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Innovative Non-Thermal Food Processing Technologies Used By The Food Industry In The United States

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INNOVATIVE NON-THERMAL FOOD PROCESSING TECHNOLOGIES USED BY THE FOOD INDUSTRY IN THE UNITED STATES

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The Faculty of the Department of Architectural and Manufacturing Sciences
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By
Harlin Kaur Saroya

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INNOVATIVE NON- THERMAL FOOD PROCESSING TECHNOLOGIES USED BY THE FOOD INDUSTRY IN UNITED STATES

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This thesis discussed the non-thermal food processing technologies being used within the United States of America. The technologies discussed in this thesis are High-Pressure Processing (HHP), Pulsed Electric Field, Pulsed Light, Irradiation, Ultra Sound, Oscillating Magnetic Fields, and Cold Atmospheric Plasma. A survey was designed and conducted to study the major reasons behind a preference for a particular technology by the organization, and the limitations for not implementing specific technologies. The survey participants were management level, food scientists and, food technologists employed by food processing companies. The questionnaire consisted of ten questions related to demographics, current technology, barriers from other technologies, and research and development of new technologies.

There were a total 223 respondents from various regions of the United States. The respondents had a wide array of industry experience. Of the respondents, 91% of the respondents had either a Bachelor’s Degree, Master’s Degree or Ph D. Thirty-six percent of the participants chose high pressure processing and 20 % chose pulsed electric as the most commonly used non-thermal food processing technologies. Rapidly increasing technologies included cold atmospheric plasma and oscillating magnetic fields. Seventy-one percent mentioned the main driver for them to choose non-thermal food processing was better nutrient and sensory properties. As per the results, 41% of respondents believed the major limitations in implementing non-thermal food processing technologies
was high investment. The results indicated the main drivers for innovation were equipment manufacturers and research. These researches were either academic or government funded.
Introduction

Background of Food Processing

Food processing dates to the prehistoric period. It was found to be effectively used in the hunter-gather humanities as per archaeological evidences. Heating and boiling were found to be effectively used to preserve various food items such as, meat, fish, vegetables, and roots. During those days, the need for preservation of food was not so intense, since the practice was to consume the food fresh. Gradually, over time, the need for food preservation became more important. Processing techniques such as sun drying, fermentation, cereal grinding, and oven baking became popular. The earliest modern technique for preservation of food was thermal food processing. These processing techniques provided desired changes, which included protein coagulation, starch swelling, textural softening, and formation of aroma components. However, some undesirable changes were observed. The undesirable changes included the loss of vitamins and minerals, freshness, and flavor. Consumers became aware of these issues, and began searching for foods, which looked fresh and tasted fresh. Hence, the food scientist began considering options for developing new technologies, which would provide a balanced process of preservation (Fellows, 2009).

During the last two decades, a considerable change regarding research and developments in the food processing technology have occurred. These new advances in food preservation technologies fall under the umbrella of non-thermal food processing. Many of the methods investigated in this study are modifications of thermal food processing technologies. Non-thermal food processing methods are also known as
minimal processing methods. These processing methods can preserve foods without substantial heating, while retaining their nutritional benefits and sensory characteristics. These processing methods also contribute by extending the shelf life of the product by inhibiting or killing microorganisms. Thus, they provide products that are fresher-tasting and more nutritious, without the application of heated chemicals. Innovative, non-thermal processes have attracted the attention of many food manufacturers, in search of new food processing methods (Brennan & Grandison, 2012).

Undeniably, there is a need for new and improved food processing technologies, which effectively disable the microorganisms in foods, while at the same time maintaining the quality of food. Therefore, the focus of this research study was on the use of non-thermal food processing techniques used in the United States. The various physical phenomena applied by these technologies results in the reduction of energy and water consumption. In turn, they would reduce the carbon and water footprint of food processing (Knoerzer, 2011). These food processing technologies played a vital role in environmental sustainability and universal food safety.
Problem Statement

The extent to which the usage of innovative non-thermal food processing technologies is prevalent in the United States is somewhat unknown. In the future, the most important priority for food science research would be related to innovative technologies, which meet customer expectations for optimum quality (Tokusoglu, 2015). Research was needed to identify the most desired non-thermal food processing technology present in the industry today, for preserving food with minimal processing. The literature was scarce regarding the use of non-thermal food processing technologies in the industry, and whether these technologies are supported and adequately funded for future research and development. The reasons for innovation of new, non-thermal food processing technologies in the United States are not very clear, for instance, which reasons promulgate innovation of these new technologies. Hence, the study can help in finding the major reasons behind innovation.

With technology innovation occurring at such a rapid pace, combined with a desperate need for food preservation within the industry, a singular solution is not applicable across the board. There are other processing methods present in the market. For instance, thermal processing is an alternative method. However, it can destroy components of food, which are responsible for individual flavor, color, taste, and texture. Hence, to keep up with consumer demands, non-thermal food processing techniques should be considered as an alternative technique. These techniques contribute to retaining the natural qualities in the food, by moderately inhibiting the progress of microorganisms. The food processing technologies provided the focus of this study were: High-Pressure
Processing (HHP), Pulsed Electric Field, Pulsed Light, Irradiation, Ultrasound, Oscillating Magnetic Fields, and Cold Atmospheric Plasma.

**Purpose of Research**

The main purpose of this thesis was to investigate the extent of innovative non-thermal food processing technology usage within the United States. Innovative technologies, which may help provide a perfect balance between safety and minimal processing while also providing a balance between adequate economic limitations and superior quality. Also, this research study investigated the major reasons food organizations had a preference of particular food processing technologies and the limitations that prohibit companies from using various technologies. There are technologies that are still under development and experiments are currently being conducted to understand how to pasteurize, decontaminate, and sterilize certain foods while preserving freshness and natural nutrients. This study investigated technologies currently being used, ones still under development, and what drives the innovation of these technologies within the United States.

**Significance of Research**

The significance of this research was to understand the non-thermal food processing technologies currently being utilized by the food manufacturers. This information can be utilized by any food processing industry to understand the new, non-thermal technologies still in the development stage. This would also provide information to organizations on how to deal with the new innovations related to equipment. Also, if the equipment were cheaper, would the companies change the technology they were currently using. Eventually, a framework can be derived from this research, which can
further be used to improve the food processing system. Thus, the research can educate food managers of the new systems available today. In addition, this study can provide an in-depth look at non-thermal food processing technologies.

**Research Questions**

1. Which non-thermal food processing technologies are being used within the organizations?
2. Which non-thermal food processing technologies are under research and development within the organization?
3. What leads a particular organization to choose the technology, which is currently being utilized by the companies?
4. What limited the organization from using the other technologies?
5. What drives innovation of new, non-thermal food processing technology in the United States?

**Limitations**

This study involved a survey, which was sent out to various food organizations. The major challenge the researcher faced were:

- Authentic and valid database: collection of email addresses of employees working in food processing companies was a huge challenge.
- Receiving a prompt and sincere response from all the organizations the survey was sent.
- Due to the tight schedule of these organizations, gathering all the data was difficult.
• Respondents may not provide accurate answers if the reputation of the company were hampered.

• Data errors could occur due to non-responses.

Assumptions

This research was conducted under the following assumptions:

• Responses were received from the majority of the organizations.

• Honest answers were provided by the organizations.

• Food manufacturing managers were aware of other non-thermal food processing technologies.

• Data was calculated with 99.9% accuracy.

Definition of Terms

The following terms were used in the present study:

Food Processing: The alteration of raw ingredients via a physical or chemical process into the food or changing the food into other forms.

Thermal Food Processing: Alterations of raw ingredients of food by applying heat to the food. This helps in inactivation of microorganisms and extension of shelf life.

Microbial: These are disease bacteria causing.

Non-thermal Food Processing: Altering the raw ingredients of the food, without or by minimal application of heat to the food for inactivation of virus and bacteria also to extend its shelf life.

High Pressure Food Processing: Method used for the preservation and sterilization of food, in which the product is processed under very high pressure. This leads to inactivation of viruses and bacteria.
**High-Pressure shucking effect:** Opening the shell, via high pressure.

**Shelf Life:** The length of time a commodity may be stored, without being unfit for use.

**Canning process:** Preservation of food in a can with or without preservatives.

**Pulsed Electric Field:** Method used for preservation and sterilization of food in which, the product is placed between two electrodes and pulses of high voltage are applied.

**Electroporation:** Application of electricity to the cells to increase the permeability of the cell membrane. Allowing chemicals or drugs to go into the cells.

**Poration:** Formation of pores or pattern of pores on a surface.

**Cabernet Sauvignon grapes:** World’s most widely recognized red wine grape variety.

**Freeze-drying:** It’s a dehydration process, typically used for preservation of perishable materials.

**Crystallinity:** the structural order in the solid.

**Gelatinization:** The process of breakage of bonds from starch molecules in the presence of heat and water allowing hydrogen bonding sites to exchange water.

**Oscillating magnetic field (OMF):** Method used for preservation and sterilization of food in which pulses are applied to the food in the form of decaying or constant amplitude sinusoidal waves.

**Irradiation:** Method used for preservation and sterilization of food by applying different forms of radiation to the food.

**Ionizing:** The process of conversation of an atom or molecule into an ion by removing one or more electrons.

**Gamma Radiation:** This is an electromagnetic radiation emitted by some atomic nuclei.
**Cold Atmospheric Plasma**: Method used for preservation and sterilization of food by applying plasma at atmospheric temperatures with low energy.

**Salmonella**: Sort of a bacteria.

**Ultra Sound**: Method used for preservation and sterilization of food by inactivation of enzymes and microorganisms at low temperature.

**Pulsed Light**: Method used for preservation and sterilization of food by intense and short-duration pulses of broad spectrum on the surface of the food.

**Fluence**: Number of particles per unit area.
Literature Review

According to Fellows (2009), the food industry today aims at providing what the customers demand. These demands are to be met by providing proper shelf life to the products via the preservation techniques. These techniques inhibit the microbiological changes, and allow time for distribution, sales, and home storage. These food processing technologies also need to keep the flavor, aroma, and texture of the food intact, and provide the required nutrients for health. In turn, this will generate income for the manufacturing companies, and the impact on the sensory properties of food will be minimal.

Initially, non-thermal food processing technologies were considered a viable substitute for thermal processing. In this process, food scientists, discovered a beneficial way of keep the freshness intact. For example, to make oysters safer for consumption, high-pressure shucking effect were used (Versteeg, 2016). Innovative technologies have many benefits and hence; the future expansion is easy to justify. A few technologies discussed in this study had an amazing concept behind their development, and some of them have become commercially profitable. However, the rest of the technologies are under research and development.

The food industry is generally divided into three main parts: processing, storage, and distribution. By the processing of foods, the microbes are eliminated to prevent food from becoming spoiled and cause a disease. It also helps in extension of shelf life, while maintaining the nutritional value of the product. There are quite a few advanced non-thermal technologies such as pulse electric field and plasma, which have been projected in the recent past. However, for these technologies to be easily applied to the food
industry, a comprehensive knowledge of their antimicrobial mechanisms, and their ability to control food safety is required (Valdramidis & Koutsoumanis, 2016). The major non-thermal food processing technologies to be discussed in this thesis are:

- High Pressure Processing (HPP)
- Pulsed Electric Field (PEF)
- Pulsed Light
- Irradiation
- Ultra Sound
- Oscillating Magnetic Fields
- Cold Atmospheric Plasma

These processes are discussed in detail in this thesis to understand the in-depth application, development, and optimization of these technologies.

**High Pressure Processing (HPP)**

This method is described as high hydrostatic pressure processing or as ultra-high pressure processing. In this method, food is subjected to pressures between 100 and 1000 MPa for up to a minute. By following this process, the micro-organisms and enzymes are removed; thus, preserving the sensory and nutritional characteristics (Tewari, Jayas, & Holley, 1999). HPP was first used in 1899 in the United States. However, in those days, the equipment was not very dependable and research was discontinued. Again towards 1990, the research began when better equipment was developed, and products like fruits, meats, and juices were being made in the USA (Tewari et al., 1999).

