil et al. (2002) demonstrated that the rate of cooling had a high impact on the reduction of total microbial growth after cooking, these studies highlight the need for rapid cooling to ensure food safety. Furthermore, food handlers' competence in good manufacturing and hygiene practices can prevent cross-contamination, in particular minimizing the *S. aureus* and *E. coli* load in the final product (Kadariya, Smith, & Thapaliya, 2014; Lahou, Jacxsens, Daelman, Van Landeghem, & Uyttendaele, 2012), which must include training in proper food processing. In addition to inadequate temperature control, post-processing contamination and poor hygiene practices are also considered to be contributing factors of foodborne disease outbreaks (Fazil et al., 2002; Kadariya et al., 2014; Lahou et al., 2012).

Biofilm formation, which is defined as the attachment of microorganisms on to food processing surfaces, is one of the risk factors for the spread of foodborne illnesses (Srey, Jahid, & Ha, 2013). Sanitizers such as chlorine used in the food industry may not be able to effectively remove these biofilms (Ryu & Beuchat, 2005). The attached biofilms on a food preparation surface can contaminate foods from one production batch to another (Iibuchi, Hara-Kudo, Hasegawa, & Kumagai, 2010; Kusumaningrum, Riboldi, Hazeleger, & Beumer, 2003; Ryu, Kim, Frank, & Beuchat, 2004; Saá, Cabo And, & Rodríguez, 2009). Several studies have reported that stainless steel and polypropylene (PP) materials promote the development of biofilm (Goulter-Thorsen, Taran, Gentle, Gobius, & Dykes, 2011; Iibuchi et al., 2010; Kusumaningrum et al., 2003; Ryu et al., 2004; Saá et al., 2009; Ngyuen et al., 2012). These material are used in the manufacture of food

storage containers and could harbor biofilms leading to the contamination of product from one batch to another. Hence, good manufacturing practices must include systems to effectively clean such food containers.

In order to minimize the effects of these risk factors, legislation in the area of food safety is continuously being strengthened in order to protect public health. In Australia, the development and implementation of the Food Standards Code's Chapter 3 was designed exactly for this purpose and to integrate the food safety management systems in to the food manufacturing industry (Baker, 2002). Standards 3.2.1 and 3.2.2 were developed by FSANZ to assist food businesses and food handlers to manage temperature control in the manufacture and storage of their products to ensure food safety (FSANZ 2014c, 2011). FSANZ has set up regulations (Standard 1.6.1) and guidelines on specific food microbiological limits in RTE products (Table 1; FSANZ 2001, 2014a, 2016). In Australia, the local governments and state enforcement authorities are responsible for monitoring the compliance with food laws and regulations (Dept. of Health 2015). The local government officers that implement these laws need to be trained to understand the effect of each food processing practices as it impact food safety. An example would be the impact of different storage containers and material on the cooling down of products, which design and material will positively influence rapid cooling. Such data are lacking in the published scientific literature.

Food Safety Control Measures

There are numerous causative factors contributing to the growth of microorganisms during the transformation of raw materials to final food products. Classical microbial growth curves which plot microbial load versus time can be used as a tool to study the effect of food processing conditions and ingredient formulations on the proliferation of microorganisms (Peleg & Corradini, 2011). Physico-chemical characteristics of the food matrix, storage conditions, interaction between the foodborne microorganisms and processing factors such as pH, water activity (a_w), nutrient source (the food product itself), and processing time and temperature have an impact on the presence and growth of microorganisms (Sofos, 2008). The growth dynamics of foodborne microorganisms need to be considered while manufacturing food products in order to achieve the recommended microbiological limits and to maintain the nutritional value of the final products (Sofos,

Table 1—Summary of RTE foods' microbiological quality.

Test	Microbiological quality (cfu/g)			
	Satisfactory	Acceptable	Unsatisfactory	Potentially hazardous
SPC	<10 ⁴	<10 ⁵	≥10 ⁵	NG
<i>Salmonella</i>	Not detected in 25 g	NG	NG	Detected
<i>Campylobacter</i>	Not detected in 25 g	NG	NG	Detected
* <i>Listeria monocytogenes</i> (can occur in RTE food)	Not detected in 25 g	NG	NG	≥10 ²
* <i>Listeria monocytogenes</i> (will not occur in RTE food)	Detected but <10 ²	NG	NG	≥10 ²
<i>Clostridium perfringens</i>	<10 ²	10 ² –10 ³	10 ³ –10 ⁴	≥10 ⁴
<i>Bacillus cereus</i>	<10 ²	<10 ²	10 ³ –10 ⁴	≥10 ⁴
Coagulase +ve staphylococci	<10 ²	10 ² –10 ³	10 ³ –10 ⁴	≥10 ⁴ , SET +ve ⁱ
<i>Escherichia coli</i>	<3	3–100	≥100	ii

Sources: adapted from (FSANZ 2001; FSANZ 2015)

*NB: In Standard 1.6.1, the detection of *L. monocytogenes* in the food are categorised into two groups which are "RTE food which *L. monocytogenes* can occur" and "RTE food which *L. monocytogenes* will not occur", the criteria of categorising RTE into these two groups have been clarified in subclause 6 (1) (FSANZ 2015)

ⁱSET will be needed if microbial test exceed 10³ cfu/g or poor handling is suspected

ⁱⁱNo pathogenic strains of *E. coli* should be found;

SPC: Standard Plate Count

NG: Not Given

RTE: Ready-to-eat

+ve: Positive

SET: *Staphylococcus aureus* enterotoxin test

2008). However, severe heat treatment to inactivate pathogens can destroy the nutrients lowering the nutritional value of the final food product (Earle, 1983; Fellows, 2009). It is, therefore, highly recommended by Earle (1983) and FSANZ (2014c) that the food industry establish an optimal time and temperature control during processing in order to limit the growth of foodborne bacteria, while maintaining its nutritive value. The heat transfer characteristics of a food product are dependent on its composition and the container it is in, and these two aspects also need to be considered when optimal heating and cooling procedures are established.

Most often, *D* and *z* values are used to determine the optimal time and temperature combination necessary to inactivate specific foodborne pathogen and/or spoilage organisms (Sun, 2006). The *D* value is defined as the time required to inactivate 90% of the microorganisms at a given temperature whereas the *z* value is defined as the temperature change required to reduce 90% of the *D* value of a specific microorganism (Sun, 2006). This means that the higher the *D* and *z* values, the higher the heat resistance of the organism. The conventional theory was that microorganisms survival and death followed first-order kinetics which is a linear time and temperature relationship (Hendrickx, Maesmans, De Cordt S, & Van Loey A, 1995). However, Buzrul and Alpas (2007) showed that microbial survival and death could follow nonlinear curves that do not obey the first order kinetics. This may lead to problems such as under- and overprocessing of foods, which means the *D* and *z* values obtained from the traditional linear microbial survival and death curves may be higher or lower than the actual, leading to improper processing of food products (Buzrul & Alpas, 2007). Buzrul and Alpas (2007) state that the microbial growth patterns that do not follow linear microbial survival and death curves are often due to slow cooling rates, which highlights the need for rapid cooling of food products. Cooling products too slowly will hold microorganisms within its optimum growth temperature for an extended period of time (Juneja & Marks, 2002). The cooling of products should not be neglected during the food processing, which should be considered a unit operation of production, as any surviving microorganisms can grow or spores rejuvenate when the products are held at its optimum temperature (Juneja & Marks, 2002). While defining the processing conditions and ingredient formulations of food, knowledge

of possible pathogenic and spoilage organisms the product could support need to be considered to prevent the possible spread foodborne disease. These growth requirements could be manipulated at each unit operation during processing to prevent their growth within the food matrix.

