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A REVIEW: APPLICATION OF FREEZE-DRYING IN MEAT PROCESSING

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Abstract
Meat products play an important role in the human diet. They are one of the main sources of proteins, trace elements, structural components, as well as vitamins that stimulate human growth and physical activity. Raw meat refers to perishable food. There are many methods of preserving the quality and shelf-life of meat products, however, in recent years, freeze-drying is becoming more and more popular, and it combines two technological steps -freezing and vacuum drying. During the process, the product undergoes dehydration by removing water to a humidity level of 2-5%. The principle of the process involves transforming the product from a frozen phase to a gaseous phase, bypassing the liquid phase. The purpose of the article is to study the possibility and relevance of the freeze-drying process in the meat industry and to examine its advantages and disadvantages, as well as the probability of growth. During this research it was revealed that in the use of freeze-drying in the meat industry for certain purposes, it is still necessary to study and adjust in order to introduce it into a particular production. However, with regard to large enterprises where various production problems often arise this technology would not only help solve these problems, but also increase the range of innovative products and expand sales markets.
Key words: freeze-drying, shelf-life prolonging, quality assessment, rehydration.

Introduction

Meat is a valuable source of nutrients such as protein, fats, iron, and zinc that are necessary for healthy growth and development of humans, but their concentration may vary depending on the type of meat and its processing type (Dal Bosco *et al*., 2022). Additionally, meat contains important fatty acids and B-group vitamins that are necessary for maintaining nervous system health (Giromini & Givens, 2023; Biesalski, 2005). For example, beef usually contains around 20% protein and 10% fat (United States Department of Agriculture, 2021), pork contains around 14% protein and 30% fat, and chicken contains around 20% protein and 2-3% fat (United States Department of Agriculture, 2018). Carbohydrates are usually present in small amounts in meat. However, it should be noted that cooking meat or industrial processing of meat can decrease its energy value (Lebret & Čandek-Potokar, 2022). It is more difficult for meat processing enterprises to meet quality standards in order to maintain the level of consumer appreciation of the safety of products. One of the methods of preserving the quality and ensuring shelf-life and nutritive value of the product and value, as well as the creation of new innovative products, is the freeze-drying process. The process combines two methods-freezing and vacuum drying. Freeze drying is the process of dehydration of a food product, during which moisture is removed from the product. Where the principle of the process is to transfer moisture from the frozen phase to a gaseous state bypassing the liquid stage (Wang *et al*., 2020). The product is quickly frozen after in a special vacuum chamber, during which the resulting condensates are immediately pumped out and removed, resulting in a product with a humidity of 2–5% (Komarova, 2020). In the food industry, such food processing methods are evaluated in the ability to swell and return the original properties of the product, also preserving its nutritive value if possible.

The freeze-drying process as a whole has many advantages, which are increasingly increasing the tendency of this process in the food industry (Harguindeguy & Fissore, 2019). *Preservation of nutrients* – the process is unique in that it preserves up to 95% of nutrients, vitamins, enzymes, biologically active substances in the product (Vetrov *et al*., 2005).

Shelf-life of products – in this process, the final moisture content of the product is 2–5%, which prevents the growth of microorganisms and allows the product to be stored for a long time in conditions of unregulated temperatures, which facilitates the production stages (Vetrov & Aniskevich, 2021).

Preservation of consumer qualities–during rehydration, the product returns its original organoleptic parameters, which increases the vastness of the use of this process in the food industry (Boicova, Alenin, & Patonina, 2020).

Low product weight–during freeze-drying process it is possible to remove 90–98% of water from the product, which significantly reduces the weight of the product. The freeze-dried product has a low weight, shape and compactness. Thus, facilitating and optimizing the processes of production chains logistics, storage (Chen *et al*., 2020).

The rate of restoration of the original parameters–restoration of the qualities of the original product with the help of rehydration takes from 5 to 40 minutes depending on the size and pre-treatment (Ma *et al*., 2019).

Trends in the production of freeze-dried products on the global market are estimated at ~ 46.94 billion dollars in 2016 and are projected to increase at an average annual rate of 7.4% (Boicova, Alenin, &

Patonina, 2020).

The purpose of the present review is to study the possibility and relevance of the freeze-drying process in the meat industry and to examine its advantages and disadvantages, as well as the probability of growth.

Materials and Methods

The monographic method was used to summarize and analyze the information and research articles dedicated to study of the use of the freeze-drying process in the meat industry. Information published from 2005 till 2023 in total 35 full text research articles and databases were analysed and summarize. To select and analyse full text research articles and monographs Scopus, Web of Science, Science Direct and ResearchGate, Google scholar research databases were used.

Results and Discussion

The main goal of the meat industry is to provide high-quality products that are convenient for consumers. Unfortunately, ensuring product safety at all stages of the supply chain-starting from slaughter, through production and logistics, and ending with consumers-is not always achievable (Pateiro *et al*., 2021).

As mentioned earlier, meat belongs to the category of perishable products, and for various reasons, a significant proportion of the edible parts of meat products are disposed of (Bogataj *et al*., 2020).