This process included immersing the packages of food in liquid, and then suddenly releasing the pressure uniformly throughout the food. By doing so, the pressure
is applied evenly, and all parts of the food receive the same treatment. The HPP process is known to be a non-thermal process. However, when pressure is applied to the foods, the temperature in them rise due to adiabatic heating. This is generated by the density of water and food components. There is a rise in temperature approximately 3 °C per 100MPa. This can go higher if the foods contain fat. Once the depressurization is complete, the temperature falls back due to adiabatic cooling (Fellows, 2009).

The basic principles of high pressure technology determine the behavior of foods under pressure. These basic principles include (Blany & Masson, 1993):

- **Le Chatelier’s Principle**: Any reaction that results in decrease in volume are enhanced whereas, reactions that increases the volume are repressed.

- **Principle of Microscopic Ordering**: At a contact temperature, if the pressure is increased, the degree of ordering of molecules of a given substance also increases.

- **Isostatic Principle**: A consistent pressure is applied on the foods from every direction. This process compresses the foods and once the pressure is released, they return to their original shape.

  If the food product contains enough moisture within itself, the pressure will not cause any damage at the macroscopic level if the pressure is being applied uniformly (Crawford, Murano, Olson, & Shenoy, 1996).

**High Pressure Processing Equipment and Working**

The companies who make equipment that can press metal, ceramic engineering components, and quartz crystals in the electronic industry are the ones who can manufacture high hydrostatic machinery. This equipment is huge and bulky. The following are the main components of the machinery (Mertens, 1995):
• A high-pressure vessel along with its end closures and a way to confine the end closures;
• A pressure generation system;
• A temperature control device;
• A material handling system; and
• A data collection system, along with controls and some instrumentation.

This system can be arranged in two ways, either a batch process for packaged foods or a semi-continuous process, where unpackaged liquid foods can be treated. The pressure vessel is a very important component of this equipment. There are quite a few aspects one should keep in mind when designing the vessel. For instance, it has to be dimensionally stable in a safe-fail way. That means, if the vessel is failing, it should breakdown with a leak. There are pressure-conducting fluids in the vessel that allow the pressure to be distributed uniformly to the product sample. The foods to be processed should be packaged flexibly when they are loaded into the high-pressure chamber. A disposable liner is injected into the stainless-steel cylinder and filtered water is used as the isostatic compression fluid. Finally, the pressure vessels are sealed. Once the process begins, pressure is generated either directly or indirectly by compression. In the direct method, the fluid is compressed in the vessel by moving a piston using hydraulic pressure, thereby reducing the volume. In the indirect compression method, an intensifier is used, which pumps the fluid directly into the vessel until the desired pressure is reached. The temperature is varied from -20°C to >100°C by electric heating elements. These electric heating elements are enclosed around the pressure vessel (Fellows, 2009). Figure 1, illustrates a pictorial representation of a high-pressure processing system. In this
figure, various components of the production systems have been mentioned (Huang, Wu, Lu, Shyu, & Wang, 2017).

![Diagram of a horizontal HPP Production system](image)

**Figure 1.** A horizontal HPP Production system (Huang et al., 2017).

Huges, Perkins and Yang and Skonberg (2016), conducted research in which HPP technology was applied on post-rigor processed abalone. In the process of chemical, microbial, and physical quality assessments, it was found that when high pressure processing was done at 300 MPa for approximately 10 minutes to the abalone, the refrigerated shelf life increased. This also did not change the physical or chemical composition of the product. This research helped the seafood industry because they can store abalone for longer periods without changing the texture and color of the product. Previously, the product could be preserved using the traditional methods, such as, freezing, dying, or canning, which did not last long.

High pressure processing methodology was applied to batters and their layer cakes. Microbial, physical, and structural changes occurred when the products were subjected to a pressure range of 300 MPa-600MPa. The research proved pressure helped in decreasing the molds, yeast, and aerobic mesophilic bacteria. Additionally, the batter become more consistent and elastic. However, when the batter was baked, the cakes were of a lesser
volume, had a darker crust, and had harder crumbs (Barcenilla, Román, Martínez, Martínez, & Gómez, 2016).

The quality of apple juice was checked after processing by HPP and thermal processing. Initially, the apple (Pink Lady, Granny Smith, and Jonagold) juices were subjected to HPP at 600 MPa for 3 minutes, afterwards a fresh set was subjected to thermal processing for 5 minutes. The juice that were treated by the HPP process retained its color better than the thermally processed juice. However, the enzyme inactivation was only possible through thermal processing. Although, the sugar and acids were less affected in both processes. The aldehyde, alcohol, ketone, and organosulfur were increased during the thermal processing technology. Also, the color and flavor of the apple juices remained better with the HPP process rather than the thermal heating process (Yi, et al., 2017).

A study was conducted by Zhang, Liu, Wang, Zhao, Sun, Liao (2016), where the quality of carrot juice was compared between high pressure processing methodology and high-temperature short-term processing (HTST). In this process, carrot juice was subjected to HPP at 550 MPa for 6 minutes and HTST processing for 110 °C for 8.6 seconds. In both the processes, it was found the juices were microbiologically safe after being stored for 20 days at 4 °C. In the storage process, the sample of juice, which was treated by the HPP process demonstrated greater nutritional, rheological, and antioxidant properties, when compared to the sample of HTST treated juice. When the sensory attributes were taken into consideration, the juice treated by the HPP methodology had fresher properties in aroma, taste, and overall suitability. However, the organoleptic
properties of the two juices reduced after storage. Therefore, it was determined the HPP methodology can be used as an alternative to produce fresh carrot juice.

The relationship between pressure and temperature in a typical HHP was described by Muntean et al. (2016). The molecules with a lower molecular weight have lesser effect on them through the HPP process. Therefore, this helped with the retention of vitamins, flavor compounds, and pigments in the processed food. At the same time, there are some compounds, which change during the HPP process. For instance, gelatinization of carbohydrates is achieved once the pressure is increased and not when the temperature increases. Additionally, proteins can be altered from their natural quality with an increase in temperature (Muntean, et al., 2016).

The figure below illustrates the pressure-temperature relationship.

![Pressure, Temperature, and Time during a HPP process](image)

*Figure 2. Pressure, Temperature, and Time during a HPP process (Ferstl, 2013).*

**Pulsed Electric Field Processing (PEF)**

In recent years, PEF technology has had an increasing interest for liquid food purification, and for refining mass transfer operations in the food industry. In this process, high amounts of electric forces are attained by storing energy from a DC power supply into a bank of capacitors, which in-turn is discharged to produce high-voltage
pulses. Once the liquid foods are placed between the two electrodes, each with high-electric strengths ranging from 20-80kV/cm applied in short pulses, the vegetative micro-organism in the food significantly reduces (Knoor, Angerbach, Eshtiaghi, Heinz, & Lee, 2001). The handling time was analyzed by multiplying the number of pulses with the actual pulse duration. In this process, two mechanisms have been proposed. If these are followed, the micro-organisms can be wiped out with these electric fields:

- Electric breakdown on cells: In this process, the PEF needs to obtain an electric field strength that is higher than the critical value, which can provoke a transmembrane potential greater than 1 volt, to most of the vegetative cells. This will lead to an immediate discharge and decomposition of the membrane (Griffiths & Walking-Riberio, 2014).

- Electroporation: In this process, the focus is to increase the membrane absorptivity since there is membrane compression and poration (Novickij, et al.).

In electroporation process, microbial inactivation occurs. The following aspects influence this process:

- The processing conditions could be the intensity of the electric field, the frequency and duration of the temperature, or the time of treatment.

- The micro-organisms could be the type, concentration, or the growth stage of the same.

- The food properties.

In the pulsed electric field food processing methodology, the inactivation of vegetative cells is greater when high electric field intensities are used with an increased duration of pulses (Novickij, et al.).
Pulsed Electric Field Equipment

There are two kinds of equipment available for the operation of this technique. The two types include batch equipment and continuous equipment. Commercially, the continuous process is preferred because the process does not have to be stopped. This results in a continuous flow. There are a few important components, which play a major role in the equipment. The important components include the following: a repetitive high voltage pulse generator, inductors, capacitors, discharge switches, liquid handling system, and a treatment chamber. Once the food is treated, it is then passed through a sterile packaging line. Also, there are supervising and control equipment that include temperature sensors made of optic fibers, electric monitors, data procurement, and regulatory microprocessors (Knoerzer, 2011).

Since this equipment utilizes high electricity, the protection of the operators becomes of prime concern. Hence, it is placed in a restricted area with interlocked gates. Also, the connections to the chambers are isolated and earthed to prevent leakage. Though there are precautions taken and measures in place to deal with this process; there are a few limitations that cannot be over looked. The main limitations are (Knoerzer, 2011):

- This process is restricted to liquid or small particles foods;
- This process can only be implemented to foods, which can withstand high electric fields;
- In this process, if a food requires salt to be added, it can only be done after PEF processing; and
- In this process, there cannot be any bubbles. The bubbles must be removed since they can cause safety issues, or can lead to a non-uniform treatment.
Pulsed electric field processing treatment has gained its popularity over the last two to three decades in the food processing industry. There have been many mechanisms and effects on the food and agricultural products due to this process, which have been discovered in the past and explained over the years. For instance, the concept of electroporation has advanced a lot since the time it was first discovered. Major changes observed in this technique include: inactivation of microorganisms, removal, pressing, osmotic dryness, and freezing. Due to the recent progress in the pulsed electric field processing, the commercial market for this process has increased (Sitzmann, Vorobiev, & Lebovka, 2016).

The application of pulsed electric field processing on the extraction of anthocyanin from red cabbage, using water as a diluter, was studied. In this process, mashed cabbage was placed in the batch treatment chamber and was exposed to the pulsed electric fields. This study demonstrated through PEF treatment the anthocyanin extraction was enhanced by 2.15 times. Also, manufactures can use this technology to extract anthocyanins from red cabbage resourcefully (Gachovska, et al., 2010).

PEF technology can be used for inactivation of microorganisms, which can lead to the preservation of food products. In the food processing technologies, this process is considered to be one of the mild processes, since it falls under the umbrella of non-thermal processing. In this study, the emphasis was on refrigerated fruit juices. Refrigerated fruit juices are processed by the PEF method to inactivate their microorganisms. The continuous flow PEF system was used with electric field strength of 20 kv/cm and flexible frequencies in apple, orange, and watermelon juices. It was observed an interdependent effect exists between the temperature and electric pulses.
This leads to less energy consumption for inactivation. Also, pH plays a major role in the inactivation, since there were different juices. However, it was dependent on the pH level of every juice (Timmermans, et al., 2014).

The effect of PEF treatment on grapes of Cabernet Sauvignon was studied by Puértolas, Saldaña, Alvarez, Raso (2010). An electric field strength of 5 kv/cm along with 3.6 kJ/kg of energy was applied to the grapes. It was found when wine phenolic content was increased, the effects lasted for a longer period of time. Once the analysis was completed, the researchers realized the treatment cost was lower. However, the cost to generate high voltage pulses with sufficient power for processing in large quantities was difficult. Therefore, it was determined the phenolic extraction can be completed easily through the PEF process.

PEF processing was applied to fresh sugarcane juice using the static treatment chamber with and without lemon and ginger, respectively. At first, fresh juice without lemon and ginger was subjected to different field strengths ranging from 30 KV cm⁻¹ and 50 KV cm⁻¹ with resistive pulse numbers as 150 and 300. These were investigated at a room temperature of 31℃ and refrigeration temperature of 4℃ for 30 days. These results were then compared to untreated samples at room temperature. The results indicated the samples treated at fields strength 30 KV cm⁻¹, 150 pulses were more stable when compared to the untreated samples. In the second part of the experiment, fresh sugar cane juice was subjected to the PFF process. However, this time lemon and ginger were added. This experiment was conducted for 14 days at various electric field intensities (10 KV cm⁻¹, 20 KV cm⁻¹, and 30 KV cm⁻¹) with 150 pulses and were refrigerated at 4℃. The results of this study indicated the best reduction of microbes was achieved at 20 KV cm⁻¹
for 150 pulses. Additionally, it demonstrated the sensory attributes of unaltered juice that lasted for two days. However, the juice that was subjected to only PEF process lasted 7 days. Once lemon and ginger were added, the PFF treated juice doubled its shelf life to 14 days (Kayalvizhi, Pushpa, Sangeetha, & Antony, 2016).