It is important that the RTE and especially PHF are stored outside the 5 to 60 °C temperature range in order to reduce the potential for pathogenic microbial growth (FSANZ, 2014c). The 5 to 60 °C temperature range is termed the temperature danger zone (TDZ) by FSANZ due to the ability of pathogenic microorganisms to grow (FSANZ, 2014c). In Australia, food handlers are advised to cook food products to a core temperature of 75 °C to ensure that vegetative foodborne microbial cells are inactivated (NSW Food Authority, 2009). With regard to inhibition of microbial growth and spore germination, FSANZ encourages food businesses to adhere to the 2/4 hr cooling practices, which is cooling foods from 60 to 21 °C and 21 to 5 °C within 2 and 4 hr, respectively (FSANZ, 2014c). Controlling temperature during heating and cooling are the main control measures that need monitoring during the preparation of catered food in order to ensure food safety (Lahou et al., 2012; Rybka-Rodgers, 2001). Cook-serve and cook-chill techniques (Figure 2) are, in general, the processing and preservation techniques that are widely used in food production to achieve the required food safety and shelf-life (Cox & Bauler, 2008; Light & Walker, 1990).

Cook-serve and cook-chill techniques are aimed at serving foods immediately after cooking or reheating after cooling (that is, cooling following the 2/4 hr process; Figure 2; NSW Food Authority, 2011), which needs to follow the 2/4 hr cooling procedure. The NSW Food Authority (2011) guidelines state that cook-serve products that are cooled and reheated have to be consumed within 48 hr to ensure the growth of pathogenic microorganisms. If not, a validated cook-chill process needs to be implemented if the food products are planned to be stored for more than 48 hr. The food service industry utilizes the heating and rapid cooling steps to attenuate any foodborne vegetative cells in order preserved the food for a prolonged period of time (Cox & Bauler, 2008). In addition, the cook-chill method is at times conducted in combination with modified atmosphere packaging (MAP), which modifies the gas composition within the package to control the growth of pathogenic and spoilage organisms (Cox &

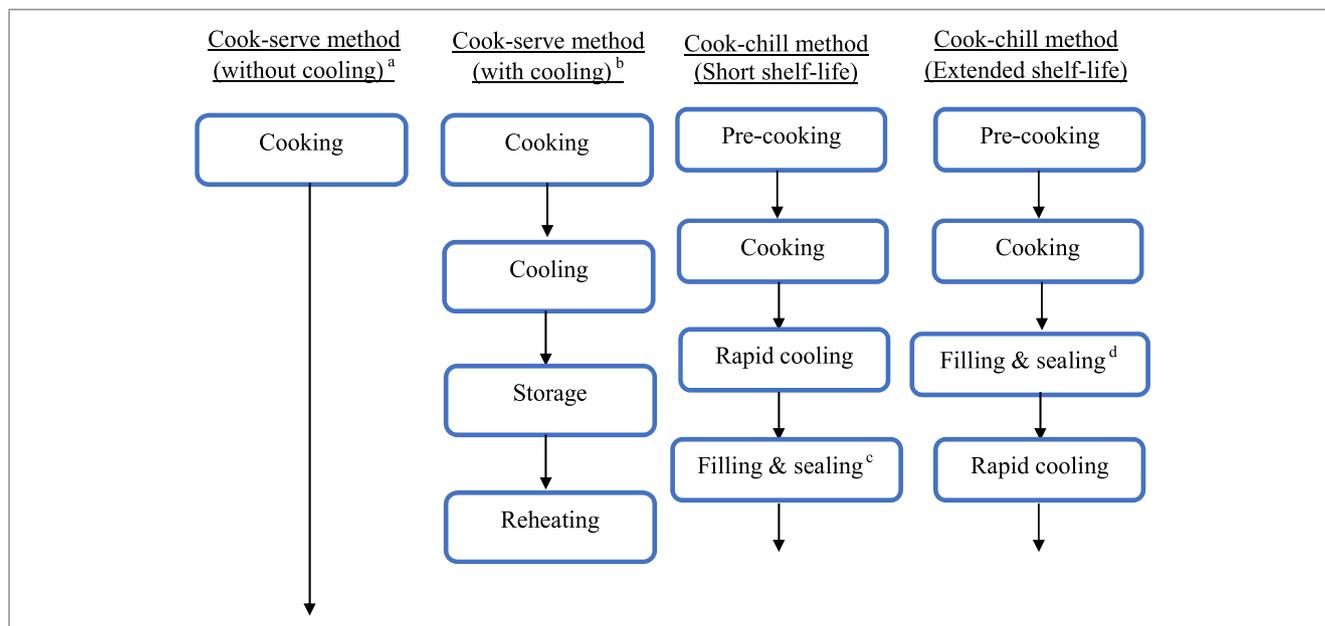


Figure 2—Flow diagram of cook-serve and cook-chill methods (Cox & Bauler, 2008; NSW Food Authority, 2011). (A) The cook-serve product has to be served immediately if the 2/4 hr cooling step is not undergone, for example, steak/beef burger. (B) The cook-serve product has to undergo the 2/4 hr cooling step if the product has no intention to serve immediately, for example, meat that is used for the sandwich preparation the next day. (C) Stainless steel gastronome trays and plastic containers are used. (D) Modified atmosphere packaging (MAP) is commonly used.

Bauler, 2008). An alternate to MAP is the *Sous-vide* process which is an extended shelf-life (ESL) cook-chill process that involves vacuum packaging in order to extend the shelf-life of a product for more than 10 days (Mason, Church, Ledward, & Parsons, 1990).

Importantly, the introduction of the cook-chill method has vastly improved the efficiency of the catering service as the food is usually precooked or prepared in advance then assembled during the final cooking step (Cox & Bauler, 2008) or in the airline industry where prepared meals are heated before served (Light & Walker, 1990). The same process can be adopted by the food manufacturing industry to control possible microbial growth during work-in-process storage. In recent years, a shelf-life of close to 10 days is allowed for short-self-life (SSL) products, which has a well-managed food safety programs such as hazard analysis critical control points (HACCP) implemented in advance (Cox & Bauler, 2008). The purpose of a HACCP food safety system is to integrate a well-managed food safety monitoring system into the manufacturing flow to minimize food safety risk. Without a HACCP plan in place, a 5-day or less shelf-life need to be quoted for these types of food products (Cox & Bauler, 2008). Currently, there is little published information on the shelf-life estimation of conventional cook-serve food and cook-chill food. This is further complicated since cook-serve food consists of different food products which are composed of a range of ingredients with different physico-chemical characteristics. Most of the past research has focused on the sensory quality of specific food products at different storage conditions and periods.

