



FOOD QUALITY

Freeze-drying Food Preservation

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Introduction

Freeze-drying is a process of food preservation that utilizes moisture removal to lower water activity (Aw). Removing a significant amount of water molecules from a food product substantially prolongs the product's shelf life. This process also preserves the nutritional value and colors of food products. Freeze-drying removes water from food products using cold temperatures and increased pressure, typically by pulling a vacuum, to quickly transform ice crystals into vapor. This process is called sublimation. Liquid water does not conduct energy as well as frozen water (ice); using frozen water optimizes the freeze-drying process. Freeze-drying is not a "kill step." This means that bacteria or other potential pathogens are not removed but are preserved in the product. If moisture is added back to the food, the microorganisms can begin to grow.

Food safety

One of the most critical aspects of freeze-drying is ensuring low water activity. Water activity is a measurement of food

indicating the amount of water found in a product that is available for chemical or microbial reactions to occur. The value of water activity is a range between 0 and 1, with 1 being pure water and 0 being no water. Most harmful organisms' growth is limited to a water activity of at least 0.85. The minimum water activity for most unwanted organisms is 0.60.

Although the freezing dryer applies the same temperature and pressure to the entire vessel, the location of the trays in the freeze dryer and where the samples are on the trays can cause a slight difference in water activity. For example, samples were placed in different positions on the trays and allowed to dry under the same conditions. The water activity results read right after drying were recorded and can be seen in Table 1. The nature of the product has more influence on the amount of water removed from the product in comparison to the location on the tray, as seen in Table 1.

Table 1. Compiled water activity data from various trials

Product	Front of pan Aw	Middle of pan Aw	Back of pan Aw
Raspberries	0.2828	0.2986	0.2692
Blackberries	0.3194	0.6022*	0.2525
Cranberries	0.2427	0.1052	0.2488
Whole blueberries	0.1145	0.1080	0.1041
Cut blueberries	0.1330	0.1408	0.1392
Pomegranate seeds	0.1725	0.1803	0.1938
Whole grapes	0.2421	0.6809	0.9173**
Cut grapes	0.2602	0.2537	0.2457
Corn	0.1078	0.0870	0.0978
Peas	0.0711	0.0715	0.0603
Nerd Gummy Clusters	0.3819	0.2617	0.2561
Scooby Snack Gummy Candy	0.6199***	0.6139	0.6129

*A wide range of water activity values was found; this could be due to the varying sizes of the blackberries.

**The grapes did not fully reach a safe level of water activity. It is not recommended that this fruit be freeze-dried.

***The Scooby Snack Gummy Candy changed little if at all. This product is not recommended for freeze drying.

Food processing is essential for many products because it includes a “kill step.” A kill step is defined as a point in which harmful or threatening pathogens are removed from a product, or microorganisms are limited to a level compliant with safety standards. An example of a kill step is cooking meat to the proper core minimum temperature. Although freeze drying utilizes intense temperatures (both low and high), it is not considered a microbial *kill step* for food processing. Many of the organisms found in the product can still survive through the process and can potentially be reactivated once reconstituted with a liquid.

Freeze drying is not a step for microbial food safety but more for preservation. To ensure the safety of freeze-dried products, properly wash and dry produce — and consistently wash hands while handling the food. The best way to wash produce is to simply use cool running water and a vegetable brush (for hard produce), scrubbing away visible dirt or grime. Drying should be done with a clean towel.

Dehydrating versus freeze drying

What is dehydration?

Dehydration, or drying, is a form of preservation that removes water from food. It is not considered a kill step. The process of dehydration is used for preservation and extending shelf life.

Dehydration is performed by applying hot air to the surface of the food. Typical forms of dehydration include oven drying and sun drying. This causes moisture within the food to evaporate and lowers its water activity.

Removing moisture within a food product can reduce the rate of enzymatic reactions and prevent the growth of microorganisms. Dehydration can cause degradation of quality in heat-sensitive components, such as color or flavor of the food.

What is freeze-drying?

As mentioned previously, freeze-drying utilizes the process of sublimation to remove water from a product in the form of ice by applying a vacuum under freezing temperatures. An important result of this process is the preservation of overall quality. With most freeze-dried samples, characteristics such as flavor and color barely change through the process and resemble that of the fresh product. This can be seen in the leafy green and pesto images (Image 5). These characteristics are preserved in freeze-drying and typically not in dehydrating because freeze-drying uses a lower temperature. The lower the temperature, the less likely the heat-sensitive characteristics, like nutrients or color pigments, are to be impacted.

When to use what

Freeze-drying preserves the food's original coloring, structure and flavor more efficiently than dehydrating. This method draws out more moisture, yielding a significantly lighter final product. The final product is light, but also fragile and brittle. The cellular structure of freeze-dried foods remains intact. The freeze-drying process also allows for better preservation of volatile compounds that are responsible for a food product's taste and smell. Lower temperatures prevent volatile compounds from evaporating, which leaves most of

the food's original flavor. To preserve color, aroma and taste — in the case of fresh herbs, for example — freeze-drying is superior to dehydration.