A study conducted by Parniakov, Bals, Lebovka and Verobiev (2016), related to the effects of PEF on vacuum freeze-drying process in apple tissues. The apple slices were subjected to a PFF treatment at an electric field strength of $E=800\,\text{V/cm}$ for various values of disintegration index $Z$. The vacuum cooling was related to lower the temperature to sub-zero level. This is when the freeze-drying experiment was performed at a pressure of 10mbar. Towards the end of the experiment, an overall microscopic and macroscopic analysis was conducted. It was found the PEF treatment resulted in the preservation of the dried samples, and it increased the tissue pores. Additionally, the PEF process accelerated the cooling-drying process, and the samples had better rehydration capacity.

Zeng, Gao, Han Zeng and Yu (2016) conducted a study where waxy rice starch was subjected to PEF processing at 30 KV cm$^{-1}$, 40 KV cm$^{-1}$ and 50 KV cm$^{-1}$. The results indicated the starches showed differences in physicochemical properties and in digestibility. The relative crystallinity and diffraction intensity were low in the starches after the treatment. As the PEF intensity increased, the gelatinization and enthalpy of the rice starches decreased. These results showed the PEF process induced changes in the granular packaging, crystalline structure, and thermal properties. This in turn effected the digestibility of the waxy rice starch.
This study demonstrated the PEF increased the rapid digestible starch content, but would decrease the slowly digestible starch and resistant starch contents. Therefore, there was increased vulnerability of PEF starches towards the digestive enzymes, a lowered relative crystallinity, and a loss of the outer package protection (Zeng, et al 2016).

**Oscillating Magnetic Fields**

Oscillating Magnetic Fields (OMF) are known for their microbial inactivation methods. The OMF are applied in the form of decaying or constant amplitude sinusoidal waves. The magnetic field can either be homogenous or heterogeneous. In the homogenous methodology, the field intensity $B$ was uniform within the area, which was enclosed by magnetic field coil. On the other hand, in heterogeneous field $B$, non-uniform and intensities decreases as the distance from the center of the coil increases. OMF are applied as pulses, thereby, reversing the charge of each pulse. The intensity of each pulse decreases with time to 10% of the initial intensity. For future development, there is a requirement of systems, where power source, number pulses, and frequencies
applied to the food can be monitored (Barbosa-Canovas, Schaffner, Pierson, & Zhang, 2000).

**Oscillating Magnetic Field Working and Equipment**

The oscillating magnetic fields are produced by passing a fluctuating current by the electromagnets. The field strengths are high when compared with the earth magnetic field, which would approximately be 5 to 100 tesla. Frequencies ranging between 5-500 kHz are applied for around 25µs to a few milliseconds. This helps in the inactivation of vegetative cells. However, if the frequencies are higher than 500 kHz, the food gets heated, and the inactivation process is not effective. In recent studies, it has been observed there are not much of an effect on the spores or enzymes. In addition, it can lead to the growth of vegetative cells. For instance, when an oscillating magnetic field strength of 12.0 T was applied to milk at a frequency of 6000 Hz, cells were reduced from 25,000 to 970ml⁻¹ (Fellows, 2009).

Effects of oscillating magnetic fields on crab sticks were analyzed in a study conducted by Otero, Pérez-Mateos, Rodríguez, and Sanz (2017). The crab sticks were frozen both with and without oscillating magnetic field application. The entire process was observed for approximately 12 months. During this process, various quality attributes were assessed. The results indicated the oscillating magnetic field had no effect on the crab sticks. The drip loss, water-holding capacity, toughness, and whiteness remained the same. Additionally, the quality of the frozen samples also remained the same. It is important to note during this experiment; the strength of the oscillating magnetic field was lower than 2mT. This is only two orders of magnitude more than earth’s natural magnetic field. The frequency range was between 6 to 59Hz. It should be
noted, if the frequencies and magnetic strengths of this study were varied, the results could have changed.

James, Reitz and James (2014) conducted a study to investigate how garlic bulbs would react when subjected to oscillating magnetic fields, as compared to freezing them under normal conditions. The results of this study showed substantial cooling in the garlic bulbs, during some of the freezing trials. However, freezing stage the oscillating magnetic fields had a significant effect on the garlic bulbs over the normal freezing method. Also, the researchers concluded super-cooling was more effective with garlic bulbs if they were frozen at an initial ambient $21 \pm 1 ^\circ C$ rather than $4 \pm 5 ^\circ C$.

**Irradiation**

The irradiation of food is a process used in the food preservation industry to increase the shelf life, and improve the microbial safety of food. This is done without inducing any chemical pesticides by exposing food to ionizing radiation. Ionizing radiation is an energy, which can freeze the electrons, and separate them from their atomic bonds without directly contacting the food particles. This methodology helps by destroying pathogenic or spoilage bacteria. This contributes to the reduction of the risk of foodborne illness. This process is also capable of delaying or eliminating the sprouting or ripening of food. At any point of this treatment, heating of food is not involved. Thus, the sensory and nutritional properties remain unchanged to a large extent (Fellows, 2009).

There are various methods in the irradiation process. However, only gamma radiation and accelerated electrons are used in the food processing applications. Other technologies, such as, alpha radiation or beta radiation may cause radioactivity. The accelerated electrons can also be converted into X-rays to utilize during food processing.
The ionizing ability helps in differentiating gamma rays, X-rays, and electrons. After the ionizing process, electrically charged ions and free neutral radicals are the byproducts. Together, they emit electrons that further cause the destruction of micro-organisms in food. The food, which contains high moisture content are treated by ionization. This process contributes in the breaking of chemical bonds by expelling the electrons from the water molecules (Knoerzer, 2011).

**Irradiation Equipment**

In the food irradiation process, there are three facilities: gamma radiation, X-rays, and electron. Additionally, there are three types of equipment where the food is exposed to ionizing radiation. This procedure is carried out in a special processing room, or in a chamber for a specific duration of time (Fellows, 2009).

- **Gamma Radiation**: This process is also known as cobalt 60, and is the most common source of ionizing energy. This setup is placed in two stainless steel tubes called source pencils. They are placed one inside the other. This setup is placed on a rack, and when the system is not being used, the entire rack is immersed in water underground. The rack is removed from the water only when the processing has to be done. The packaged food is passed through the belt and goes into the room where the package is subjected to source pencils. The energy in the form of gamma ray’s passes through and treats the food (Fellows, 2009).
• Accelerated Electrons: This process is also referred to as an E-beam accelerator. The working of this setup is similar to that of a television tube. Rather than being extensively discrete, and striking a phosphorescent screen at a very low energy, the electrons are focused and fast-tracked at the speed of light. This effect fabricates quick reaction on the molecules. The electrons in this process accelerate energies to 5, 7.5 or 10MeV, along with beam power of 10 KW (Fellows, 2009).

• X-Rays: In this methodology, the electrons are focused by an electron beam accelerator on a metal plate where some of the energy is taken in and the rest is
converted to X-rays. The X-rays can penetrate the food boxes up to 15 inches thick or more. Therefore, when the food is being processed, the majority of the radiation goes through without being absorbed by the food (Cleland & Stichelbaut, 2013).

Figure 6. A three-dimensional drawing of an X-ray with dual pallet carriers (Cleland & Stichelbaut, 2013).

Mishra, Gautam and Sharma (2011) conducted a study on preserving sugarcane juice. In an ideal situation, fresh sugarcane juice changes its color soon after withdrawal. Due to fermentation, it spoils within a few hours. Hence, a research study was conducted that applied gamma radiation along with preservatives, and low temperature storage to make the juice last long. In this process, the preservatives used included citric acid (0.3%), sodium benzoate (0.015%), and sucrose (10%) stored at 10°C. Towards the end, it was noticed that the researchers were successful in extending the shelf life of the juice to 15 days at 26 ± 2°C and for 35 days at 10°C. This process did not adversely affect the biochemical, antioxidant, and organoleptic characteristics. Also, the microbial load was lowered below a noticeable level.
A study was conducted by Mahmoud, Awad, Madani, Osman, Elmamoun, and Hassan (2015) where the effect of gamma radiation on millet grains was studied. The grains were subjected to gamma radiation at different doses: 0.25kGy, 0.5kGy, 0.75kGy, 1.0kGy and 2.0kGy. After the experiment, it was observed that a radiation level above 0.5kGy on the grain lowered the fungal incidence and free fatty acids content. At the same time, there was a reduction in anti-nutrients, such as, tannin and phytic acid. As a result, there was an increase in the vitro protein digestibility and protein solubility of the grain. This experiment proved gamma radiation was safe for shelf life extension of millet grains.

Wang, Ding, Zhang, Li, Wang, Luo, Li, Li, and Chen (2017) conducted a study to examine the effect of e-beam processing on the structural and functional properties of albumin (protein, which is soluble in water), globulin (protein found within the blood), glutenin (major protein within wheat flour), and wheat germ protein isolate. The end results indicated that e-beam irradiation with optimal conditions was a very effective process to enhance water absorption, oil absorption, and foaming properties of proteins. It was determined the best results were obtained below 60kGy. It provided the optimal condition for oil absorption activity in albumin, globulin, and glutenin. Whereas, 30kGy was best for water absorption, as well as glutenin and wheat gram protein isolate. Therefore, it is essential to choose the right irradiation dose to meet the different prerequisites of protein functional properties.

The effect of e-beam processing of two beef products, (steaks and hamburgers) regarding the shelf life extension, safety, and sensory attributes was studied by Cárcel, Benedito, Cambero, Cabeza, and Ordóñez (2015). Salmonella (bad bacteria) was
inactivated by using different doses of irradiation, by first order kinetics. To understand the shelf life extension, bacterial numbers were periodically counted. In this experiment, the Gompertz function was used to study the outcome of irradiation on the sensory attributes. At the same time, optimization of the irradiation doses was done by making the most of sensory scores of samples and reducing the instrumental color changes. These optimum doses assured maximum worth of the product and proved that e-beam processing greatly affects the safety and sensory attributes of both poultry products.

To identify and measure the internal structure of pomegranate, a study was conducted using the X-ray computed tomography by Arendse, Fawole, Magwaza, Opara (2016). The evaluation and volume estimation of the internal structure of the fruit was done by setting up a commercial X-ray system with a radiation source of 245 kW and electron current of 300µA. This helped in the generation of two-dimensional radioscopic images. The two dimensional radioscopic images were then reconstructed into three-dimensional images. This technology helped in accurately foreseeing the physical attributes of the fruit, such as, length, diameter, and peel thickness. This study mentioned the technology was capable of inspecting internal defects, which cannot be found with human eye. However, there were drawbacks that needed to be considered. For instance, the entire system was complex and costly. Also, the data acquisition time and image analysis were high, which makes it difficult for the system to be readily applicable for immediate inspections. Therefore, further research can help in determine whether computing and image analysis cost can be reduced.
Cold Atmospheric Plasma

In general, plasma is categorized in thermal or non-thermal. The thermal plasma needs high pressure and temperature with dense electrons; whereas, non-thermal plasma is generated at atmospheric temperatures that range between 30°C-60°C with low energy. Cold atmospheric plasma is a unique food processing technology, which is widely used for air decontamination of airborne bacteria, elimination of organic chemicals or bacteria by the liquid treatment, and for decontaminating the surface of foods, equipment packaging, and work surfaces (Thirumdas, Sarangapani, & Annapure, 2014).