The type of container such as stainless steel (SS), PP, or crystallized polyethylene terephthalate (CPET) are types of packaging material used in the food industry. The chemical structure of these materials and their design have an impact on the rate of post-processing cooling. Limited and fragmented literature exists on the impact of these food packaging material to determine the optimum cooling characteristics to maintain food safety and

quality, which needs to be determined to optimize a food safety program.

Principles of Heat Transfer in Food Processing

Heat transfer theory is widely applied in thermal processing, such as the process of cooling products after retorting, in the food industry in order to preserve the quality as well as enhance the safety of foods (Earle, 1983). The time it takes to cool or freeze food is important in ensuring the quality and safety parameters are maintained (Erdogdu, Sarkar, & Singh, 2005; Jafari & Alavi, 2008) and fast cooling or freezing is the objective of all modern processing techniques. The first law of thermodynamics states that heat energy cannot be either created or destroyed but instead it can undergo transformation (Fellows, 2009). During cooling, the heat energy from food will transfer to the food container and pass to the surrounding environment and dissipate, which means the thermal-physical properties (for example, density and thermal conductivity) of the food containers and the food products need to be considered concurrently to determine effective cooling (Fellows, 2009). There are three modes of heat transfer namely, conduction, convection and radiation (Goldstein et al., 2010) of which conduction and convection are of importance to the food service industry in cooling down products.

In conduction heat energy is transferred from one molecule to another via molecular vibration (Sun, 2006), for example, heating foods such as pieces of meat. The time and temperature relationship can be expressed numerically in heat transfer rate through the Fourier equation (Earle, 1983). The Fourier equation is applied for conduction heating under unsteady state heat transfer (Earle, 1983). Unsteady state heat transfer occurs in food processing where the temperature changes over time during processing, thereby, resulting in a variable time and temperature relationship (Earle, 1983). In general, the temperature gradient between the product and the heat source acts as the driving force with the resistance of heat energy flow retarding heat transfer. Thermal conductivity (k)

is the numerical explanation of a materials heat transfer property (Earle, 1983). Although the k value of food products is generally regarded to be constant, it may fluctuate with temperature due to the impact of temperature on the physicochemical characteristics of food products during food processing (Marcotte, Taherian, & Karimi, 2008). The k value of food products always needs to be considered when formulating the heat transfer of heating and cooling unit operations (Rybka-Rodgers, 2001). The area and the distance of heat transferred are also accounted for in the expression of heat transfer rate in the Fourier equation (Eq. 1). In general, the Fourier equation (Eq. 1) shows that the larger the temperature difference (dT/dx that acts as the driving force), the faster the heat transfer (dQ/dt). Furthermore, the heat transfer can be accelerated using greater conductance force (k) of the food products and packaging material where conduction acts as the main method of heat removal within the solid food products and container microstructure (Erdogdu, Uyar, & Palazoglu, 2010).

The Fourier equation (Eq. 1)

$$dQ/dt = kAdT/dx$$

where dQ/dt is the heat transfer rate/quantity of heat energy passed through (J/s); k the thermal conductivity of food product/material ($J/m/s/^{\circ}C = W/m/k$); A the cross-sectional area of material (m^2); dT/dx is the temperature differences per unit distance/temperature gradient ($^{\circ}C/m$) (Earle, 1983).

Convection is a heat transfer method that takes place in fluid products (Sun, 2006). The buoyancy and gravity forces effect on the molecular motion forms convection currents, which facilitate the rate of cooling within the food (Erdogdu et al., 2010). In general, convection results in a significantly faster heat transfer rate relative to conduction (Erdogdu et al., 2010; Goldstein et al., 2010). There are two types of convection in food processing: natural and forced convection. Natural convection is facilitated by the changes in fluid density, forced convection is driven by extrinsic factors that promote heat transfer (Erdogdu et al., 2010). In most cases, combinations of natural and forced convections are used in food processing (Goldstein et al., 2010). An example of this combination can be explained through the cooling of uncovered fluid food products in the refrigerator. Natural convection will occur within the product and transfer heat to the surface of the product. Forced convection currents will occur over the surface of the product due to the cool air generated by the refrigerator that will remove the heat from the surface of fluid food products, in turn, cooling the product. In general, the forced convection can generate higher cooling rate than natural convection due to its increased efficiency (Bohuon, Collignan, Rios, & Raoult-Wack, 1998).

In terms of heating and cooling properties, another important factor of food is its specific heat capacity (c_p), which is defined as the capacity of the material to store heat energy (Sun, 2006). It is the product's characteristic that affects the transfer of thermal energy during cooling. Thermal diffusivity (α) is a material's ability to transfer heat relative to its density (ρ) and the c_p value at constant pressure per unit area (Eq. 2; Sun, 2006). Theoretically, a higher k value results in higher α values when the ρ and c_p values of the material are constant (Eq. 2). In an ideal food processing situation, a combination of higher k - and α -values and lower c_p value transfer heat faster (higher cooling rate). In other words, the heat energy is able to transfer and diffuse through the food products into the external environment faster when the products have a low heat energy storing capability, leading to faster cooling.

Thermal diffusivity (Eq. 2)

$$\alpha = k/\rho c_p$$

where α is the thermal diffusivity of food product/material (cm^2/s); k the thermal conductivity of food product/material ($J/m/s/^{\circ}C = W/m/k$); ρ the density of food product/material (kg/m); and c_p is the specific heat capacity of food product/material under constant pressure ($J/kg/^{\circ}C$) (Sun, 2006).

Factors affecting the cooling rate

Experimentally, the cooling rate can be determined by plotting the changes in temperature over time (Desmond, Kenny, Ward, & Sun, 2000; Sun & Wang, 2000). It is difficult to distribute heat evenly in food due to the heterogeneous character of food and the unsteady heat transfer (Kumcuoglu, Turgut, & Tavman, 2010). The USA Food Code and FSANZ Food Standards Code (FDA, 2013; FSANZ, 2014c) define several components that affect the cooling rate of food such as the type of containers (packaging material) that the food is placed in, food type (composition, that is, fat, protein and water content) and the cooling method.

