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UWP 104E
September 3, 2021
Word Count: 2739

An Overview of the Freezing and Preserving of Foods

Introduction

Now more than ever, the freezing and preserving of food is one of the most important processes in the food industry. The number of fast food restaurants has increased, with food being prepared and frozen by their suppliers, and consumer-bought frozen food consumption has spiked in recent years; with 59% of Americans in 2021 stating that they eat frozen foods often or nearly all the time for dinner (Gelski, 2021). Although methods for keeping food below freezing temperatures have been around since the invention of the refrigerator in 1834, relatively new practices have begun to emerge in the freezing of foods (Sandvik, 2021). A main method used in industry is the use of a cryogenic freezer, which utilizes liquid nitrogen at an operating temperature of -80˚C (Fennema, 1978). This freezer allows for industry efficiency, with low production and liquid nitrogen costs, and a timely production speed. Furthermore, levels of moisture in the food can be adjusted, maintaining or improving the initial quality and texture of the food after it is frozen (Huan, 2003).

Today, there are still pressing issues associated with freezing and added preservatives in food production. Some chemicals produced in the freezing process have been linked to a multitude of diseases and added preservatives have been found to disrupt the original quality of the food.

This review discusses different freezing methods with respect to food quality and cost efficiency, examines the effects of chemicals and added preservatives in frozen foods affecting shelf life and health risks, and compares frozen foods with their largest competitor.

Current Freezing Methods

Cryogenic Freezing

The most widely used method of freezing in industry is cryogenic freezing. A cryogenic freezer works by immersing or spraying food with liquid nitrogen (LN_2). This method became popular in the early 1960s and is currently used for the freezing of individual products, ranging from frozen peas to McDonald's beef patties (Peterson, 2016). Cryogenic freezing, also referred to as "flash freezing", is a top choice among manufacturing companies in that it is cost and time efficient, while maintaining the original quality of the food undergoing nucleation (Hidas, 2020). A study analyzed the effects of cryogenic freezing on tiger shrimp and found that the temperature of the LN_2 had no relationship with the level of moisture lost in the freezing process, but did have an effect on the time needed for the shrimp to reach the desired freezing temperature of -18˚C (Boonsumrej, 2007). With this freezing method, manufacturers can optimize their production by finding a cost-to-time efficiency equilibrium (Pham, 2014). Since cryogenic freezing allows for preserving the quality of food, it has begun to be applied to eggs which are one of the most common breakfast foods; with the average American consuming 279 eggs per year (Petreycik, 2019). Eggs typically stay fresh in a refrigerator for 3-5 weeks but cryogenic freezing can allow for liquid egg whites to be stored for up to 120 days without spoilage and liquid whole eggs to be stored for 90 days (Hidas, 2020).

Air-blast Freezing

Air-blast freezing, or air impingement freezing, is the second most popular industrial freezing method (Peterson, 2016). This method functions by coating food in water and blowing cold high-velocity air at the food through cylindrical tubes (Sarkar, 2004). Air-blast freezers also use N_2 as a coolant but keep its temperature well above the boiling point at around -35˚C. This method is most effective in freezing a mixture of foods together, such as a TV dinner, and is not part of the manufacturing line. Air-blast freezing usually has a high intake volume which allows for large quantities, or in some cases pallets of food, to be frozen simultaneously. The study mentioned above examined the relationships between air velocity, time to freeze, and quality of the food. The results found that freezing time had a direct relationship to air velocity, but percent freezing loss and air velocity were inversely proportional (Boonsumrej, 2007). For manufacturers, air-blast chambers can also be used to bake, roast, and toast foods by supplementing sub-zero N_2 with heated nitrogen-oxygen hybridized air. This multifunctional chamber could help industry reduce floor space and complement a wide variety of foods (Sarkar, 2004).

Other methods

There are several other methods of freezing that are also used in industry such as freeze drying and plate freezing. Freeze drying, first utilized during WWII, is a method of freezing in which most of the water and other solvents in the food are removed in low-temperature vacuum-sealed chambers (Hilgedick, 2020). Freeze dried foods are popular among outdoor enthusiasts and restaurant suppliers due to the freezing method's ability to extend shelf life and reduce weight for transport (Mathews, 2011).

Plate freezing is a form of freezing used to reduce packaging costs and storage space. This method uses two metal plates at sub-freezing temperatures to press the food into a brick-shaped formation, alleviating the majority of air pockets that were initially present (Peterson, 2016). Plate freezing is used for flat products such as pastries, fish fillets, and vegetables such as asparagus and spinach (Singh, 2018).