Dehydrating uses warm air to remove moisture. This process changes the appearance of the food, leaving it discolored or brown, and the product loses its original shape and texture. Dehydration can produce a leathery final texture. The overall texture of dehydrated foods tends to be tougher, more dense or chewier. This is caused by the shrinkage and collapse of cell walls in the dehydration process. The heat used in the dehydration process can cause volatile compounds to evaporate out of the product, resulting in a loss of aroma and a flavor profile that is less complex. But when a chewy texture is desired — jerky is an example — dehydration is superior to freeze drying.

Best foods to freeze dry (for home gardeners/consumption)

When it comes to freeze drying at home, it is important to have a basic understanding of what items freeze dry the best and what items to potentially stay away from. It is important to note that cutting fresh produce may be needed to ensure the pieces are thin enough for effective sublimation and drying. Examples of fruits and vegetables that should be cut before freeze-drying are apples, strawberries, cucumbers and carrots.

Produce with thin outer layers can be freeze-dried with the skin still on, if desired. Produce with thick outer layers, such as blueberries or grapes, need to be cut despite their small size because the outer layer does not allow efficient sublimation to occur, resulting in not fully dried or sticky-textured items. Some of the best performing produce items are small berries with thin layers, such as raspberries or blackberries, which do not need to be cut. It is important to note that variation within the size of the berry may change how effective freeze drying is, causing inconsistencies in drying.

Vegetables that are small, such as peas or corn off the cob, dry well and can be put into the trays in bulk. Leafy greens, such as herbs, are easily freeze dried whether on or off the stem. Since greens tend to have high amounts of water within them, the finished product is delicate and easily broken if handled. However, this may be helpful if the goal is to create homemade seasonings.

When freeze drying items that may be displaced by the air flow inside, place a layer of cheesecloth on top of the items to ensure they will not move around the inside of the dryer. The preparation and form of vegetable may also impact the results. The thinner or smaller the vegetable is cut, the less time it may take for efficient freeze drying to occur. Table 4 below shows a comparison of the water activity obtained for carrots cut

into various shapes. A similar trend can potentially be seen with other vegetables as well.

Blanching vegetables before freeze drying not only cleans the surface of the produce but can also help enhance the overall quality of the produce by deactivating the enzymes that could cause loss of color, flavor or nutrition over time. As seen with the potatoes in Image 1, the appearance of the blanched versus raw potatoes shows the difference in quality preservation after freeze drying occurs. Blanching reduces the amount of powdered starch that appears after freeze-drying. This is because blanching causes starch to swell and break down.



Image 1: Freeze-dried potato slices. The four on the left were raw. The four on the right were blanched.

Foods not recommended to freeze dry:

Gummy candy — If you are looking to freeze dry nonproduce items like candy, the same rules apply in terms of outer layers and cutting thick pieces. Gummy candies with a waxy coating may not dry properly because the sublimation cannot penetrate the surface.

Chocolate — Freeze drying should be used only with candies that have minimal chocolate because chocolate is too high in fat to properly dry. Chocolate will end up bubbling or boiling in the dryer, melting off and creating a sticky mess.

High fat content foods — Avoid freeze drying products high in fat, such as peanut butter or oils. Products high in fat lack water needed for freezing and sublimation to occur. The long cycles of freeze drying can also cause fat rancidity as the fats are oxidized and degraded.

Unnecessary for preservation — Some foods do not need to undergo the freeze-drying process because they already have the desired shelf stable characteristics. If the product is already shelf stable, freeze drying would not be a necessity — the microbial load is already controlled. Some examples are honey, tea blends and dried pasta. While some of these can be freeze dried to change the characteristics or texture, it isn't necessary from a preservation standpoint.

Experiment 1. The impact of form on freeze-dried results

To determine how the form and processing conditions of a product impacted the final freeze-dried product, apples, ranging from fresh to canned apple pie filling, were tested. (Table 2). The apple pie filling and applesauce dried well, resulting in dense pieces that can easily be stored for future use (Image 3). The presence of skin on the fruit was examined to understand how the thin skin of the apple may change the amount of drying that occurs. In a slice (1/8th of the apple), minor differences in the amount of water removed were found. As mentioned with the vegetables earlier, the size of the pieces does change how long it will take to dry and how effective water removal is.

The juice tested was store-bought. It turned into a sticky residue (Image 2), indicating that most of the liquid within the product was water that then sublimated out. If using freshly produced juice using homegrown produce, this result may be different due to the amount of solids within.

Table 2. Recorded water activity values of apples in varying processing conditions and forms

Product	Aw
Slice (1/8 th of apple), with skin	0.2009
Slice (1/8 th of apple), without skin	0.2592
Juice (from store)	0.2613
Pie filling	0.1911
Applesauce	0.1769



Image 2: Freeze-dried, store-bought apple juice after testing.



Image 3: Freeze-dried applesauce (left) and apple pie filling (right).

Experiment 2. Does produce need to be blanched?