Cold Atmospheric Plasma Working and Equipment

Cold atmospheric plasma can be developed by applying electromagnetic waves on gas at lower pressure; thereby, leading to a thermodynamic non-equilibrium nature. There are several mainstream methodologies for the generation of atmospheric pressure. Three of these methodologies include dielectric barrier discharge, corona discharge, and gliding arc discharge. These require mild conditions to run and are of keen interest in the food industry. In the earlier days, plasma treatments were performed in vacuum chambers. However, with the advancements in technologies, researchers have discovered new techniques, such as, atmospheric pressure plasma. This technology helps in reducing cost and increases the treatment speed. For the generation of the cold plasma, also referred to as gliding arc, two components are required. The two required components are power supply and plasma emitter. The equipment requires an AC power of 60Hz and an operating output rate of 60mA at 15kV. The equipment operates in the open with electrodes of 3mm thickness, which are attached at the top and bottom along with stainless steel lugs. The rods are secured at a definite distance of 3mm from the plasma.
creating point and are bent at an angle of 45°. The minimum area between the gas inlet and plasma creating point is 8mm (Dey, et al., 2016).

![Diagram](image)

Figure 7. Atmospheric pressure argon plasma experimental set up (right) and a picture of plasma equipment treating waste water sample (left) (Mohamed, Al-Shariff, Ouf, & Benghanem, 2016).

Cold atmospheric pressure was applied to wheat flour at a low level of cold plasma using powers of 0.19W/cm² and 0.43 W/cm² at different time periods. These samples were collected and were tested for physical and chemical changes. The results demonstrated cold plasma treatment did not impact the microflora. However, the process did alter the molecular weight distribution of wheat protein polymers. In the process of treatment, the cold plasma oxidized free fatty acids and phospholipids. Ultimately, all these qualities enhanced the functionality of wheat flour leading to the formation of strong dough (Bahrami, et al., 2016).

Oh, Roh and Min (2016) investigated the effect of cold plasma (using different plasma forming gases) on the physical properties of defatted soybean meal (DSM)-based
edible film (DSM film). The effects of cold plasma treated DSM film in packing smoked salmon, for storage stability, was studied and it was determined the storage stability increases. The DSM film was created by molding film-forming solution, which was prepared by high pressure homogenization. Next, the ink adhesion test was performed that helped to understand, O\textsubscript{2}-, N\textsubscript{2}-, He-, and Ar-CPT (cold plasma treatment) increased the stretch-ability of DSM film, N\textsubscript{2} and Ar-CPTs helped in increasing the lightness, and O\textsubscript{2} and air-CPTs improved the film’s printability. The CPT increased the tensile and moisture properties of the DSM film.

Figure 8. Graphical representation of cold plasma treatment of defatted soy bean meal-bases edible film for food packaging (Oh, Y.A, Roh, S.H, & Min, 2016 ).

Siciliano, Spadaro, Prelle, Vallauri, Cavallero, Garibaldi, and Gullino (2016) studied the use of cold atmospheric plasma, for the detoxification of hazelnuts from four forms of aflatoxins (AFB\textsubscript{1}, AFB\textsubscript{2}, AFG\textsubscript{1}, AFG\textsubscript{2}). The operating parameters of cold atmospheric plasma were altered for the detoxification process. The effect of various gases was verified. Next the power and exposure time were altered that ranged from, 1-12 minutes with power from 400-1150W. In the end of the test, it was determined this method allowed complete detoxification with the help of high power for a few minutes.
The maximum temperature increment was 28.9°C; thereby, proving cold atmospheric plasma to be a promising technology for the aflatoxin detoxification of hazelnuts.

The effect of cold atmospheric plasma on anthocyanins and color in pomegranate juice was investigated by Bursać-Kovačević, Putnik, Dragović-Uzelac, Pedisić, Režek-Jambrak, and Herceg (2016). The results of the treatment were observed at three working conditions: (i) Treatment Time, (ii) Treated Juice Volume and (iii) Gas Flow. The highest anthocyanin stability was achieved at 3 min, 5cm$^3$ volume and 0.75 dm$^3$/min gas flow. The use of this technology also helped in the increment of anthocyanin content from 21% to 35% and color change.

In order to disinfect fresh fruits and vegetable slices, which had salmonella deposited on them, a cold atmospheric plasma treatment was applied. A plasma treatment of 2 minutes, (this means each part on surface was exposed to 1s of plasma) inactivated approximately 90% of the salmonella on carrot slices and 80% on cucumber and pear slices. The physical and chemical properties, such as, water, color, and nutritional content were overserved and it was found that, the changes were within the acceptable range. In this study, it was determined that cold plasma treatment on the vegetables and fruits was a successful methodology (Wang, et al., 2012).

**Ultrasound**

Ultrasound technology has been used as an alternative processing technology over thermal processing techniques. This technology can be used for pasteurization and preservation of food by inactivation of enzymes and microorganisms at low temperatures. In the ultrasound food processing industry, there are two divisions (Fellows, 2009):

- Low intensity ultra sound (less than 1 W cm$^{-2}$)
• High intensity ultra sound (Between 10- 1000 W cm²)

The low intensity ultra sound methodology is known as non-destructive analytical method. It is used in gauging the structure, composition, and flow rate of foods. Where high-intensity ultra sound methodology uses high frequencies, it causes physical damage to the tissues. Hence, they are used for cutting food or cleaning the equipment. The physical and chemical effects of ultra sound processing in liquid and solid medium have been significantly used. In liquid medium, there are extreme physical forces generated, such as, acoustic streaming, cavitation, shear, micro-jet, and shockwaves. These forces further lead to the origin of ultra sound applications for food processing: emulsion, tenderization, and filtration (Chandrapala, Oliver, Kentish, & Ashokkumar, 2012).

Table 1 represents the applications of the ultrasound food processing industry. The major advantage of ultrasound food processing technology is its effectiveness against vegetative cells, spores, and enzymes. Additionally, the process time and temperatures are reduced to a large extent. In Table 1, various applications of ultrasound technology have been described. Here, the conventional methods have been mentioned along with the principle of the ultrasound technology on the food types is stated.
<table>
<thead>
<tr>
<th>Applications</th>
<th>Conventional methods</th>
<th>Ultrasound principle</th>
<th>Advantages</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking</td>
<td>Stove</td>
<td>Uniform heat transfer</td>
<td>Time saver, improves heat transfer and organoleptic quality</td>
<td>Meat, Vegetables</td>
</tr>
<tr>
<td></td>
<td>Fryer</td>
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<td></td>
<td>Water Bath</td>
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<tr>
<td></td>
<td>Freezing by other products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drying</td>
<td>Atomization</td>
<td>Uniform heat transfer</td>
<td>Time saver, improves heat transfer and organoleptic quality</td>
<td>Dehydrated products</td>
</tr>
<tr>
<td></td>
<td>Hot Gas stream</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Pulverization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marinating</td>
<td>Brine</td>
<td>Increasing mass transfer</td>
<td>Time saver, improves heat transfer and organoleptic quality</td>
<td>Cheese, Fish, Meat, Vegetables</td>
</tr>
<tr>
<td>Degassing</td>
<td>Mechanical treatment</td>
<td>Compression-refraction phenomenon</td>
<td>Better hygiene, Time saver</td>
<td>Chocolates, Fermented products</td>
</tr>
<tr>
<td>Filtration</td>
<td>Filters</td>
<td>Vibrations</td>
<td>Better filtration, Time saver</td>
<td>Liquids</td>
</tr>
<tr>
<td>De-molding</td>
<td>Greasing</td>
<td>Vibrations</td>
<td>Reduction in product loss, Time saver</td>
<td>Baked products</td>
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<tr>
<td></td>
<td>Teflon molds</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Silicon molds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De-foaming</td>
<td>Thermal/Chemical/Mechanical treatment</td>
<td>Cavitation phenomenon</td>
<td>Better hygiene, Time saver</td>
<td>Fermented and carbonated products Sauces</td>
</tr>
<tr>
<td>Emulsification</td>
<td>Mechanical treatment</td>
<td>Cavitation phenomenon</td>
<td>Time saver</td>
<td>Sauces</td>
</tr>
<tr>
<td>Oxidation</td>
<td>Air contact</td>
<td>Cavitation phenomenon</td>
<td>Time saver</td>
<td>Alcohols</td>
</tr>
<tr>
<td>Cutting</td>
<td>Sharp tools</td>
<td>Cavitation phenomenon</td>
<td>Accurate and repetitive cutting, Time saver</td>
<td>Fragile products (cakes, cheese)</td>
</tr>
</tbody>
</table>

Table 1

*Applications of Ultrasound in food processing (Chemat, Zill-e-Huma, & Khan. 2015).*
Ultrasound Working and Equipment

Ultrasound food processing equipment consists of a generator and a piezoelectric transducer. The piezoelectric transducer diffuses ultrasound to the food through a horn and it is immersed in the liquid. This setup can either be placed in heating equipment for thermo-sonication (technique used for liquid food preservation) or in pressurized vessels for food preservation. The ultrasound process has less effect on smaller molecules and are responsible for the change in color or flavor (Mathavi, Sujatha, Bhavani, & Karthika, 2013).

Figure 9. Ultrasonic in food processing. (Mathavi, Sujatha, Bhavani, & Karthika, 2013).

Pulsed Light

Pulsed light food processing technology uses intense and short-duration pulses of broad spectrum. This is also known as white light, and is used to ensure microbial decontamination on the surface of either food or packaging materials. The inactivation efficiency of pulsed light is directly proportional to intensity and number of pulses delivered. It has a similar spectrum as sunlight, which has wavelengths ranging from ultraviolet 170 nm to infrared 26 nm. It peaks between 400-500 nm. As pulsed light is
produced in short pulses that range from 1µs-0.1 s, they are approximately 20,000 times the intensity of sunlight at sea level. In the process, the energy that is exposed on the food or on the packaging materials is measured as fluence and is quoted in units of J cm\(^{-2}\). A number of synchronized mechanisms, for example, chemical modification to proteins, membranes, and nucleic acids lead to the inactivation of microorganisms. The wavelengths for ultra violet light range from 100-400 nm. This range is further subdivided into (Elmnasser, et al., 2007):

- UVA (315-400 nm)
- UVB (280-315 nm)
- UVC (200-280 nm)
- UV (100-200 nm)

The absorption of energy by consolidated carbon bonds in proteins and nucleic acids give antimicrobial effects of light at UV wavelengths. This effects leads to crosslinking in DNA, and the results become irreversible. However, short term treatment with pulsed light or ultra violet light have less effect on the nutritional or sensory properties of various foods. Since these technologies penetrate the foods to a limited depth, they are suitable for surface treatments (Knoerzer, 2011).

**Pulsed Light Working and Equipment**

The generation of pulsed light is done by charging the capacitors, which discharge the power as a high-voltage pulse of electricity to lamps filled with inert gas. The electricity goes through the gas into the lamp allowing it to emit a very strong pulse of light. These rapid pulses of lights (generated at a speed of tens per second) are directed to the surface or packaging of the food. There are ammeters that measure the lamp current
for each flash. Next, they determine the light intensity and spectrum. Also, there are silicon photodiode detectors, which measure the fluence in the ultra violet wavelengths. The system was programmed to stop automatically if any of the above arrangements did not function. In general, the processing of food using this technology was done at 1-20 pulses with energy densities ranging between 0.1-50 Jcm\(^{-2}\). The fluence and spectral density can be regulated for different applications. The entire process can be optimized for various food by adjusting the number of lamps frequency of flashes (Fellows, 2009).

Panozzo, Manzocco, Lippe, and Nicoli (2016) performed a research study where the effect of pulsed light on selected wheat gluten properties were investigated. The gluten photo-reactivity was highly effected by hydration, which leads it to be higher in 1% gluten suspension as compared to gluten powder. In addition, there were browning reactions due to the processing. Pulsed light lead to structural modifications of gluten proteins, which resulted in a reduction in the gluten immunoreactivity. In summary, the pulsed light can be regarded as a non-thermal decontamination technology, as well as, a well-organized approach to steer the structure and functionality of protein rich ingredients.