Food waste and spoilage represent a substantial problem in today's world, too. The magnitude of this issue is significant enough to be treated as a serious concern. The problem of food loss and waste in the meat sector is particularly important from economic and environmental perspectives (Karwowska, Laba, & Szczepanski, 2021). The production of meat and meat products has a negative impact on the environment (meat has the highest emissions per kilogram of food compared to other food products), which necessitates rational management of these products throughout the entire chain (stages of production, processing, transportation, and consumption) (Karwowska, Laba, & Szczepanski, 2021).

As research on food losses and waste, with a particular focus on the meat sector, has shown: it is estimated that up to 23% of the production in the meat sector of edible parts is lost and wasted (Ishangulyyev *et al*., 2019).

The highest proportion is at the consumption stage, accounting for 64%, followed by production (20%), distribution (12%), and primary production and post-harvest processing (3.5%) (Karwowska, Laba, & Szczepanski, 2021). Losses and spoilage occur for various reasons, including improper management of raw material and product distribution, time constraints, regime constraints, logistics, trimmings, and consumer apathy (which increased particularly in 2019 due to the pandemic). These are substantial figures, especially considering that a high percentage of people worldwide lack access to nutritionally dense food, and even more so to protein (Cooper, 2023).

Given the above-mentioned subset of issues in the meat sector, it is possible to posit the potential use of freeze-drying technology on a large scale for more extensive applications. Beyond the potential to alleviate meat loss issues through the widespread use of freeze-drying technology, such as freeze-drying scraps, raw meat necessary for long-term storage and use in sausage products, highly-demanded raw materials during large-scale purchases (which could also reduce costs and simplify logistics), and other bottlenecks where spoilage and product loss most often occur. Moreover, this technology could open the potential for introducing new innovative products with enhanced protein content, such as protein snacks made from scraps, products made from inexpensive by-products, semi-prepared marinated products for grilling, ready-made meat products, and others. These products can offer consumers convenience and flexibility, making them ideal for quick meal preparation or use in culinary arts, and for long-term storage if necessary in emergency situations, without leading to waste in the long run (Chen *et al*., 2021). Considering that demand for freeze-dried products is projected to grow by 6.8% from 2022 to 2032, consumers are opting for ready meals and packaged food products for quick and easy consumption amid hectic schedules (FMI, 2022). This could also open up new markets in places where there is a need for nutrient-dense protein foods, thereby increasing productivity. Freeze drying is considered an expensive dehydration procedure for food, and for this reason, it has only been used when necessary or when the high added value of the final product could justify the costs. (Stratta *et al*., 2020).

When comparing the capital and operating costs of freeze-drying on a large scale with experimental laboratory equipment, it was found that, with the correct implementation and operation of the equipment (continuous cycle and full load), despite the total cost of the cycle for industrial sublimation drying being 25 times higher, the cost per product is six times lower due to increased productivity. This is clearly expected, as the main aim of the scaling process is to reduce costs and increase productivity (Stratta *et al*., 2020). However, there isn't much research assessing the economic data on the implementation of sublimation technology on a large scale, suggesting a need for further in-depth study of the economic aspect of implementing this equipment in the meat sector.

The product to be freeze dried must be completely frozen. The freezing process is the first stage of the freeze-drying process, which affects the outcome of the process (Assegeheng *et al*., 2019). The speed of the process contributes to the maximum preservation of the initial properties of the product, with the help of properly formed ice crystals (Babic & Arroqui, 2009). The freezing process usually occurs up to -20 till -30 °C. The faster and deeper freezing process goes, the less ice crystals form in the product, the faster they will evaporate at the next stage of 'drying', the higher the result of the quality of the final product will be (Yang, Zhang, & Liandong, 2021). Freezing is possible both in individual aggregate equipment and in the freeze-dried equipment itself (if it has such a function) (Ciurzynska & Lenart, 2011).

In the freeze-drying equipment, the dried material supplied to vacuum pumps is under vacuum for the entire freeze-drying process (Nowak & Jakubczyk, 2020). At the beginning of this stage, air is pumped out and pressure is created. The required absolute pressure will depend on the physical characteristics of the product. If the pressure is increased, the sublimation rate will slow down and the temperature of the product will increase (Chen *et al*., 2020).

In the process of vacuum freeze-drying, heat is supplied to the product. The process is aimed at eliminating moisture. Vacuum drying occurs with a degree of vacuum below the 'triple point' (~6 mBar) (Vetrov & Aniskevich, 2021). Due to this, water (moisture) is present only in two phases – ice and steam. The vacuum allows the ice in the product to turn immediately into steam without passing through the water phase. In this process, the ice contained in the product turns into a gaseous state and accumulates inside the chamber by a condensation system (Eur food technologies, 2020). The drying temperature varies from -10 to -35 °C.

In the process of all freeze drying the products undergo their own physico-chemical changes (Figure 1).