As discussed earlier, potatoes were studied to determine how blanching impacts the overall result of freeze drying. Table 3 shows that the blanching had little impact on the finished water activity when compared to raw potatoes. The parboiled samples were more visually appealing. Potato tots were dried along with the raw and parboiled potatoes. The tots were notably thick in width, which caused less effective drying. (Note the higher recorded water activity value in Table 3.) Although there was no color change, the tots' texture was extremely dense and hard. Parboiling thin-cut potatoes is the most effective way to freeze dry potatoes for storage.

Blanching vegetables before freeze-drying does not seem to change the amount of water removed through sublimation in comparison to raw forms but can have greater impact on the quality of the produce. Carrots that were blanched versus raw were freeze-dried together and compared afterward. The orange color was preserved for both, but the blanched samples were much more vibrant and comparable to the color of the raw product (Image 4). The size of the samples was also compared to demonstrate how thickness and surface area could change the results. Carrots of varying sizes were freeze-dried together, and the water activities were compared after. It was found that the various cuts used were all effective forms for freeze drying carrots successfully.



Image 4: Freeze-dried blanched carrot coins

Table 3. Recorded water activity values of potatoes in varying processing conditions and forms

Product	Aw
Par-boiled potatoes	0.0296
Raw potatoes	0.0355
Potato tots	0.4450

Table 4. Recorded water activity values of carrots in varying processing conditions and form

Product	Aw
Blanched – diced	0.1633
Blanched – coin	0.2027
Blanched – stick	0.2549
Raw – shredded	0.1969
Raw – diced	0.2241
Raw – coin	0.1636
Raw – stick	0.2972

How to reconstitute freeze-dried products

An important part of the freeze-drying process is recording the weight of everything before and after drying. This is essential for products that will be reconstituted later as it gives a basis on how much water should be added. Record the weight of the tray with the product on it before and after freeze-drying. To find the weight of the water lost through sublimation, subtract the weight of the tray with the product before by the weight of the tray with the product after. The amount of water lost through that calculation is the amount that should be added back to the product when reconstituted. Some products may be more fragile in texture, so add water slowly to preserve the product structure. Allowing the product to sit in the water is also essential as it will be able to soak up the water.

Recipe ideas:

Pesto

Freeze drying can prolong the shelf life of pesto (without the oil added.) The color does not change (Image 5), and the taste is unaffected. The paste should be reconstituted with water. The amount of water will vary, so adding small amounts at a time is ideal. Once the paste has reached a favorable texture, then you can add the amount of oil required by the recipe. These steps can be done in either order, either water or oil first, but a more uniform product was found with adding water first.



Image 5: Freeze-dried pesto.

Cornbread

Freeze-dried corn can replace cornmeal in a cornbread recipe. Blend freeze-dried corn into a similarly textured powder and use that in place of cornmeal. The substitution is a 1:1 ratio — use the same amount of freeze-dried corn as you would cornmeal. As for results, both had similar rise and texture properties, indicating that the substitution is valid.



Image 6: Freeze-dried corn.

Smoothie bites

Fruit-based, low-fat smoothies make a fun snack when freeze dried. Dry them in molds or as a bark-like snack. If you use molds, they must be thin and made of silicone to ensure that the product can be effectively dried. In Image 7, a fruit and Greek yogurt blended product was freeze dried in a thin mold to make smoothie treats.



Image 7: Freeze-dried smoothie

Cheesecake-filled raspberries

Turn freeze-dried raspberries into a sweet treat. One idea for a treat is using raspberries and a cream cheese filling. Stuff a cream cheese blend into the raspberries before freeze-drying. Because the water activity is sufficiently lowered, the raspberries do not need to be refrigerated but can be consumed as a shelf-stable snack.



Image 8: Freeze-dried raspberries with cream cheese filling.

References

- Kasalo, Blanka. "Why Experts Say the 'Kill-Step' Is so Important to Food Quality Control." AAPS, AAPS, 20 Aug. 2019, <https://www.aaps.ca/blog/why-experts-say-the-kill-step-is-so-important-to-food-quality-control#:~:text=The%2520%E2%80%9Ckill%2520step%E2%80%9D%2520in,be%2520taken%2520seriously%2520and%2520optimized.>
- Mohammadi, Xanyar, et al. "Impact of Three Different Dehydration Methods on Nutritional Values and Sensory Quality of Dried Broccoli, Oranges, and Carrots." *Foods* (Basel, Switzerland), U.S. National Library of Medicine, 14 Oct. 2020, <https://pubmed.ncbi.nlm.nih.gov/articles/PMC7602416/>.
- Nowak, D., & Jakubczyk, E. (2020). The Freeze-Drying of Foods — The characteristic of the process course and the effect of its parameters on the physical properties of food materials. *Foods*, 9(10), 1488. <https://doi.org/10.3390/foods9101488>
- "Water Activity (AW) in Foods." U.S. Food and Drug Administration, FDA, 27 Aug. 2014, www.fda.gov/inspections-compliance-enforcement-and-criminal-investigations/inspection-technical-guides/water-activity-aw-foods.

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