The slowest heating point (SHP), which is usually found at the geometric center of most solid food products, has to be monitored during food processing in order to evaluate the efficiency of cooling (Auwah, Ramaswamy, & Economides, 2007). Results of several heat transfer analyses showed that the cooling rate on the product surface will be higher compared to any other positions especially the SHP in the product (Bohuon et al., 1998; Chourasia & Goswami, 2008; Kaluri & Basak, 2013). Furthermore, the surface of a food which has a faster cooling rate can act as the driving force to generate the movement of heat due to the temperature difference between the surface and that at the SHP (Kaluri & Basak, 2013). Novel cooling techniques have been reported to have a significant effect on preserving the quality and safety of food by rapidly cooling products, these include vacuum cooling (Zheng & Sun, 2005), adsorption cooling, cryogenic cooling, and magnetic cooling (Gaukel, 2016; Tassou, Lewis, Ge, Hadawey, & Chaer, 2010).

Cold Storage Practices in the Food Service Industry

During food processing, the industry normally cools products in their final packaging. However, most of the reported studies in this area focused mainly on the heat transfer mechanisms of the food product and simply ignored the effects of the container they were in (Bohuon et al., 1998; Chourasia & Goswami, 2008; Kaluri & Basak, 2013). Several studies have focused on the impact of special packaging techniques such as MAP on microbiological and sensory quality of foods. These studies did not investigate the impact of the cooling procedure and its impact on the microbial or sensory quality (Marzano & Balzaretto, 2012; Patsias, Chouliara, Badeka, Savvaidis, & Kontominas, 2006). Patsias et al. (2006) showed that in a chicken product a higher ratio of carbon dioxide (CO_2) to nitrogen (N_2 ; 90%/10%) gas mix would give better sensory quality and lower final microbial count compared to that packed with a low ratio of CO_2 to N_2 (30% to 70%) gas mix. Marzano and Balzaretto (2012) studied the effect of MAP and the production method on the final microbiological quality of precooked lasagna in terms of pathogens and spoilage microorganisms. They studied two different packaging types, CPET, and cellulose polyethylene terephthalate (CELL-PET) containers, in conjunction with the MAP technique (50% CO_2 + 50% N_2). The results showed that both containers provided a satisfactory shelf-life

(28 days) for the precooked lasagna. However, the higher oxygen in the headspace detected in the CELL-PET (18.8%) containers compared to CPET (2.2%) on day 28 may encourage the growth of aerobic microorganisms. Because of the lack of knowledge on the impact of conventional packaging and cooling procedures on food safety, the cooling of food products within appropriate containers need to be investigated to understand the processes required to obtain the desirable cooling down rate to maintain food safety.

Erdogdu et al. (2010) indicated that the food industry utilizes forced convection cooling methods instead of natural convection to achieve a faster cooling rate. Desmond et al. (2000) and Sun and Wang (2000) showed that the vacuum cooling method used in the food industry was able to cool cooked meat faster than forced convection cooling utilizing slow-air. By exerting low pressure to reduce the boiling point of water, the vacuum cooling technique was able to evaporate the water faster than using air-blast, slow-air, and water-immersion cooling (Desmond et al., 2000; Sun & Wang, 2000). This process may result in deterioration of the products quality, including weight, and texture, due to moisture loss from evaporation (Desmond et al., 2000; Sun & Wang, 2000). In general, air cooling may be suitable for the cooling of food if the air velocity is optimized to achieve a faster cooling rate as well as to enhance the product's sensory quality (Bohuon et al., 1998; Desmond et al., 2000; Erdogdu et al., 2010).

Food Containers

The food industry uses different types of containers to store work-in-progress and final products during cooling down. The most common materials used in the construction of these containers are food grade stainless steel and plastics (Cox & Bauler, 2008). In addition to functioning as a method of containment, food containers also act as an outer shield to protect food from contamination (Robertson, 2013). The thickness, k -value, α -value, and surface area of the container greatly influence the overall cooling rate of food products that are placed in these containers (Auwah et al., 2007). The overall aim of cooling food products is to cool them as quickly as possible in order to prevent microbial growth and/or spore germination.

Stainless steel (SS)

Stainless steel (SS) is an iron-chromium (Fe-Cr) alloy that is normally used in the food industry as it does not react with food and is resistant to corrosion (Lai, 2012). SS has three microstructures which are due to its specific elemental composition (Cobb, 2010). They are austenitic, ferritic, and martensitic which display decreasing order of crystal size. Among these three microstructures, austenitic stainless steel trays (type 304 and 304L) are widely used in the food industry (Cox & Bauler, 2008).

Austenitic (Type 304 and 304L). Type 304 is the most common class of stainless steel used in the food industry. Type 304 is listed by the American Iron and Steel Inst. (AISI) as a 300 series SS with a composition of chromium (Cr): 17.5% to 19.5%, nickel (Ni): 8% to 10.5%, manganese (Mn): 2%, silicon (Si): 1%, sulphur (S): 0.03%, phosphorus (P): 0.045%, and carbon (C): 0.07% max (Lai, 2012). The Fe-Cr-Ni composition of type 304 gives it high-temperature durability (Lai, 2012). However, this may cause the food container to resist a rapid temperature change during cooling (Lai, 2012). The Ni element endows acid resistance characteristics that are useful in the food industry (Lai, 2012) as many food products are acidic in nature.

Type 304L is an improved version of type 304 with its lower C content (0.03% max) created by balancing the percentage composition of other composed elements (Lai, 2012). The lower C content improves the resistance of type 304L to corrosion without greatly affecting its k -value (Lai, 2012). Several studies have shown that the variation of k -values of 304 and 304L SS could be slightly impacted by temperature and the elemental composition (Assael & Gialou, 2003; Graves, Kollie, McElroy, & Gilchrist, 1991; Sweet, Roth, & Moss, 1987). These studies also determined both types of SS k value to be approximately 14 to 17 W/m/K (Assael & Gialou, 2003; Graves et al., 1991; Sweet et al., 1987). The k -value of SS is lower compared to other commonly used metals such as aluminum (220 Wm/K; Fellows, 2009). Aluminum is seldom used in the food industry even though it has a high k -value because at higher temperatures it leaches into food (Bassioni, Mohammed, Al Zubaidy, & Kobrsi, 2012). Aluminum, when ingested, can be absorbed and deposited into the human bone matrix and human brain tissue which may ultimately increase the risk of osteoporosis and Alzheimer's disease, respectively (Bassioni et al., 2012).

The α and c_p values of type 304 and 304L austenitic SS have been shown to be approximately 0.04 cm²/s and approximately 0.4 to 0.6 kJ/kg/°C, respectively (Bogaard 1985; Graves et al., 1991; Sweet et al., 1987). Sweet et al. (1987) concluded that the similarity of the α and c_p values might be due to the similar density and weight percentage of elements in type 304 and 304L SS. In such cases, food manufacturers may use type 304 and 304L SS interchangeably. The low k - and α -values show that food products which are placed in type 304 and 304L may have slower cooling rate compared to other metal packaging materials such as aluminum (conducting heat transfer slower; Assael & Gialou, 2003; Graves et al., 1991; Sweet et al., 1987). This could keep the products within an organism's optimum growth temperature for longer allowing it to multiply leading to food spoilage (Juneja & Marks, 2002).