New and upcoming methods

In addition to the existing methods of freezing in industry, there are two technologies that are rising in the field; electro-freezing (EF) and ultrasound-assisted freezing (UAF). EF is a fairly recent technology that was first tested in 2018. EF uses DC or AC current, where two electrodes can be in contact with the sample (FA-CF) or not in contact with the sample (FA-EF). FA-CF uses a pulsed high DC voltage between narrowly spaced electrodes that are in contact with the sample, causing nucleation (Fallah-Joshaqani, 2021). This method causes the formation of polynuclear complexes similar to those found in ice. The other method of EF, FA-EF, uses both static and alternating electric fields not in contact with the sample. A method of FA-EF that has been studied on food is static electric fields (SEF). Research has shown that SEF can produce small ice sized crystals that preserve the quality of the tested foods; reducing protein denaturation and cell damage (Jha, 2018). Similar to SEF, alternating electric fields (AEF) also produced good results, with ice crystal size having an inverse relationship to the strength of the AEF.

Another new technology being tested in this field is UAF, which induces nucleation and promotes ice crystal growth through ultrasonic waves. This method has shown promising potential by allowing for the rapid freezing of foods within an ultrasonic bath. The frequency and wattage of the ultrasound bath can be altered based on the size and type of food to optimize freezing time. Studies have found that UAF is able to decrease the size of ice crystals formed in the freezing process of fruits and vegetables, causing less damage to cellular and tissue structures (Fu, 2020). UAF can also be coupled with liquid carbon-dioxide (LCO_2) infusion to reduce the freezing time further. Ultrasound-assisted immersion (UIF), another branch within UAF, is used for meat products. UIF combines cryogenic freezing and UAF to promote nucleation and has shown to extend the storage life of meat products with no loss in quality (Wu, 2021). Overall, UAF allowed for better texture preservation than slow freezing methods. Although UAF and EF have proven effective in the lab, more research must be done before ramping up to industrial scale.

Chemicals and added preservatives

Advanced glycation end-products

Advanced glycation end-products (AGEs) are proteins or lipids commonly found in frozen meats that when exposed to sugar, undergo glycation and can be harmful when consumed. Studies have found that AGEs are linked to diabetes, kidney disease and cardiovascular disease (Singh, 2001). Additionally, for individuals already diagnosed with diabetes and renal failure, AGEs can worsen conditions and cause tissue injury (Goldin, 2006). Two common AGEs existing in raw frozen pork, N-carboxymethyl lysine and N-carboxyethyl lysine, have been found to decrease in the first 30 days in storage at -18˚C, but increase from days 30-90. After 90 days, the AGE levels are higher than they were when the pork was first processed, which can lead to many health problems (Yu, 2021). Freeze-thaw cycles also increase the growth rate of AGEs and significantly decrease the shelf life of the frozen meat (Wu, 2021).

Ice nucleating proteins

Ice nucleating proteins (INPs) allow gram-negative bacteria to promote the growth of small ice crystals (Roeters et al., 2021). Ice crystals with small radii allow the food to retain a larger amount of its initial moisture and increase its shelf life (Schwidetzky, 2021). INPs can be applied during the freezing process or be included in the food packaging of the frozen food. A commonly used INP, erwinia herbicola (e. herbicola), when tested on surimi allowed the fish to reach a better gelling capacity and maintain its original texture after freezing. When applied to the packaging of frozen dough, the results showed that bread crumbs hardening was alleviated by 50% due to retention of moisture (Tian, 2020). The addition of INPs also allows for these foods to undergo multiple freeze-thaw cycles before they lose quality. Although some INPs may cause harm if consumed, the commonly used e. herbicola strain has not been linked to any health risks. To date, the implementation of INPs are not widely used and have not been proven effective on the industrial scale (Tian, 2020).

Essential oils

The addition of essential oils (EOs) to frozen vegetables has gained popularity in recent years. EOs have antimicrobial and antioxidant properties which help to reduce spoilage and improve bodily functions such as digestion, headache relief, and skin conditions (West, 2019). Frozen green peppers, for example, accumulate two main bacterial strains, L. monocytogenes and L. grayi. These bacteria strains are linked to the spoilage of food which can significantly impair one's health (Tao, 2021). When green peppers are impregnated with EOs, research has shown that cinnamon EOs were able to interrupt the growth of L. grayi and oregano EOs were able to inhibit growth of L. monocytogenes (Tao, 2021). For meats and seafood, the addition of marjoram and zataria EOs were able to significantly decrease the growth of psychrotrophic and pseudomonas bacteria (Pourmollaei, 2021). These additions of EOs in frozen foods have proven to mitigate bacterial growth and increase the shelf life of the product.

Sugar & carboxylic acid

For centuries, sugar has been used to reduce the spoilage of frozen meats. However, sugar has been linked to many chronic diseases such as diabetes, cardiovascular disease, and obesity (Rippe, 2016). With low-calorie diets gaining popularity and complaints of food taste distortion due to copious amounts of added sugar, replacement preservatives have begun to emerge. Carboxylic acid is an organic acid commonly found in fruits, which has potential to enhance chemical-bioactive properties and increase the shelf life of food. (Marques, 2020). When carboxylic acid was used in place of sugar on walleye pollack surimi, the fish was able to stay in storage for nearly twice as long than with sugar (Sato, 2021). Not only did the shelf life and taste of the surimi improve, but this additive has no harmful side effects and was able to reduce the caloric makeup of the fish.