Xu and Wu (2016) conducted a study to analyze the impact of pulsed light on the decontamination, quality, and bacterial attachment of fresh raspberries. The qualities of the raspberries were evaluated during the 10 days of storage at 4°C and the duration of pulsed light was 5s, 15s and 30s. On the 10\(^{th}\) day, all the raspberries, which were treated by pulsed light maintained significantly lower total bacterial count, and total yeast, and mold count. The sample of raspberries treated for 30 seconds were successful in removing the bacteria, but failed to maintain its efficiency in storage. The samples were
treated for 5s for the decontaminate of fresh raspberries since it did not damage the quality during the storage. The researchers concluded the pulsed light treatment could be used for decontamination of fresh raspberries.

A study was conducted by Koh, Noranizan, Karim, and Nur-Hanani (2016) to investigate the effect of pulsed light fluence on a particular cut type of cantaloupes. In this study, fresh-cut cantaloupes in various cut types were treated at 6 Jcm$^2$. These samples were subjected to various fluences that included: 2.7, 7.8, 11.7, and 15.6 Jcm$^2$. They were stored at temperatures of 4 ± 1°C for approximately 28 days. Toward the end of the study, it was found to be the spherical shape was the most suitable shape for pulsed light treatment, because it had the lowest microbial count before and after treatment. For shelf life extension, the samples that were treated at 7.8 Jcm$^2$ turned out to be the best. In the end, it was concluded the pulsed light treatment was a potential technique for the extension of shelf life, and inactivation of microorganisms without comprising nutritional quality.
Methodology

Research Objective

A survey was developed and administered to understand the perception of food scientists, technologists, food manufacturing managers, and management team members on the use and innovation of non-thermal food processing technologies.

Design and Development

This study was completed by conducting a survey in the US region, using Qualtrics software. This questionnaire was derived from a previous study, which was performed to study novel food processing technologies in the world (Jermann, Koutchma, Margas, Leadley, & Ros-Polski, 2015). The survey was designed on the Qualtrics site. It consisted of ten straightforward questions. These questions were based on demographics, current technology, barriers of using innovative non-thermal technologies, and research and development of new technologies. The demographic portion of the survey contained questions about the education level, years of experience in the industry, region in the United States, and company size. The survey was directed at employees working in management or research level positions within food processing companies. This allowed the researcher to understand, which technologies are being used within the industry, and what leads the users to choose them.

The questionnaire for the survey (Appendix D) was approved by Western Kentucky University’s Instructional Review Board (IRB) (Appendix A).

Participants Recruitment

A survey was sent to employees working in upper management or scientist and technologist levels within the food processing companies to gauge their response on their
use of non-thermal technologies. The first step of this study was to gather a database. This database was created by datamining various social networking tools available in the market. This database consisted of employees working at management level and employees on research teams in food processing companies. Several networking tools were used to create the database and a list of companies was generated using Hoovers site. Hoovers site has a global database including over 85 million companies. Only food processing companies located in the United States were selected. Based on the company name, LinkedIn, a social networking site, was used to gather information about employees working within the organization. As, the entire employee information could not be retrieved from LinkedIn, Zoom-Info, and Lead411 were utilized. These sites were used during the collection of employee names and respective email addresses. These email addresses were used to distribute the survey.

Once the database was ready and the survey was hosted on Qualtrics, Mailchimp was used to distribute the emails. Mailchimp is an email marketing service that helps in bulk distribution of emails. The email campaign ran on Mailchimp, had the IRB approval form attached to the email, and was followed up with the survey link. This campaign was run between 10:30 am and 12:00 pm. This was considered to be the most active time for the corporate industry. Of the participants one was randomly selected and provided a $60 Amazon gift card for completing the survey.

**Data Analysis**

The data collected from the study was analyzed using Qualtrics software. The descriptive statistics included the frequency and the percentage of the frequency for all variables. Chi-square tests of independence and data were considered to be
statistically significant at the 95% confidence level unless otherwise noted. The unit of analysis of the dependent variable determined the type of quantitative analysis conducted. The relationship between the demographic dynamics and the non-thermal food processing practices were analyzed using bivariate analysis. This analysis helped in gaining a clear understanding of the co-relation between the demographic aspects and respondents. Also, the relationship between other variables was studied to understand the reasons specific technologies were used.
Results and Discussion

Demographics of Participants in Food Processing Industries

The survey was distributed to upper management personnel, food scientists, and technologists working in 421 food processing companies within the United States of America. A total of 223 responses were received. Table 2 demonstrates demographic data collected regarding education, industry experience, company size, and region in the United States. The demographics in the study were quite diverse. Of the respondents, 42.4% possessed a bachelor’s degree, 34.5% held a master’s degree, 15% had a PhD., and 7.9% had a high school diploma. The industry experience of these respondents varied greatly, with 33.5% with 6-10 years’ experience, 32.5% with 0-5 years of experience, 27% with 10-20 years of experience and 7.4% with over 20 years of experience.

Regarding the size of the food company, 37.4% of the respondents belonged to medium sized companies with employee strength ranging from 1000 – 9,999; 31.1% of the respondents were employed by small-medium companies that ranged from 100-999 employees; 22.9% of the respondents were employed by large scale industries with more than 10,000 employees; 8.8% of the respondents represented very small companies with less than 100 employees. In addition, the respondents indicated the region of United States their company was located. Respondents from the West Region lead with 27.2%, the Northeast Region with 25.8%, the Mideast Region with 24.3%, and the South Region with 22.9%.

Respondents were given a list of different types of food, and were asked to select the foods being processed in their company. The survey results indicated most processed foods were meat products (23.3%). A study conducted by Guenther, Jensen, Batres-
Marquez, and Chen (2005) concluded meat consumption in the United States was high, especially, in the area of processed meats. Since processed meats cost less than organic meats, lower income people preferred processed meats. These meats included beef, chicken, and turkey. The second highest food category indicated was flours and cereals (18.5%). This was followed by seafood (17%), fruits and vegetables (13.6%), dairy (12.6%), beverages (12.6%), and oils and fats (12.6%). Few respondents chose the other option (7.8%). The other option constituted dry fruits, glazes, packed foods, and lunches. Liquor industry respondents were the lowest (3.4%) when compared to the others.

There was no significant relationship \( (p > 0.05) \) between industry experience of the respondents with obstacles limiting them from using the non-thermal food processing technologies, main drivers for innovation, and upcoming non-thermal food processing technology within the organization. That meant the experience of the participants was not necessary to state either limitations of using non-thermal food processing technologies or drivers for innovation in the industry or upcoming non-thermal food processing technologies.
### Table 2

**Demographics of participants from the food processing industry.**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Description</th>
<th>(%)</th>
<th>Frequency</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Education</strong></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>High School</td>
<td>7.9%</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bachelor's Degree</td>
<td>42.4%</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Master's Degree</td>
<td>34.5%</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PhD</td>
<td>15%</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td><strong>Industry Experience</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-5 years</td>
<td>32.5%</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6-10 years</td>
<td>33.5%</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-20 years</td>
<td>26.6%</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over 20 years</td>
<td>7.4%</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td><strong>Company Size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Less than 100</td>
<td>8.8%</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100-999</td>
<td>31.1%</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000-9,999</td>
<td>37.4%</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More than 10,000</td>
<td>22.9%</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td><strong>Region in US</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Northeast</td>
<td>25.8%</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mideast</td>
<td>24.3%</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>22.9%</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>27.2%</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td><strong>Types of food</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fruits &amp; Vegetables</td>
<td>13.6%</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meat Products</td>
<td>23.3%</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seafood</td>
<td>17%</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dairy</td>
<td>12.6%</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Beverages</td>
<td>12.6%</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flours and Cereals</td>
<td>18.5%</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oils and Fat</td>
<td>12.6%</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liquor</td>
<td>3.4%</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>7.8%</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>
Non-thermal Food Processing Technologies Implemented in the Food Industry

The respondents were asked to select the non-thermal food processing technologies they had already implemented in their organization (Table 3). It was observed there was a mixed blend of responses. The response rate for high pressure and pulsed electric field technologies was observed to be higher when compared to the other technologies. The survey results indicated 35.6% of the respondents chose high pressure processing as their non-thermal food processing technology. A survey (N= 52) was conducted in North America by the food safety working group to understand the trend in novel food processing technologies. In that survey, it was found the respondents chose high pressure processing as the most widely used technology (80%) within their organizations (Jermann, Koutchma, Margas, Leadley, & Ros-Polski, 2015). In the current study, approximately thirty-six percent of the respondents preferred high pressure processing technology in their organization. There is a huge difference in response percentage for both the studies, due to the number of respondents and the geographical location of both studies were different.

Pulsed electric field (20.0%) was the second most widely used non-thermal technology. These were followed by pulsed light (13.2%) and irradiation (12.2%), respectively. The response rate observed for oscillating magnetic fields was 7.8%. However, the percentage of people not using any of the non-thermal technologies was higher at 8.3%. Oscillating magnetic field seemed to be receiving a good response rate due to a mixed response across various studies (Brennan & Grandison, 2012). The ultrasound technology (3.4%) and cold atmospheric plasma (2%) received lower responses. When consumers were asked about consuming processed food by novel
technologies, they opted to buy food that has been processed by cold atmospheric plasma (Cardello, Schutz, & Lesher, 2007).

Table 3

*Non-Thermal Food Processing Technologies (N= 205).*

<table>
<thead>
<tr>
<th>Description</th>
<th>(%)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Pressure Processing</td>
<td>35.6%</td>
<td>73</td>
</tr>
<tr>
<td>Pulsed Electric Field</td>
<td>20.0%</td>
<td>41</td>
</tr>
<tr>
<td>Pulsed Light</td>
<td>13.2%</td>
<td>27</td>
</tr>
<tr>
<td>Irradiation</td>
<td>12.2%</td>
<td>25</td>
</tr>
<tr>
<td>Ultra Sound</td>
<td>3.4%</td>
<td>7</td>
</tr>
<tr>
<td>Oscillating Magnetic Fields</td>
<td>7.8%</td>
<td>16</td>
</tr>
<tr>
<td>Cold Atmospheric Plasma</td>
<td>2.0%</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>2.0%</td>
<td>4</td>
</tr>
<tr>
<td>None</td>
<td>8.3%</td>
<td>17</td>
</tr>
</tbody>
</table>
A significant relationship \(\chi^2=164.37, p<0.001\) existed between the type of foods and non-thermal food processing technologies used to process these foods. In this relationship, it was observed the respondents who processed meat products used high pressure processing technology in their organization (15.1%). In a research study conducted recently by Hygreeva and Pandey (2016), it was observed when high pressure processing was applied on meat products to improve the quality and safety of the products, it proved to be an efficient strategy. However, when high pressure processing was paired with a multi-hurdle approach (use of natural antimicrobial and antioxidants) the best results were obtained.

Organizations who processed seafood preferred high pressure processing technology (Table 4). The relationship between seafood processing by high pressure technology was high (10.2%). A study that forecasted the global food market for 2014-2015 indicated, 5% of seafood processing was conducted by high pressure technology (Huang, Wu, Lu, Shyu, & Wang, 2017). As per the current study, the results seemed to be similar. Industries who process seafood chose high pressure as their technology. The respondents who selected flours and cereals processing as their industry type, chose high pressure as their processing technology (8.3%). Fruits and vegetable processing industries, also choose high pressure technology (5.4%).

Pulsed electric field processing (3.4%) was the preferred non-thermal food processing technology for the oils and fat companies. The same response rate (3.4%) was observed for meat processing industries. According to Knoor, Angerbach, Eshtiahgi, Heinz, and Lee (2001), the pulsed electric field processing technology was more dominant for liquid food purification and mass transfer operation. The survey results also
demonstrated the industries who processed beverages widely choose pulsed electric field technology for processing (4%). Respondents selected pulsed electric processing technology as their first choice for beverage processing. The respondents from the fruits and vegetable processing industry chose pulsed electric technology field as their second option (2.9%).