Plastics

The food industry regularly uses plastic to store work-in-progress product as a convenient primary food container. Food-grade and chemical resistant plastic is designed to be lightweight and flexible, and can be obtained in variable shapes and sizes. There are several types of plastics that are used in the food industry such as polyethylene (PE), PP, and polyethylene terephthalate (PET).

Polypropylene. PP is also widely used as a cook-serve and cook-chill food container due to its rigid, transparent, and chemical resistance properties (Cox & Bauler, 2008). The PP chemical structure consists of repeating organic propene units (Brown, 1992). Because of the orientation of the methyl groups attached to the propene backbone, which affect its flexibility, different PP-based containers, such as pouches, films, and bottles can be manufactured (Brown, 1992).

Present research is focused on the improvement the thermal properties of PP as well as the efficiency of its manufacturing process (Weidenfeller, Hofer, & Schilling, 2004). An improved manufacturing process is facilitated by crystallization of PP or adding metal particles such as copper and iron to the plastic which reduces the cooling rate during the injection molding process during manufacture (Boudenne, Ibos, Fois, Géhin, & Majesté, 2005; Radhakrishnan & Sonawane, 2003; Weidenfeller et al., 2004). The addition of metal ions to lower the cooling rate during the injection molding process indirectly changes the chemical structure,

which in turn lowers the cooling rate of food products stored in these packaging materials. The lowering of the cooling rate could impact safety if the products are to be chilled in these containers, for example, work-in-progress product that need to be chilled stored in-between processors.

Several studies have determined the k -value of PP to be approximately 0.23 to 0.25 W/m/K at room temperature (Boudenne et al., 2005; Radhakrishnan & Sonawane, 2003; Weidenfeller et al., 2004). Others (Boudenne et al., 2005; Radhakrishnan & Sonawane, 2003) observed that the c_p value of PP varies due to the presence of metal ions and thickness. They also showed that the c_p values of PP containers were $1,731 \pm 85$ and $1,600$ J/kg/K at 25 and 23 °C, respectively (Boudenne et al., 2005; Radhakrishnan & Sonawane, 2003). In addition, the thermal diffusivity (Eq. 2) indicates that a slight change in the c_p value would give rise to differences in the α value. As PP-based packaging on the market has a range of different densities and thicknesses, this may cause differences in α values (Sun, 2006) resulting in, the heat transfer characteristics and cooling rates of each of the packaging materials will be different. This suggests that the same food product placed in different types of PP will cool down differently. In order to maintain consistent cooling rates and to minimize any post-processing microbial growth, products should be placed in the same type of container with same dimensions consistently in order to achieve consistent cooling rates (FDA, 2013), which the food processor needs to institute as the production process is established.

Crystallized polyethylene terephthalate. Semi-rigid and opaque CPET is the most commonly used thermoplastic material for packaging RTE meals in the airline catering service due to its hot food endurance properties (Brown, 1992). CPET is derived from PET, a condensation polymer of the polyester family (Brown, 1992). Before CPET is synthesized, PET is formed via the condensation process of terephthalic acid and ethylene glycol under controlled conditions to give a low molecular weight polymer (Marsh & Bugusu, 2007). CPET is then formed via the addition of a nucleating agent such as benzoic acid to PET which increases the crystallinity and heat resistant properties (Brown, 1992). Lasagna products packaged in CPET containers with an amorphous polyethylene terephthalate film showed that due to the oxygen barrier properties of the packaging material, resulted in low microbial growth in the final product, thereby, enabling a longer shelf-life (Marzano & Balzaretto, 2012). Sterilized CPET has to be used to prevent cross-contamination from the packaging material prior to placing the food in the container. As CPET is sensitive to high pH, it may not be suitable for the application of strong sanitizers (Marsh & Bugusu, 2007), which makes it difficult to control possible cross-contamination.

CPET is known to have good heat resistant properties, but its heat transfer characteristics are not well understood (Robertson, 2013). The good thermal tolerance enables CPET to be stable when heated in a microwave or oven (Robertson, 2013). Natu, Lofgren, and Jabarin (2005) investigated the gaseous barrier properties of CPET at different crystallized structures. Their results showed that the larger the crystals found in the semi crystalline regions in CPET, the lower the oxygen permeability. Overall, the authors concluded that different levels of crystallized morphologies were able to render different gaseous barrier properties to CPET. However, the cooling down rates of food placed in these types of containers have not been reported, which needs to be established for efficient food industry applications.

PHF Products

The components of PHFs and their effect on heat transfer, absorption, and retention

It is always a challenge for the food industry to determine the overall thermal properties of heterogeneous food compared to homogenous food. In the food industry, food engineers study the structures, and compositions of food such as fat, protein, water, and salt that influence its thermal properties during heat transfer. They can utilize this knowledge to design the most suitable and economical processing condition to achieve the desired outcome. Dincer (1995) has determined the α -value of different food products with different shapes (spherical and cylindrical) by using a predictive model. The results showed that size and shape of food products has a significant impact on the overall α -value during cooling. For example, ground meat, which has smaller particle size and shape to a piece of meat such as a stake, is expected to have larger overall k and α values during cooling, influencing its heat transfer characteristics as well as cooling rate.

Most often in a food system, there are two k values that can be defined, the overall k value and the intrinsic k value (Fellows, 2009). The overall k value gives an indication of the thermal conductance ability of whole food product, whereas the intrinsic k value indicates the thermal conductance of each of the food constituents such as protein, water, carbohydrate, and fat (Fellows, 2009). The overall k -value is not directly related to the mass or volume of the food constituents but is influenced by the intrinsic k value of each component (Marcotte et al., 2008; Reddy & Karthikeyan, 2010). Increasing the fat and protein contents of a food reduces the k -value concomitantly, thereby increasing the heat resistance (Reddy & Karthikeyan, 2010). Salt, as it binds water, has the effect of decreasing a_w and reducing k value (Reddy & Karthikeyan, 2010). Marcotte et al. (2008) reported that a limited amount of salt, which is required for flavor, would not influence the thermal properties of food products.

Because of the complexity of food products, several thermal conductivity models have been developed taking into account the overall k value of heterogeneous foods with respect to its composition, moisture content, and temperature (Huang & Liu, 2009; Kumcuoglu et al., 2010; Marcotte et al., 2008; Ramesh, 2000; Reddy & Karthikeyan, 2010). It is very difficult to study the thermal properties of food products accurately on a case-by-case basis and Ramesh (2000) showed that cooked rice had a higher moisture content but lower porosity (volume ratio of water to air) than uncooked rice. The cooked rice with a higher air volume has a lower overall k value as air is a poor conductor of heat (Ramesh, 2000). The combinatory model of thermal conductivity prediction developed by Reddy and Karthikeyan (2010), which combined four other thermal conductivity models, showed that the k value of food products was directly proportional to the moisture content. In general, the k -value outcomes of these studies were found to be inconsistent and this may be due to the different food materials studied with varying moisture contents. Only a few studies have investigated the k value in liquid foods that are mainly heated or cooled by convective heat transfer (Madoumier, Azzaro-Pantel, Tanguy, & Gésan-Guiziou, 2015; Muramatsu, Tagawa, & Kasai, 2005; Phinney, Frelka, & Heldman, 2017).