Direction of future research in the freezing and preserving of foods

Freezing methods

The current freezing methods used in industry today have over 50 years of research behind them but there are still areas for further studies to be done. Both cryogenic and air-blast freezing use N_2 as a coolant which is a harmless chemical that instantly evaporates after the freezing process. However, with air-blast freezing, improvements can be made to the timeliness and quality of preservation. Air blast freezing uses N_2 in its gaseous form and the warmer temperature in comparison to cryogenic freezing leads to a lower freezing rate. Another issue with air-blast freezing is that its slow freezing process causes the quality of the food to lose moisture and form new bonds, altering the texture of the food (Boonsumrej, 2007). For example, tofu generated protein-protein interactions instead of water-protein interactions in the air-blast freezing process, which caused the soybean curds to become harder after the thawing stage (Ali, 2021). To improve the quality of foods frozen through air-blast systems, future research should focus on optimizing the timeliness of the freezing process.

Freeze drying and plate freezing have a smaller scope of application and also have 50 years of research perfecting these methods. However, EF and UAF are new and upcoming technologies that have shown high potential (Jha, 2018; Fu, 2020). Their application has been proven on the lab-scale with both methods reducing protein denaturation and cell damage by inducing small ice crystals and UAF increasing the freezing rate of fruits, vegetables, and meats. Future research on these two technologies should focus on scaling up from lab settings to industry.

Chemicals and added preservatives

Increasing the shelf life of foods without additional health risks is one of the most important aspects of the food freezing industry. Although some chemicals produced in the freezing process such as AGEs are inevitable, there are new methods, such as the addition of essential oils, that have proven to increase shelf life and mitigate bacterial growth (Yu, 2021; Tao, 2021). However, more research must be done on INPs and alternatives to sugar before these practices can be used in industry. INPs have shown promising potential with their ability to increase food quality and allow for foods to undergo multiple freeze-thaw cycles. Only a few INP bacteria have been tested and these results have only been proven on a small scale (Tian, 2020). Therefore, research should be directed in finding more strains of bacteria and applying those findings to the industrial scale. Likewise, carboxylic acid is an effective substitute for sugar but findings have only been proven experimentally and with a limited scope of foods (Sato, 2021).

Is canned food a better alternative to frozen food?

The main reason that food is frozen is to maintain the initial quality and texture of the food, while allowing for long term storage which is typically 2-4 months in below 0˚C storage (ASPA, 2021). The largest competitor to frozen foods would be canned foods, as they can last up to two years at room temperature (Gravely, 2017). However, there are many limitations associated with canned foods, in that they cannot contain a variety of foods, such as TV dinners, and the initial texture of the food is lost due to the addition of brine solutions (Lemon, 2017). Many nutrients are also lost in canned food that are not lost when the same foods are frozen. A study from 2005 compared the carotenoid levels in canned and frozen corn (Scott, 2005). Carotenoids are compounds found in fruits and vegetables that are responsible for pigmentations and have health benefits such as antioxidant abilities and eye health (Stahl, 2003). Two types of corn were examined, White Shoepeg (WS) and Golden Whole Kernel (GWK) and results showed that both types of corn had lowered carotenoid levels when comparing canned to fresh corn, but had heightened carotenoid levels after the fresh corn was frozen (Scott, 2005). Although frozen food can maintain or increase the quality of food with respect to texture and nutritional value, canned food still has an advantage in shelf life and in cost of storage due to no need for refrigeration (Gravely, 2017). The ultimate goal in future research of frozen foods should be centered around improving the shelf life of foods through advancements in freezing methods and breakthroughs in added preservatives.

Conclusion

Overall, the food freezing industry has expanded tremendously in recent years. With the consumer purchasing frozen foods at an all time high and the expansion of fast food chain suppliers, industries have had to increase supply while not jeopardizing the quality of the food. The most widely used methods of freezing, cryogenic and air-blast, are cost-efficient and able to maintain the quality of the food, although more research could be done on air-blast freezing to optimize freezing rates (Boonsumrej, 2007). Two new methods of freezing, electro-freezing and ultrasound-assisted freezing have promising potential as shown by experimental results (Jha, 2018; Fu, 2020). When it comes to added preservatives and chemicals in the freezing process, advanced glycation end-products are harmful chemicals produced in meat products and hinder the shelf life of the food (Yu, 2021). However, new additives such as essential oils, ice nucleating proteins, and alternatives to sugar have the potential to extend the shelf life of frozen foods across all food groups and positively affect the health of consumers (Tao, 2021; Tian, 2020; Sato, 2021).

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