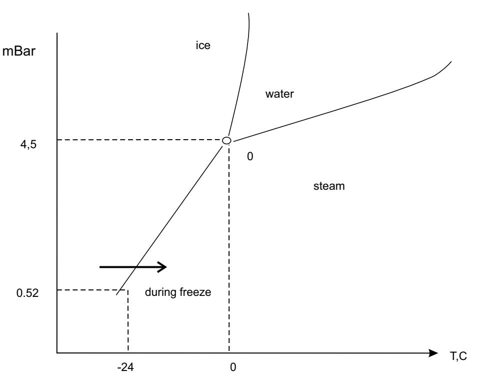

Figure 1. Physical process in products during freeze drying (Kasyanov, 2018).

The product is frozen in the solid phase. With a gradual increase in pressure and temperature, the regions in the graph are divided into 3 adjacent parts: the region of solid, liquid, and gaseous states, which all intersect at a common point-which is called the 'Triple Point' (Vetrov & Aniskevich 2021). All 3 phases have the possibility to exist, are in equilibrium with each other only at certain values of temperature and pressure of the triple point. This is followed by the transformation of the solid phase into a gaseous one with an increase in pressure and an increase in temperature to the desired totals (Wolkers, 2021).

Most products and their raw materials can be freeze-dried without significant changes in the output properties for this regulation and selection of modes of all stages from freezing to freeze-drying itself, it is necessary to know the properties of the drying object (product) itself (Kasyanov, 2018). The freeze-drying process in the meat sector depends on the quality of the products dehydrated by sublimation, which in turn depends on the initial properties of the raw materials, the conditions and modes of their technological processing, and the conditions of storage and rehydration. A key factor in the freeze-drying of meat is the selection of raw material. Likewise, the presence of a higher percentage of fat tissue can slow down the process and the quality of rehydration, as fatty acids block the pores in muscle capillaries which are important for rehydration. Multiple tests have shown that the raw material intended for drying must be well-aged, as the presence of dense connective tissue and cartilage complicates the drying of meat pieces and slows down their rehydration process. The quality of dehydrated meat depends on the level of development of autolytic processes in the raw material. Meat dehydrated in a state of rigor mortis has the worst properties. When rehydrated, it poorly absorbs water and remains tough (Zhang *et al*., 2021).

The freezing process influences not only the quality of the dried products and the duration of the drying process, but also the structure of the pores in the meat tissue. For freezing raw meat for subsequent drying, the most effective temperature reduction rate is 1-2 °C per hour; prior to sublimation, the temperature should be set 10-20 ° C below the product's eutectic point (Ma *et al*., 2018).

The shape and slicing of meat products also affect the process and its optimization. For example, to increase the drying speed and uniformity of dehydration of different pieces of meat, it is better to slice the frozen meat across the muscle fibres. In this way, freeze-drying gradually removes moisture from macro and micro capillaries and maintains the porosity of the dehydrated product, which is very important for an efficient rehydration process (Farkas & Singh, 2006).

During freeze-drying, denaturation changes in protein substances can occur, accompanied by a decrease in their solubility and decrease in enzymatic activity. As a result of these changes, the colour of the meat changes due to the conversion of myoglobin into metmyoglobin and the development of melanoidin formation reactions. The nature and depth of changes in meat properties depend on the temperature and duration of the process. The parameters depend on the type, part, and processing of the product, as well as the ultimate goal and the required final characteristics of the product (Oyinloye & Yoon, 2020). In cyclical experiments with variable pressure, the lower the pressure in the system, the faster the drying process occurs. Moreover, a variable pressure cycle contributed more to reducing the time of freeze-drying and lowering energy costs (Ma *et al*., 2019).

The freeze-drying effectively preserves and dehydrates the acidity in low-acidity products.

Water activity affects the rate of freeze-drying where when it decreases, the drying process is accelerated sodium chloride in meat facilitates and accelerates the drying process and reduces the water activity (a_w) level of the meat (Mediani *et al*., 2022).

During the drying process, structural changes occur in the muscle tissue of the raw material due to the removal of moisture. When properly set parameters are used, the moisture is gently removed through the tissue's micro and macro capillaries, leaving porosity. Muscle fibres retain their integrity compared to raw meat but become denser and shorter while preserving their cross-striation.

Research shows that the B-group vitamins contained in meat after freeze-drying are lost at approximately 5-10% compared to the levels present in the raw material (Zhang *et al*., 2021).

The freeze-drying process of meat products and its improvement vary individually especially on an industrial scale and depends on numerous factors such as physicochemical characteristics, types of meat, slaughter and cleaning, processing, the end product's purpose, and others that are especially crucial in creating new products.

Conclusions

In many segments of the food industry, the freeze-drying process is fully implemented and effectively used. As for the meat industry, many successful experiments have been carried out to modernize and ensure this process of meat processing plants, but there is no extensive use of the process in this industry at this stage.

Despite many advantages and prospects, this process is still very expensive, and it is very difficult for small and medium-sized enterprises to implement it in large volumes from an economic point of view.

With regard to large enterprises where various production problems often arise, this technology would not only help solve these problems, but also increase the range of innovative products and expand sales markets. Thus, the progressive technology still deserves its more extensive application in modern and large-scale meat processing, considering the fact that meat is an expensive and perishable product.

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