In this study, 3.4% of the respondents chose irradiation technology to process flours and cereals. A study conducted by Bhat, Wani, Hamdani, Gani, and Masoodi (2016) found gamma irradiation was used on whole wheat flour. The experiment determined gamma irradiation was useful for enhancing the physicochemical and functional properties. These properties are necessary in the preservation of bakery products. Thus, this supports the respondents’ selection of irradiation technology as their second-best option for flours and cereals in the current study. Respondents also chose irradiation as their second-best option for the processing of meat (3.9%). Respondents from the dairy industry considered pulsed light technology as their top innovative technology to process dairy foods (3.4%).
Table 3

**Relationship between types of food and various non-thermal food processing technologies (N=205).**

<table>
<thead>
<tr>
<th>Non-Thermal Food Processing Technologies</th>
<th>Fruits &amp; Vegetables</th>
<th>Meat Products</th>
<th>Sea Food</th>
<th>Dairy</th>
<th>Beverages</th>
<th>Flours &amp; Cereals</th>
<th>Oils &amp; Fat</th>
<th>Liquor</th>
<th>Others</th>
<th>Chi 2</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Pressure Processing</td>
<td>5.4 (11)</td>
<td>15.1 (31)</td>
<td>10.2 (21)</td>
<td>2.4 (5)</td>
<td>2.4 (5)</td>
<td>8.3 (17)</td>
<td>2.9 (6)</td>
<td>0.5 (1)</td>
<td>1.5 (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulsed Electric Field</td>
<td>2.9 (6)</td>
<td>3.4 (7)</td>
<td>2.4 (5)</td>
<td>1.5 (3)</td>
<td>4 (8)</td>
<td>2 (4)</td>
<td>3.4 (7)</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td>164.37</td>
<td>0.00***</td>
</tr>
<tr>
<td>Pulsed Light Irradiation</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td>0 (0)</td>
<td>3.4 (7)</td>
<td>3.4 (7)</td>
<td>1.5 (3)</td>
<td>2.9 (6)</td>
<td>2.4 (5)</td>
<td>2 (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra Sound</td>
<td>2.4 (5)</td>
<td>3.9 (8)</td>
<td>1.5 (3)</td>
<td>1.5 (3)</td>
<td>1 (2)</td>
<td>3.4 (7)</td>
<td>2.4 (5)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oscillating Magnetic Fields Cold</td>
<td>0.0 (0)</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td>1 (2)</td>
<td>2 (4)</td>
<td>0.5 (1)</td>
<td>0 (0)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold Atmospheric Plasma Others</td>
<td>0.5 (1)</td>
<td>0.0 (0)</td>
<td>0.5 (1)</td>
<td>0.0 (0)</td>
<td>0.5 (1)</td>
<td>0.0 (0)</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>2.4 (5)</td>
<td>1.5 (3)</td>
<td>0.5 (1)</td>
<td>2.9 (6)</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td>1 (2)</td>
<td>0.0 (0)</td>
<td>2.4 (5)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* = p < .05  
** = p < .01  
*** = p < .001
**Non-thermal Food Processing Technologies Under Development**

Table 5 represents the list of non-thermal food processing technologies under development in the food processing industries. Out of 206 respondents, 82 (39.8%) of them did not have any food processing technology under development. This could have been due to using current technology, or not using any non-thermal methods to process their foods. The most common technologies under development were oscillating magnetic fields (14.1%) and cold atmospheric plasma (14.1%). As per the current study, these two technologies were selected to be the most popular upcoming food processing technologies. Food processing industries in the United States are actively involved in developing technological innovations to process the foods faster and at a lower cost. There has been a huge support from machinery manufacturers to sell their product, while providing various options to the food processing industries to increase their sales. Also, consumer demands play a major role for the processing industries to implement new and innovative technologies (Fortuin & Omta, 2009).

Irradiation (12.1%) ranked third amongst the non-thermal methods selected by the respondents, and was followed by pulsed electric field (11.2%). In the food processing industry, pulsed electric field technology was a mild process for the removal of microorganisms (Timmermans, et al., 2014). This could be the primary reason why the food processing industry chose pulsed electric field technology as their preferred non-thermal food processing technology. Pulsed electric field technology provide minimal changes in food attributes while assuring optimum safety. The remaining technologies received limited response: high pressure processing (5.3%), ultrasound (4.4%), and pulsed light (2.9%). A few respondents listed technologies under
development other than those listed in the survey. This included ohmic heating (thermal food processing technology), mapped packaging, and e-beam (both are irradiation technology).

Table 4

*Non-thermal food processing technologies under experiment (N= 206).*

<table>
<thead>
<tr>
<th>Description</th>
<th>(%)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Pressure Processing</td>
<td>5.3%</td>
<td>11</td>
</tr>
<tr>
<td>Pulsed Electric Field</td>
<td>11.2%</td>
<td>23</td>
</tr>
<tr>
<td>Pulsed Light</td>
<td>2.9%</td>
<td>6</td>
</tr>
<tr>
<td>Irradiation</td>
<td>12.1%</td>
<td>25</td>
</tr>
<tr>
<td>Ultra Sound</td>
<td>4.4%</td>
<td>9</td>
</tr>
<tr>
<td>Oscillating Magnetic Fields</td>
<td>14.1%</td>
<td>29</td>
</tr>
<tr>
<td>Cold Atmospheric Plasma</td>
<td>14.1%</td>
<td>29</td>
</tr>
<tr>
<td>Other</td>
<td>2.9%</td>
<td>6</td>
</tr>
<tr>
<td>None</td>
<td>39.8%</td>
<td>82</td>
</tr>
</tbody>
</table>
Table 6 revealed the relationship between processing technologies implemented in food processing and the ones under development. A significant relationship ($x^2 = 105.29, p < .001$) was observed between the two. A total of 205 responses were collected for these two questions. Respondents who implemented, high pressure processing technology, but did not use any other technology under development were 11.7%. Even while analyzing Table 3, it was noticed a huge number of respondents had chosen high pressure processing technology for processing their food types (35.3%). The second highest votes were given to industries that had installed pulsed light (6.8%). Industries, which had pulsed light technology installed did not have any other food processing technology under development. The respondents’ choice for pulsed electric field technology (6.3%) was observed to be very close to pulsed light. However, the number of respondents who chose pulsed electric field as their food processing technology were higher than respondents who chose pulsed light (Table 3).

From Table 6, it can be inferred that the relationship between cold atmospheric plasma technology and high pressure processing technology was 7.8%. This indicated a few industries who implemented high pressure processing preferred cold atmospheric plasma as their technology for development. Initially, cold atmospheric plasma was used only for sensitive materials, but slowly with the developments in technology, it is now viewed as a novel technology. This technology is an eco-friendly process, which helps in the preservation of foods for longer periods of time (Thirumdas, Sarangapani, & Annapure, 2014).

The relationship between oscillating magnetic field and high pressure processing proved to be a strong one (6.8%). As per Table 3, 35.61% of the industries choose high
pressure processing, and 6.8% of those utilized oscillating magnetic in their research departments. Recently, oscillating magnetic fields has gained more attention from food scientists and manufacturers (Otero, Pérez-Mateos, Rodríguez, & Sanz, 2017). However, more research needs to be conducted to make a conclusive statement. On the other hand, high pressure processing has been a promising processing technology over the past two decades (Baptista, Rocha, Cunha, Saraiva, & Almeida, 2016). Therefore, food manufacturers are conducting experiments on oscillating magnetic fields to see if it could perform at the same or at a higher level than high pressure techniques.

Also, one can infer from Table 6, a few respondents who use high pressure and pulsed electric field as their processing technology, had irradiation as their developing technology (4.9%).
Table 5

*Relationship between currently and under development non-thermal food processing (N=205)*

<table>
<thead>
<tr>
<th>Implemented Non-Thermal Food Processing Technologies</th>
<th>HPP</th>
<th>PEF</th>
<th>PL</th>
<th>Irradiation</th>
<th>Ultra Sound</th>
<th>OMF</th>
<th>CAP</th>
<th>Others</th>
<th>None</th>
<th>Chi2</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td>% (N)</td>
<td>105.29</td>
<td>0.00 ***</td>
</tr>
<tr>
<td>HPP</td>
<td>1 (2)</td>
<td>1.5 (3)</td>
<td>1 (2)</td>
<td>1(2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEF</td>
<td>4.4 (9)</td>
<td>1 (2)</td>
<td>1 (2)</td>
<td>3.9 (8)</td>
<td>0.5 (1)</td>
<td>1(2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>PL</td>
<td>1 (2)</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0.5 (1)</td>
<td></td>
</tr>
<tr>
<td>Irradiation</td>
<td>4.9 (10)</td>
<td>4.9 (10)</td>
<td>1.4 (3)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1.5 (3)</td>
<td>0.5 (1)</td>
<td>0 (0)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra Sound</td>
<td>1 (2)</td>
<td>0.5 (1)</td>
<td>1 (2)</td>
<td>0.5 (1)</td>
<td>0 (0)</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OMF</td>
<td>6.8 (14)</td>
<td>3.9 (8)</td>
<td>1.5 (3)</td>
<td>1.5 (3)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAP</td>
<td>7.8 (16)</td>
<td>2.4 (5)</td>
<td>0.5 (1)</td>
<td>1.5 (3)</td>
<td>0 (0)</td>
<td>1.5 (3)</td>
<td>0.5 (1)</td>
<td>0 (0)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0.5 (1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1 (2)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>11.7 (24)</td>
<td>6.3 (13)</td>
<td>6.8 (14)</td>
<td>2.9(6)</td>
<td>2.4 (5)</td>
<td>3.4 (7)</td>
<td>1.5 (3)</td>
<td>1 (2)</td>
<td>5.9 (12)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* = p < .05  
** = p < .01  
*** = p < .001

***HPP (High Pressure Processing); PEF (Pulsed Electric Field); PL (Pulsed Light); OMF (Oscillating Magnetic Field); CAP (Cold Atmospheric Plasma).
Reasons for Using Non-Thermal Food Processing Technologies by Companies

Table 7 represents the list of reasons why respondents chose non-thermal food processing technologies. Better nutrient and sensory quality (71.14%) was the main reason for companies to use non-thermal food processing technologies. Companies implemented non-thermal food processing technologies in order to maintain the sensory qualities and nutrients of the foods. As the eating habits of the population is changing, people are becoming more susceptible to chronic diseases. This fact has motivated the food industry to develop technologies, which can help in preservation of food products, while maintaining the sensory and nutrient qualities (Morales-de la Peña, Welti-Chanes, & Martín-Belloso, 2016). Of the respondents, 39.30% believed enhancing products shelf life was the main driver for using non-thermal food processing technologies. The longer the product can last, without any change in its nutrients, the better it is (Li & Farid, 2016). Solution for safety problems (25.37%) was an important factor for food processing companies to choose their technology. Government/regulatory requirements (13.43%) and cost savings (13.43%) had equal responses. The results indicated companies prefer to have equipment that helped them in the area of cost savings. Since finance played a major role in the decisions made the companies, it becomes essential for organization to have equipment that contribute to energy savings. Convenience (11.94%) was also chosen by a few respondents.
Table 7

*Reasons for choosing non-thermal food processing technologies by companies (N= 201).*

<table>
<thead>
<tr>
<th>Description</th>
<th>(%)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution for safety problems</td>
<td>25.4%</td>
<td>51</td>
</tr>
<tr>
<td>Government/regulatory requirements</td>
<td>13.4%</td>
<td>27</td>
</tr>
<tr>
<td>Enhancing product's shelf life</td>
<td>39.3%</td>
<td>79</td>
</tr>
<tr>
<td>Better nutrient/sensory quality</td>
<td>71.1%</td>
<td>143</td>
</tr>
<tr>
<td>Price (cheaper equipment)</td>
<td>10.5%</td>
<td>21</td>
</tr>
<tr>
<td>Cost saving (energy, water)</td>
<td>13.4%</td>
<td>27</td>
</tr>
<tr>
<td>Convenience</td>
<td>11.9%</td>
<td>24</td>
</tr>
<tr>
<td>Collecting results for research</td>
<td>11.4%</td>
<td>23</td>
</tr>
<tr>
<td>Others</td>
<td>6.0%</td>
<td>12</td>
</tr>
</tbody>
</table>
A significant relationship ($\chi^2 = 110.87, p < .001$) existed between non-thermal food processing technologies that have been implemented in food industries, and reasons for choosing those technologies (Table 7). Respondents indicated better nutrient/sensory processing (30%) was the major reason for selecting high pressure processing technology. A study conducted by Hygreeva, and Pandey (2016) on high pressure processing for meat products concluded high pressure processing was an efficient strategy for developing healthier meat products. The results also indicated food processing industries choose high pressure processing technology for better nutrient and sensory qualities. In the current study, the other reason for choosing high pressure processing by respondents was enhancing products shelf life (17%) followed by solution for safety problems (12.5%).