The c_p value of food products can vary according to the type of food and food processing methods applied during production (Fellows, 2009). In studying the c_p value, the mass fraction of moisture, fat, protein, carbohydrate, and ash must be considered (Fellows, 2009). During preparation, food products will undergo

a series of chemical and physical changes, for instance, protein denaturation, decrease in density, moisture loss, fat degradation, and loss (Marcotte et al., 2008). All of these factors influence the c_p value of products especially water loss (Marcotte et al., 2008). Products with higher fat contents were shown to have higher c_p values (Marcotte et al., 2008). In general, a high fat food product with a higher c_p value have a higher heat energy storing capability and the heat energy could be used to dissolve the fat during heating (Marcotte et al., 2008). Theoretically, this suggests that food manufacturers have to cool meat products longer than rice as meat has higher fat content and consequently higher heat capacity when other factors such as air volume and temperature are constant. Practically, cooked rice may cool slower than cooked meat due to multiple factors such as volume and food particle shapes (Kostaropoulos & Saravacos, 1997). Appropriate cooling techniques need to be used in order to ensure that both the surface and the center of any food item is cooled rapidly and reach the required temperature simultaneously, and forced cooling techniques utilized must ensure homogenous cooling of the food items (Korese, Sturm, Roman, & Hensel, 2017). If not it could lead to localized proliferation of foodborne pathogens or food spoilage.

The published k and α values for cooked food products are rare in the literature due to the complex predictive mechanisms and multiple factors that have an impact on them (Kostaropoulos & Saravacos, 1997; Marcotte et al., 2008). Similarly to the k -value, the α -value is also highly dependent on the thermal-physical properties of food (Kostaropoulos & Saravacos, 1997). The assumption that α value is directly proportional to the k value has been shown to be due to the increase of moisture content and temperature (Eq. 2; Kostaropoulos & Saravacos, 1997; Marcotte et al., 2008). Food composition, especially fat content, has an inverse effect on the α value (Eq. 2; Marcotte et al., 2008).

The physical properties of a food product such as viscosity, particle size, density, and solid/liquid ratio are the major determinants of the heat transfer method (that is, conduction, convection, and radiation; Bohuon et al., 1998). There have been several studies that investigated the effects of one heat transfer method at a time, but it is common in practice that both conduction and convection methods occur simultaneously in food processing (Erdogdu et al., 2010). For example, in a product such as cooked chicken in gravy, the chicken will cool via conduction, and the gravy will cool via convection (Cox & Bauler, 2008). In addition, stirring is recommended in some cases as it facilitates cooling by generating forced convection (Awuah et al., 2007). In general, the cooling rate and the k value are influenced by the total ingredients present in a heterogeneous food product (Erdogdu et al., 2010; Reddy & Karthikeyan, 2010).

Cooling Rate and Food Safety

It is believed that improper temperature control and cooling procedures during food processing are the most common risks threatening public health safety. In general, popular cooked chicken dishes, rice, and pasta meals are often prepared in mass-catering facilities and in the industry, where they are processed, packaged, and chilled ready for preparation by the consumer. *Salmonella*, *C. perfringens*, *B. cereus*, *S. aureus*, *Campylobacter*, *L. monocytogenes*, and *E. coli* are of particular concern in the spread of foodborne diseases and standards, and guidelines need to be developed and enforced in order to control their spread through these types of foods (FSANZ, 2001, 2014c).

Chicken-based products are considered PHFs that are often implicated foodborne disease transmission (Dalton et al., 2004; Oz-

FoodNet, 2014). Cooked chicken is the most common food vehicle to be associated with several types of microorganisms as it provides a favorable environment for the survival and/or growth of bacterial pathogens such as *Salmonella*, *C. perfringens*, *E. coli*, *L. monocytogenes*, & *Campylobacter* (Adams & Moss, 2008). Furthermore, chickens naturally carry these organisms in their gut (Adams & Moss, 2008) and can contaminate the meat during slaughter. *Salmonella* have been found to be associated with cooked meat and egg products (OzFoodNet, 2014). Several studies have investigated the effect of thermal processing (heat resistance) on *Salmonella* in cooked chicken (Juneja, 2007; Murphy et al., 2002; Murphy, Beard, Driscoll, & Duncan, 2003). Juneja (2007) showed that the D -values for *Salmonella* in cooked ground chicken breast at 55 °C to be 6.08 ± 0.15 and Murphy et al. (2003) showed that for the same organism the D value at 55 °C in a differently cooked chicken breast was 24.07 ± 1.85 min. Juneja (2007) eliminated the cooked chicken meat fat before inoculation with *Salmonella* but Murphy et al. (2003) did not do this in their studies. The difference between the D -values from these two studies indicate the impact of fat content and heat processing on reducing the microbial load. Murphy et al. (2002) also studied the effect of packaging film under vacuum conditions on the heat resistance of *Salmonella* and *L. monocytogenes*. They showed that there was a time-temperature dependent relationship between packaging type (heat transfer rate) and heat resistance of bacteria. However, it is difficult to compare these studies as the heat resistance of *Salmonella* may vary due to different factors such as serotypes, type of raw material, processing condition, packaging/container type, food composition, added ingredients, pH, fat content, and so on (Juneja, 2007; Murphy et al., 2002, 2003).

In Australia, outbreaks and sporadic cases of *Campylobacter* are often associated with chicken meat consumption (Stafford et al., 2008). *Campylobacter* infections in Australia are often associated with inadequate heat processing and post processing cross-contamination (Wallace, 2003). Eideh and Al-Qadiri (2011) studied the sublethal effect of chilled and frozen storage on *C. jejuni* in autoclaved (121 °C for 15 min) chicken breast. The results showed that even at longer holding period at cold storage (4 °C) and freezing (-18 °C) temperatures *C. jejuni* did not grow but was not totally eliminated (Eideh & Al-Qadiri, 2011), which means that if there were to be any temperature abuse the organisms could multiply if its growth conditions were met.