Industries who chose pulsed electric field as their non-thermal food processing technology implemented technology primarily, to obtain better nutrient/sensory qualities (14%). This was followed by enhancement of products shelf life (9%). A few respondents chose pulsed electric field for its solution regarding safety problems (4%). Some respondents selected pulsed electric field as their non-thermal food processing technology to meet the government/regulatory requirement (3%). The respondents had a blend of all the reasons to choose pulsed elect field as their processing technology. Thus, pulsed electric field processing was considered a balanced and user friendly technology.

The respondents in this study who had implemented pulsed light processing selected better nutrient/sensory qualities (10%) as their reason. Hwang, Cheigh, and Chung (2015) conducted a research study to observe the efficiency of pulsed light on decontamination treatment for various liquids. The results proved the technology had
great potential to ensure microbial safety of transparent liquids. However, the researcher indicated pulsed light processing can lead to undesirable results, such as, deconstruction of nutrients and changes in sensory quality. Thus, it was observed the option chosen by respondents does not match this study. There were other respondents who mentioned they had implemented this technology for solution of safety problems (4%), followed by enhancement of its shelf life (3.5%), and cost savings (2.5%).

Industries who had implemented irradiation as their food processing technology choose this technology primarily for better nutrients/sensory quality (8.5%). The next reasons were extension of shelf life (5.5%) and government/regulatory approvals (3.5%). It was noticed other reason given for the use of irradiation included, price (3%), cost savings (3%), and solution for safety reasons (3%).

Industries implementing oscillating magnetic fields preferred technology for better sensory/nutrient quality (5.5%). The next reasons included enhancement of shelf life (3.5%) and research results (2.5%). Since oscillating magnetic field is still under development (Table 5), this could be a reason for the respondents to select research results as their option.
**Table 8**

*Relationship between non-thermal food processing technologies used within industries and reasons for choosing them (N=200).*

<table>
<thead>
<tr>
<th>Implemented Food Processing Technologies</th>
<th>Solu. for Safety Prob. % (N)</th>
<th>Govt./Regu. Req. % (N)</th>
<th>Enhancing Prod. Shelf Life % (N)</th>
<th>Better Nutr./Sen. qual. % (N)</th>
<th>Better Price (cheap. equip.) % (N)</th>
<th>Better Conv. % (N)</th>
<th>Better Coll. results for res. % (N)</th>
<th>Others % (N)</th>
<th>Chi 2</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPP</td>
<td>12.5 (25)</td>
<td>5.0 (10)</td>
<td>17.0 (34)</td>
<td>30.0 (60)</td>
<td>0.5 (1)</td>
<td>1.5 (3)</td>
<td>4 (8)</td>
<td>4.5 (9)</td>
<td>0.5 (1)</td>
<td>110.87</td>
</tr>
<tr>
<td>PEF</td>
<td>4.0 (8)</td>
<td>3.0 (6)</td>
<td>9.0 (18)</td>
<td>14.0 (28)</td>
<td>2.0 (4)</td>
<td>2.5 (5)</td>
<td>3.5 (7)</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td>*</td>
</tr>
<tr>
<td>PL</td>
<td>4.0 (8)</td>
<td>1.5 (3)</td>
<td>3.5 (7)</td>
<td>10.0 (20)</td>
<td>2.0 (4)</td>
<td>2.5 (5)</td>
<td>1.0 (2)</td>
<td>1.5 (3)</td>
<td>0.5 (1)</td>
<td></td>
</tr>
<tr>
<td>Irradiation</td>
<td>3.0 (6)</td>
<td>3.5 (7)</td>
<td>5.5 (11)</td>
<td>8.5 (17)</td>
<td>3.0 (6)</td>
<td>3 (6)</td>
<td>1.0 (2)</td>
<td>1.0 (2)</td>
<td>0.5 (1)</td>
<td></td>
</tr>
<tr>
<td>Ultra Sound</td>
<td>0.5 (1)</td>
<td>0.0 (0)</td>
<td>1.5 (3)</td>
<td>1.5 (3)</td>
<td>0.5 (1)</td>
<td>1.5 (3)</td>
<td>0.5 (1)</td>
<td>0.0 (0)</td>
<td>0.5 (1)</td>
<td></td>
</tr>
<tr>
<td>OMF</td>
<td>1.5 (3)</td>
<td>1.0 (2)</td>
<td>3.5 (7)</td>
<td>5.5 (11)</td>
<td>1.5 (3)</td>
<td>1.5 (3)</td>
<td>1.0 (2)</td>
<td>2.5 (5)</td>
<td>0.0 (0)</td>
<td></td>
</tr>
<tr>
<td>CAP</td>
<td>0.5(1)</td>
<td>0.5(1)</td>
<td>0.0(0)</td>
<td>1.5 (3)</td>
<td>0.5 (1)</td>
<td>0.0 (0)</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td>0.5 (1)</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>0.5 (1)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>0.5 (1)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>1.5 (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1.0 (2)</td>
<td>1.0 (2)</td>
<td>1.0 (2)</td>
<td>2.0 (4)</td>
<td>0.5 (1)</td>
<td>1.5 (3)</td>
<td>0.5 (1)</td>
<td>1.0 (2)</td>
<td>2.5 (5)</td>
<td></td>
</tr>
</tbody>
</table>

* = p < .05  
** = p < .01  
*** = p < .001  

*** HPP (High Pressure Processing); PEF (Pulsed Electric Field); PL (Pulsed Light); OMF (Oscillating Magnetic Field); CAP (Cold Atmospheric Plasma).
Main Drivers for Innovation in Non-Thermal Food Processing Technologies

Respondents were asked about the main drivers for innovation in the non-thermal food processing technologies (Figure 10). Approximately 44% of the respondents chose equipment manufacturers, while 42.3% selected government research as their main reason for innovation. Academic research (33.3%) and large scale food manufacturers (33.3%) were on the same level. The lowest response given was medium scale food manufacturers (9%).

Knoerzer (2016) had conducted a study on non-thermal food processing technologies according to that innovation was the key for sustained growth of the food industry. This innovation can be achieved through process intensification, which eventually can lead to reduction in energy costs. Equipment manufacturers all over the world provide multiple innovative solutions for non-thermal food processing technologies.

Advances in technology occur when there is enough research pertaining to the topic by experts and substantial experiments have been performed (Larédo & Mustar, 2005). In our study, 75% of the respondents stated research, either academic or government, was the driving force for innovation rather than the trial and error method.
**Figure 10.** Main drivers for innovation in non-thermal food processing technologies.
A significant relationship ($\chi^2 = 63.14, p < .01$) existed between developing technologies, and the drivers for innovation of these technologies (Table 9). Companies using oscillating magnetic field as their developing technology, selected academic research (7.5%) as the reason for innovation in their non-thermal food processing industry. Academic research plays a major role in the development of technologies. The common methods for research evaluation is assistance on collaboration of bibliometric literature techniques. This helps in attaining a structural database, which can lead one to hidden knowledge (Lin, 2016). Equipment manufacturers (7%) were the next most common reason for the development of oscillating magnetic fields. The respondents indicated, industries who manufactured the equipment played a major role in the development of the technologies. Their companies are the makers of the machines used to process the food. Government research (6.5%) received a high rate of responses from the respondents. It can be concluded that government research does lead to innovation. One reason could be the government researchers following the regulations designed the regulations.

Respondents who selected cold atmospherics plasma as their upcoming technology believed government research (7.5%) leads to the innovation of non-thermal food processing technologies. Another factor included equipment manufacturers (7%). The companies who selected irradiation as their developing technology believed equipment manufacturers (5.5%), large scale food manufacturers (5.5%) and government researchers (5.5%) drive the innovation of these new technologies.

Companies who did not have any technology under development believed equipment manufacturers (16%) and government researchers (16%) lead the innovation,
followed by academic research (13%) and large scale food manufacturers (10%). A few respondents who did not have any technology under development selected the others option (8.5%). Respondents believed research, funded either from the companies or government, played a vital role in innovation. There was a study conducted by Esbjerg, Burt, Pearse, Glanz-Chanos (2016) on innovation in the food sector. The study found innovation suppliers and retailers played a major role regarding innovation in the food industry. Additionally, it is essential to communicate within the industry to understand the demands. This means the teams must communicate internally and externally, to understand what needs to be developed and how to make the most resources available to meet consumer’s demands.
Table 9

*Relationship between non-thermal food processing technologies under experiment and the reason for their innovation (N=201).*

<table>
<thead>
<tr>
<th>Food Processing Technologies that are under Experiment</th>
<th>Equ. Manu. % (N)</th>
<th>Large Scale Food Manu. % (N)</th>
<th>Medium Scale Food Manu. % (N)</th>
<th>Acad. Resh. % (N)</th>
<th>Govt. Resh. % (N)</th>
<th>Others % (N)</th>
<th>Chi 2</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPP</td>
<td>3.5 (7)</td>
<td>3 (6)</td>
<td>1 (2)</td>
<td>2 (4)</td>
<td>2.5 (5)</td>
<td>0 (0)</td>
<td>63.14</td>
<td>0.01**</td>
</tr>
<tr>
<td>PEF</td>
<td>4.5 (9)</td>
<td>4.0 (8)</td>
<td>0.5 (1)</td>
<td>5.0 (10)</td>
<td>4.5 (9)</td>
<td>1.5 (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PL</td>
<td>1.5 (3)</td>
<td>2.0 (4)</td>
<td>1.5 (3)</td>
<td>0.0 (0)</td>
<td>1.0 (2)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irradiation</td>
<td>5.5 (11)</td>
<td>5.5 (11)</td>
<td>1.0 (2)</td>
<td>4.0 (8)</td>
<td>5.5 (11)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra Sound</td>
<td>2.0 (4)</td>
<td>2.0 (4)</td>
<td>0.0 (0)</td>
<td>1.0 (2)</td>
<td>2.5 (5)</td>
<td>0.0 (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OMF</td>
<td>7.0 (14)</td>
<td>5.5 (11)</td>
<td>3.0 (6)</td>
<td>7.5 (15)</td>
<td>6.5 (13)</td>
<td>0.0 (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAP</td>
<td>6.5 (13)</td>
<td>2.5 (5)</td>
<td>2.0 (4)</td>
<td>4.0 (8)</td>
<td>7.5 (15)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>0.0 (0)</td>
<td>1.5 (3)</td>
<td>0.0 (0)</td>
<td>1.0 (2)</td>
<td>0.0 (0)</td>
<td>0.5 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>16.0 (32)</td>
<td>10.0 (20)</td>
<td>0.5 (1)</td>
<td>13.0 (26)</td>
<td>16.0 (32)</td>
<td>8.5 (17)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* = p < .05  
** = p < .01  
*** = p < .001

***HPP (High Pressure Processing); PEF (Pulsed Electric Field); PL (Pulsed Light); OMF (Oscillating Magnetic Field); CAP (Cold Atmospheric Plasma)
A significant relationship ($\chi^2 = 26.04, p < .05$) existed when company size and main drivers for non-thermal food processing were compared (Table 10). The results of the current study indicated, 20.4% of the participants from the large-scale industries with employees ranging from 1000-9,999 believed equipment manufacturers played a vital role in the development of new non-thermal food processing technologies. Kanovsaka and Tomaskova (2015) conducted a study on the trends in customer service and mentioned, equipment manufacturers usually are under pressure to produce the best and latest technology in their equipment to survive in the business. There is a constant implementation and change of strategies to provide the best end product.

Sixteen percent of the participants from medium scale industries with employees ranging from 100-999 believed government research played a vital role in the innovation of non-thermal food processing technologies. In general, research helped to find the pros and cons of any technology being developed. Companies try to uncover the needs of their clients on the basis of detailed and varied research (Wallsten, 2000). Respondents from this industry sector believed large scale food manufacturers (13.93%) and equipment manufacturers (11.5%) lead the way for innovation.

Respondents from the enterprise level industries where the employee strength is > 10,000, had a mixed response. They believed all the options, at some point were important for innovation. Equipment manufacturers (10.5%) and government research (10%) were the top reasons selected. These were followed by large scale food manufactures (8.5%) and academic research (7%).
Table 10

*Relationship between company size and main drivers for non-thermal food processing technologies (N= 201).*

<table>
<thead>
<tr>
<th>Total Number of Employees</th>
<th>Main Drivers for Innovation of Non-Thermal Food Processing Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 100</td>
<td>1.5 (3)</td>
</tr>
<tr>
<td>100-999</td>
<td>11.5 (23)</td>
</tr>
<tr>
<td>1000-9,999</td>
<td>20.4 (41)</td>
</tr>
<tr>
<td>&gt;10,000</td>
<td>10.5 (21)</td>
</tr>
</tbody>
</table>

* = p < .05  
** = p < .01  
*** = p < .001
Factors that Limits Companies from Using Non-Thermal Food Processing Technologies

Participants were asked about the obstacles preventing them from using non-thermal food processing technologies in their organizations. Of the respondents, 41.6% mentioned high investment as the largest factor for not using non-thermal food processing technology. The next limitation observed in this study was technology being under development (35.6%). A few respondents indicated a lack of quality equipment (31.7%) in the food processing industry restricted them from using it. Lack of scientific information (21.3%) regarding technologies was considered to be an obstacle for implementing non-thermal food processing technologies. Lack of funding (13.9%) and increased product price (14.9%) were also considered as barriers in the implementation of these technologies. Lack of training (5%) and absence of government/regulatory approvals (3%) were the least perceived barriers.

The results in Figure 11, the major reasons chosen by respondents were high investment, lack of quality equipment, and technology not being available. Lee, Lusk Mirosa, & Oey, (2015) conducted a study in China comparing high pressure processing and pulsed electric field processing techniques to thermal processing. These results were shared with consumers in order to understand their perceptions. Foods processed through non-thermal technologies cost more when compared to thermal technologies. This was the reason why more than half of the consumers did not choose non-thermal food processing technologies. However, once, they were educated on how the technologies worked, participants were willing to pay the cost for non-thermal processed foods. This
research contributed to the current study with regards to understanding the impact consumer education has on the use of non-thermal technologies.

In another study conducted in the United States, the importance of having quality equipment for manufacturing was discussed. According to O'Connor, Yu, and Lee (2016), it is essential to have high quality equipment, and quality management throughout the organization, in order for an industry to prosper.

Figure 11. Factors that limit companies from using non-thermal food technologies.
Conclusion and Future Recommendations

The results of this study, on innovative, non-thermal food processing technologies, has helped to understand the usage of non-thermal food processing technologies within the United States. The survey was sent to 5,000 employees in 421 food processing companies of that 223 respondents data were collected. The data provided answers to the research questions raised at the beginning of this study. The research questions and the conclusions of this study were:

- Which non-thermal food processing technologies were being used within the organizations?
  - There was a total of 205 respondents for this category and the 35.6% of them chose high pressure processing as the most widely used technology within their company. The next most widely used technology was pulsed electric field (20%). The least used technologies were ultrasound (7%) and cold atmospheric plasma (4%).

- Which non-thermal food processing technologies were under research and development within the organization?
  - Though research and development was an integral part of product based companies; 39.8% of respondents mentioned, they did not have any technologies under development as of now nor projected for the next 5 years. The remaining participants stated oscillating magnetic fields and cold atmospheric plasma were the most developing technologies. Also, the technologies used the least were ultra sound (9%) and pulsed light (6%).
• What leads a particular organization to choose the technology, which is currently being run by them?
  o Of the 201 participants, 71.1% of them mentioned the reason for them to choose non-thermal food processing technology was better nutrient and sensory properties of the product. The next most common reason chosen by the participants was enhancement of shelf life for the product (39.3%). A few respondents mentioned they used non-thermal food processing technologies for decontamination, food safety, and fast processing ability.

• What limited the organization from not using the other technologies?
  o Respondents had a mixed reaction to the barriers they faced in choosing the technology. Of the respondents, 41.6% of them believed non-thermal food processing technologies were a high investment; whereas, 35.7% believed the technology they are looking for is still under development, and 31.7% believed there is lack of quality equipment. Only 6% of the respondents believed absence of government or regulatory approvals restricted them from using non-thermal food processing technologies.

• What drives innovation of new non-thermal food processing technology in the United States?
  o The participants’ responses were almost equally spilt among all the options provided to them. Equipment manufacturers (43.8%) and government research (42.3%) were considered the major reasons and very close to them were academic research (33.3%) and large scale food manufactures (33.3%).
The responses collected had a good blend of various regions in the United States, and 92.1% of the participants had a bachelor’s degree or higher. The representation of the company size was also diverse. There were respondents from small scale, medium scale, large scale, and enterprise level. Therefore, it can be concluded, the responses collected were diverse and researcher collaborated variable data. This put together has given the cause and effects for actual implementation of non-thermal food processing technologies on industrial scale.

Future Recommendations

The current study dealt with the usage of non-thermal food processing technologies within the United States. The following are topics to be considered for future research studies:

- What impact do non-thermal food processing technologies have on the environment?
- Combination of novel thermal and non-thermal food processing technologies usage within the United States?
References


James, C., Reitz, B., & James, S. (2014). The freezing characteristics of garlic bulbs (Allium sativum L.) frozen conventionally or with the assistance of an oscillating weak magnetic field. *Food and Bioprocess Technology, 8*(3), 702-708.


thermal processing of cloudy apple juice. *Food Science and Technology, 75*, 85-92.


Appendix A

DATE: September 19, 2016

TO: Harlin Saroya, Masters
FROM: Western Kentucky University (WKU) IRB

PROJECT TITLE: [961026-1] Non-Thermal Food Processing Technologies
REFERENCE #: IRB 17-088
SUBMISSION TYPE: New Project

ACTION: APPROVED
APPROVAL DATE: September 19, 2016

REVIEW TYPE: Exempt from Full Board Review

Thank you for your submission of New Project materials for this project. The Western Kentucky University (WKU) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Exempt from Full Board Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by an implied consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

This project has been determined to be a Minimal Risk project.

Please note that all research records must be retained for a minimum of three years after the completion of the project.

If you have any questions, please contact Paul Mooney at (270) 745-2129 or irb@wkue.edu. Please include your project title and reference number in all correspondence with this committee.
Appendix B

INFORMED CONSENT DOCUMENT

Project Title: Innovative Food Processing Technology Methods Used by the Industry
Investigator: Harlin Kaur Saroya. Graduate Student of Architectural Manufacturing Sciences
Department at WKU. Phone: 859-916-3015. Email: harlinkaur.saroya764@topper.wku.edu

You are being asked to participate in a project conducted through Western Kentucky University.
The University requires that you give your agreement to participate in this project.

You must be 18 years old or older to participate in this research study.

The investigator will explain to you in detail the purpose of the project, the procedures to be
used, and the potential benefits and possible risks of participation. You may ask any questions
you have to help you understand the project. A basic explanation of the project is written below.
Please read this explanation and discuss with the researcher any questions you may have. You
should keep a copy of this form for your records.

1. Nature and Purpose of the Project: I am conducting a survey on food manufacturer’s
knowledge, perception and attitude towards the non-thermal food processing technologies in The
United States of America.

2. Explanation of Procedures: This research will be carried out in a survey format. This
survey will consist of few questions pertaining to non-thermal food processing techniques.
Please answer the questions to the best of your knowledge, it will only require a few minutes of
your time.

3. Discomfort and Risks: There are no known risks associated with this study. All your
responses will be confidential and, no harm will result upon your participation.

4. Benefits: As a reward of your participation, at the end of the survey, you may enter your
email address for a chance to win a $60 amazon gift card. Your participation may be used to
encourage further research on the subject matter.

5. Confidentiality: All data obtained from the subject matter, will be kept confidential and
will only be reported in an aggregate format.

6. Refusal/Withdrawal: Refusal to participate in this study will have no effect on any
future services you may be entitled to from the University. Anyone who agrees to participate in
this study is free to withdraw from the study at any time with no penalty.

You understand also that it is not possible to identify all potential risks in an experimental
procedure, and you believe that reasonable safeguards have been taken to minimize both the
known and potential but unknown risks.

Your continued cooperation with the following research implies your consent.

THE DATED APPROVAL ON THIS CONSENT FORM INDICATES THAT
THIS PROJECT HAS BEEN REVIEWED AND APPROVED BY
THE WESTERN KENTUCKY UNIVERSITY INSTITUTIONAL REVIEW BOARD
Paul Mooney, Human Protections Administrator
TELEPHONE: (270) 745-2129
Hello Food Industry Employee!

My name is Harlin Kaur Saroya. I am a student at Western Kentucky University. I am conducting a survey on food processing technologies in The United States of America.

Would you like to participate in this anonymous survey, it will only require a few minutes of your time?

As a reward for your participation, you may give consent to have your name be entered into a $60 lottery gift card that can be used on Amazon.com at the end of the survey.

Your participation in this survey is strictly confidential and you are free to withdraw yourself from the survey at any time with no penalty.

Please be advised, only individuals 18 years or older may participate in this survey. Are you at least 18 years old?

Please click here - XXXXXXXXXXXXXXX
Appendix D

Q1 Which of the following food manufacturing and processing sectors does your organization fall under? (Check all that apply)

☐ Fruits & Vegetables
☐ Meat Products
☐ Seafood
☐ Dairy
☐ Beverages
☐ Flours and Cereals
☐ Oils and Fat
☐ Liquor
☐ Others, please specify: ____________________

Q2 Which non-thermal food processing technology has been implemented in your organization? (Check all that apply)

☐ High Pressure Processing
☐ Pulsed Electric Field
☐ Pulsed Light
☐ Irradiation
☐ Ultra Sound
☐ Oscillating Magnetic Fields
☐ Cold Atmospheric Plasma
☐ Other, if other please specify. ____________________
☐ None

Q3 Which non-thermal food processing technology is under experiment and would be used in the coming 5 years in your organization? (Check all that apply)

☐ High Pressure Processing
☐ Pulsed Electric Field
☐ Pulsed Light
☐ Irradiation
☐ Ultra Sound
☐ Oscillating Magnetic Fields
☐ Cold Atmospheric Plasma
☐ Other, please specify ____________________
☐ None
Q4 What is the major reason behind using the non-thermal food processing technology in your organization? (Check all that apply)
☐ Solution for safety problems
☐ Government/regulatory requirements
☐ Enhancing product’s shelf life
☐ Better nutrient/sensory quality
☐ Price (cheaper equipment)
☐ Cost saving (energy, water)
☐ Convenience
☐ Collecting results for research
☐ Others, please specify ____________________

Q5 What factors limited or prevented your organization from using non-thermal food processing technologies? (check all that apply)
☐ High investment
☐ Increase in product price
☐ Absence of government/regulatory approvals
☐ Lack of funding
☐ Lack of sufficient scientific information
☐ Technology is still under development
☐ Lack of training
☐ Lack of quality equipment
☐ Others, please specify ____________________

Q6 Who are the main drivers for innovation of non-thermal food processing technologies in the United States?
☐ Equipment Manufacturers
☐ Large scale food manufacturers
☐ Medium scale food manufacturers
☐ Academic research
☐ Government research
☐ Others, please specify ____________________

Q7 How many years have you been working in the food processing industry?
☐ 0-5 years
☐ 6-10 years
☐ 10-20 years
☐ Over 20 years
Q8 What is your highest level of your education?
- High School
- Bachelor's Degree
- Master’s Degree
- PhD

Q9 Which region in the United States are you located in?
- Northeast
- Mideast
- South
- West

Q10 How many employees are working in your organization?
- less than 100
- 100-999
- 1000-9,999
- More than 10,000