In 2005 and 2010, OzFoodNet reported two *Listeria* outbreaks from cooked cooled meat in South Australia and Victoria, respectively (The OzFoodNet Working Group, 2006, 2012). High mortality (approximately 16%) and hospitalization (approximately 45%) rates were associated with these cases and they appeared to impose a significant threat to public health. *L. monocytogenes* is resilient to stresses such as high salt, low a_w , low pH, and low temperature as they are found in cured meats (Adams & Moss, 2008). In Australia, all of the RTE foods must undergo a 6D process, which means that a 6 log reduction of *L. monocytogenes* load is required to enhance food products safety (FSANZ, 2016). The Australian food standard 1.6.1 list several product characteristics that can prevent the growth of *L. monocytogenes* (FSANZ, 2016, 2014a). At low temperature, synergistic effects from other processing factors such as pH, salt concentration, a_w , and nutrient composition can inhibit the growth of *L. monocytogenes* (Sutherland, Miles, & Laboyrie, 2003). Extrinsic factors such as packaging type can also be utilized for the same purpose (Murphy et al., 2002, 2003). Few studies have demonstrated the effects of thermal inactivation and packaging film thickness on *L. monocytogenes* in cooked

chicken breast (Murphy et al., 2002, 2003). Although *L. monocytogenes* can be easily eliminated by pasteurization, the cooked chicken products still remain a risk of being cross-contaminated by *L. monocytogenes* during post-processing procedures such as cooling and storage steps (Goh et al., 2014; Murphy et al., 2002, 2003). In general, PHF products that favor the growth of *L. monocytogenes* need to be rapidly cooled with care to prevent possible cross contamination in order to minimize its growth.

Slow cooling has been shown as one of the causative reasons of *C. perfringens* foodborne illness transmission in mass-catered food (Bennett et al., 2013). The optimum pH range of *C. perfringens* (5.5 to 9) increases the likelihood of food poisoning in cooked chicken which has an approximate pH range of 6 to 7 (Bates & Bodnaruk, 2003; Patsias et al., 2006). A risk assessment of illness due to *C. perfringens* by Golden, Crouch, Latimer, Kadry, and Kause (2009) concluded that improper cooking may be the main factor to affect the growth of *C. perfringens* and not product cooling. However, there is still the risk of multiplication of any vegetative cells that survived the heating process or germination of spores during the cooling period, if rapid cooling was not carried out (Golden et al., 2009), which indicates that rapid cooling needs to be incorporated in to the production process to ensure safety.

In general, *E. coli* is used as the hygiene and safety indicator in food products. With an increase in the frequency of *E. coli* contamination, the probability of product containing the O157:H7 strain of this organisms, which is capable of causing fatal disease, is greater (Eribo & Ashenafi, 2003). Keeratipibul, Meethong, Techaruwichit, and Thephuttee (2010) showed that the microbial testing of *E. coli* could be carried out within the processing facility in the food industry as an indicator of poor food hygiene practices particularly during the cooling and storage unit-operations.

Two *B. cereus* outbreaks occurred in Queensland, Australia in 2002 and 2007 where the implicated food vehicle was rice (The OzFoodNet Working Group, 2003, 2008). *B. cereus* outbreaks have exclusively arise due to temperature abuse in products that support the growth of this organism (McElroy, Jaykus, & Foegeding, 1999). Wang et al. (2014) showed that the emetic toxin (cereulide) is not destroyed by heating at 80, 90, and 100 °C for 15 min to 2 hr. These authors also showed no enterotoxin production by *B. cereus* in rice, which is a food item that supports its growth, that was cooked at 80 °C for 15 min and stored at 15 °C for 72 hr. Several studies demonstrated that *B. cereus* forms highly heat resistant spores during storage (Ankolekar & Labbé, 2009; Wang et al., 2014). Ankolekar and Labbé (2009) determined a *D*-value of 12.7 to 27.9 min at 95 °C for emetic-producing spores. These studies (Ankolekar & Labbé, 2009; Wang et al., 2014) further showed that inadequate cooling and improper storage temperatures will allow the heat resistance spores to germinate and cause foodborne illnesses in cooked rice. This feature may also hold true for most high carbohydrate containing foods such as pasta. Furthermore, cross-contamination is possible due to their ubiquitous presence in food.

There were no *E. coli* and *L. monocytogenes* outbreaks reported in Australia that were associated with adequately heat processed high carbohydrate foods. However, according to guidelines and standards for such products (Table 1; FSANZ, 2001, 2014c), *E. coli* and *L. monocytogenes* need to be tested for after the cooling step as hygiene and food safety indicators (Goh et al., 2014; Keeratipibul et al., 2010). Testing for *L. monocytogenes* is particularly important as it is a psychotropic bacterium that can grow in refrigerated environments including in high carbohydrate foods (Sutherland et al., 2003).

Complex food items that are ready to heat and eat by the consumer such as, Bolognese meals are a common foods items that consist of multiple components that can support the growth of a wide range of organisms. Products such as Bolognese meals, consists of spaghetti, and ground beef in the Bolognese sauce, that contain mainly tomato puree and onion (Armstrong & McIlveen, 2000). Because of the diverse ingredients used and the characteristics of Bolognese meals (that is, low pH, high a_w , and high protein and carbohydrate), *B. cereus*, *E. coli*, *L. monocytogenes*, *Salmonella*, and *S. aureus* can be considered as common bacterial pathogens that these products could support. *L. monocytogenes* should, therefore, be tested for in chilled Bolognese meal type products as a food safety indicator (Table 1; FSANZ, 2001).

Although it is rare to find *Salmonella* in pasta type meals, it is occasionally found in low population levels in low moisture food product due to improper temperature control and the addition of ingredients which affect the pH and a_w of the final food products (Podolak et al., 2010). The main problem is that *Salmonella* may grow due to inappropriate food handling, especially due to slow cooling (Podolak et al., 2010). *Salmonella* was found in pasta during an outbreak in 2004 that caused 90 cases of food poisoning where seven people were hospitalized (The OzFoodNet Working Group 2005). Furthermore, high-fat raw ground beef, normally used for Bolognese preparation, has been reported to create a favorable environment for the growth of *Salmonella* (Hill et al., 2011). This type of product may promote *Salmonella* growth if temperature control is inadequate throughout processing.

E. coli is a known contaminant of cooked ground beef (Dlusskaya et al., 2011; Durack et al., 2011; Eribo & Ashenafi, 2003; Hill et al., 2011). In Bolognese sauce like products, moisture migration between pasta and sauce gives rise to an environment that promotes the growth of microorganisms (Durack et al., 2011). The presence of organic acid and added ingredients such as spices to increase the acidity of Bolognese sauce enhances *E. coli* survival during cold storage at 4 °C, *E. coli* have been noted to grow over low a_w (0.95) and a wide pH range (4.4 to 9.0; Eribo & Ashenafi, 2003). The US Dept. of Agriculture (USDA) regulation specifies that ground beef containing products need to be cooked to a minimum core temperature of 71.1 °C (USDA 2015a). Thermal processing should be able to eliminate heat-labile *E. coli* especially for meat products but there are some high heat resistant strains that may survive and cause public health hazards after subsequent storage (Dlusskaya et al., 2011). Rapid cooling can be utilized to prevent the growth of any surviving heat resistant strains (Poumeyrol, Morelli, Noel, & Cornu, 2011).

In the case of *B. cereus*, both types of the toxins produced by these organisms have been associated with complex food products such as Bolognese meals. Pirhonen et al. (2005) reported on an incident associated with home-made minced meat pasta dish. The spores that survive heating and low pH in the Bolognese meals appeared to initiate the production of enterotoxin in the host's guts causing diarrheal symptoms after consumption (Pirhonen et al., 2005; Rajkovic, Kljajic, Smigic, Devlieghere, & Uyttendaele, 2013).

It is possible for *S. aureus* to grow during the initial pasta production process and the heat stable toxin will not be affected by the drying process (Valik & Görner, 1993) or by the final product preparation/heating process. Even if the vegetative cells do not survive processing, the heat stable toxin may survive not only drying but the subsequent baking and can cause illness in complex food products that can support its growth and toxin formation (Kadariya et al., 2014). A study by Durack et al. (2011) on lasagna, a high protein, carbohydrate, and moisture product similar to Bolognese,

showed that even with the inclusion of mild acid resulted in the multiplication of *S. aureus* and *E. coli* during cold storage.

Food Spoilage and Sensory Quality

Food spoilage is defined as the point at which any perceptible negative changes are detected by the consumer, these changes can be physical, biochemical, and microbial (Gram et al., 2002). Enzyme actions and lipid oxidation are the common biochemical spoilage reactions that generate off-flavor and discoloration (Cox & Bauler, 2008). During product storage, food spoilage is unavoidable and therefore the food industry tends to utilize preservation techniques (for example, rapid cooling) to minimize product spoilage. Shelf-life is the combination of two central issues in the food industry: it is the period of time that food remains organoleptically acceptable and safe to consume (Cox & Bauler, 2008). Food manufacturers use the shelf-life limits to inform consumers of possible food safety and quality issues that may occur if the food is consumed after the stated date (Sofos, 2008). However, determining and optimizing shelf-life is challenging, mainly because the reduction of spoilage organisms may cause a subsequent increase in growth of pathogens due to the loss of their antagonistic effect on the pathogens (Gram et al., 2002; Hoyle et al., 2009). This is because a low population level of spoilage organisms is beneficial for the growth of foodborne pathogens as there is limited competition for the nutrients in the medium (Gram et al., 2002).

Pasteurization to 75 °C aims to diminish spoilage microorganisms (for example, lactic acid bacteria) and enzymes (for example, lipases) to minimize unacceptable sensory changes (Cox & Bauler, 2008). Different metabolites produced by the specific spoilage microorganisms in respective food products cause different food spoilage outcomes (Gram et al., 2002). For example, the presence of *Enterobacteriaceae* cause off-odor in meat products due to the production of hydrogen sulfite (Gram et al., 2002). In general, the total plate count (TPC), which is a test for the presence of aerobic microorganisms on a food product is merely a rough estimate of food spoilage microorganisms compared to tests for specific spoilage microorganisms such as lactic acid bacteria (Naveena, Muthukumar, Muthulakshmi, Anjaneyulu, & Kondiah, 2014). Furthermore, there are also several types of pathogens that are considered as food spoilage organisms such as *Salmonella* and *Clostridium* (Dave & Ghaly, 2011). Rapid cooling of food products can prevent the growth of pathogens and spoilage microorganisms (FSANZ, 2017). Moreover, sensory tests (for example, consumers' preference or acceptance test) and chemical tests (for example, pH, a_w , and nutrients composition testing) need to be incorporated into product testing in order to deduce the point at which spoilage occurs (for example, off-odor, appearance changes) after preservation and processing (Naveena et al., 2014; Patsias et al., 2006; Rodríguez-Pérez, Zurera-Cosano, Ma García-Gimeno, Barco-Alcalá, & Ma Castillejo-Rodríguez, 2003).

Meat products are an ideal medium for microbial growth due to their high a_w and high protein content (Dave & Ghaly, 2011). Many types of microorganisms such as lactic acid bacteria and *Enterobacteriaceae* have been studied for their ability to spoil meat products under different intrinsic (for example, pH and a_w) and extrinsic factors (for example, temperature and atmosphere; Gram et al., 2002; Hoyle et al., 2009; Naveena et al., 2014; Patsias et al., 2006). Exo-enzymes formed by some microbes can also oxidize fat in meat products leading to off-flavors and -odors, which is a loss of quality (Adams & Moss, 2008). Besides, lower a_w food ($0.6 < a_w < 0.84$) such as cooked rice may favor the growth

of mold spoilage instead of bacterial spoilage (Fellows, 2009). In low pH Bolognese pasta meals, the spoilage outcome may be different to the conventional cooked meat. This is because the low pH could favor the growth of molds in Bolognese sauce (Sperber, 2010). Armstrong & McIlveen (2000) conducted a sensory evaluation of chicken tikka masala and Bolognese meat sauce produced by the *sous vide* technique over a storage period of 40 days. The results showed less desirable appearance of Bolognese meat and chicken tikka masala sauce from day 20 onwards, but the details of chemical and microbial spoilage of products were not studied in this research (Armstrong & McIlveen, 2000). The study provided an overall conclusion that the application of processing and additional ingredients (for example, spices) will influence the overall spoilage outcome of food products (Armstrong & McIlveen, 2000).

Conclusion

In recent decades ready-to-eat and ready-to-cook food products produced and sold by the food industry have been associated with foodborne disease outbreaks costing the governments billions of dollars across the globe. PHFs such as cooked meat products, rice, pasta, lasagna, and Bolognese meals which are common ready-to-eat (heat and eat) and ready-to-cook (such as bake and eat) meals have been reported to cause foodborne disease outbreaks and sporadic cases of illness all over the world. Common foodborne pathogens, namely, *Salmonella*, *Listeria*, *Escherichia*, *Bacillus*, *Campylobacter*, *Clostridium*, and *Staphylococcus* cause these foodborne disease outbreaks and sporadic cases associated with foods that support their growth. The method and rate of cooling appear to play a significant role in determining the population of microbial pathogens in foods. The cooling rate is an important Critical Control Point in any HACCP plan and, therefore, the cooling rate needs to be established during the product development stage. Reaching the proper holding or storage temperature within an appropriate time period can ensure the safety of foods, such as following the Australian guidelines for cooling food products. Accordingly, food products need to be cooled rapidly and keeping products within the temperature danger zone should be avoided in order to inhibit the growth and survival of foodborne pathogens. Further, foods need to be packed in proper packaging materials to minimize the post-processing contamination. During the product development stage when the rate of cooling down is established the impact of the packaging material needs to be considered. Food engineers should focus on designing cooling plants with a view to reducing the product temperature to outside the temperature danger zone within the minimum possible time as per FSANZ or similar guidelines. The cooling stage of the operation needs to be considered a critical control point and its rate monitored to ensure a rapid cooling and validated. Much research has been conducted on the growth of foodborne pathogens in different food products, the effects of different ingredients on their survival and growth conditions in food. However, little published research exists on the effects of product cooling rate on these organisms and even fewer research efforts on the impact of food packaging material on the cooling rate and the growth of pathogens in food. Future research needs to be carried out to determine the effect of different cooling rates, the impact of packaging materials and cooling techniques, for example, vacuum cooling, adsorption cooling, magnetic cooling, cryogenic cooling, to determine the best cooling method, rate of cooling, and the impact of packaging material in order to produce safe food products.

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