Practical Applications of Food Dehydration: A Review

F. E. CUNNINGHAM

Animal Sciences Department, Kansas State University, Manhattan, Kansas 66506

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ABSTRACT

Removal of water from foods is one of the oldest methods of preserving foods. Today nearly all foods can be preserved by a variety of controlled dehydration processes. Many chemical and physical changes can take place during food dehydration and those changes determine the ultimate quality of the dried and rehydrated product. This review concerns some of the more common drying methods, selected drying processes for various foods and a summary of the nutritive value of dehydrated foods.

This review appraises selected facets of food preservation by drying. Engineering aspects of the unit operation of drying were well presented in a symposium published in 1978 (42). That symposium generally dealt with drying theory and modeling, drying of granular materials and drying of continuous sheets.

Food preservation by moisture removal is based on microbial growth and chemical reactions occurring only when moisture is available. By removing moisture, deteriorative reactions are reduced or prevented. The influence of water activity on microorganisms in food is the subject of a review article (J9). Food spoilage by microorganisms tolerating low water activities was reviewed by Troller (49). This paper identifies food products preserved by dehydration, with processes normally used, and summarizes the nutritive value of dehydrated foods.

Dehydrated foods and drying processes

Many types of commercial driers are used to remove moisture from a wide variety of food products. The type of drier selected depends upon the food to be dried, operation costs, the necessary operating conditions and the desired physical form of finished product. Common types of driers and examples of foods dried are cited in Table 1.

Drying methods and types of driers have been discussed in detail by Brown et al. (8), so this review only briefly mentions types of driers in relation to food products commonly dried by different drying methods. Following is a potpourri of dehydrated foods, most of which are readily available to consumers.

Alcoholic products. Beer containing high alcohol and low total solids is produced by freeze drying (18). Whiskey may be dried by first encapsulation with dextrins, soluble polysaccharides or gelatin, added to a 30-60% alcohol concentration. The constantly stirred slurry is spray-dried under low temperature. Ten percent of the alcohol is lost during spray-drying; however, a stable powder is produced. Whiskey and brandy powders with wide application in the confectionery industry (55) can be produced.

Apples. About 4% of the U.S. apple crop is used in dried products. Dried apples are prepared as rings, quarters, slices, chopped or as powder. Tunnel dehydration is the commonest method of drying, but some apple products are dried in kilns (20). Apple nuggets, a low-moisture product, are vacuum-shelf-dried.

Apricots. About 19% of the total apricot crop is dried. About 15% is dehydrated in tunnel dryers, while the remainder are sun-dried as halves. The cut fruit is sulfured to preserve color and nutritional quality (11). To improve their appearance, apricot halves are often dried for 3 to 5 h in the sun, then dehydrated, which, of course, differs from sun-drying. Apricots, when pureed, are dried by the foam-mat technique (25).

Bananas. Approximately 5% of the banana crop is sun-dried. Strips or dices are tray dried and, occasionally, puree of banana may be drum or spray-dried (11). Dehydrated banana products are gaining popularity, particularly in developing countries (44).

Butter. The manufacture of a powder containing 80% butterfat originated in Australia (21). Butter, containing 80% fat, 18% non-fat milk solids and 2% moisture, can be spray-dried in vertical tower driers. The product has

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TABLE 1. Common types of driers and examples of foods dried (15).

<table>
<thead>
<tr>
<th>Drier</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drum drier</td>
<td>Milk, certain vegetable juices, cranberries and bananas</td>
</tr>
<tr>
<td>Vacuum shelf drier</td>
<td>Limited production of certain foods</td>
</tr>
<tr>
<td>Continuous vacuum drier</td>
<td>Fruits, vegetables</td>
</tr>
<tr>
<td>Continuous belt (atmospheric) drier</td>
<td></td>
</tr>
<tr>
<td>Freeze driers</td>
<td>Meats</td>
</tr>
<tr>
<td>Spray driers</td>
<td>Whole eggs, egg yolk, blood albumin and milk</td>
</tr>
<tr>
<td>Rotary driers</td>
<td>Some meat products, usually not used for food products</td>
</tr>
<tr>
<td>Cabinet or compartment driers</td>
<td>Fruits and vegetables</td>
</tr>
<tr>
<td>Kiln driers</td>
<td>Apples, some vegetables</td>
</tr>
<tr>
<td>Tunnel driers</td>
<td>Fruit and vegetables</td>
</tr>
</tbody>
</table>

good stability with no particular processing or drying problems (7).

Cheese. Cheeses are spray-dried, drum-dried or freeze-dried. Soft cheeses are usually freeze-dried. Well-cured cheese, selected for flavor, is shredded and dried at room temperature, with air flow, to 8-12% moisture. In the second stage, temperature is increased and the cheese is dried to about 3%, then compressed or grated for use in macaroni, soups, salads or other cheese dishes.

Other fruits. California accounts for more than 90% of the U.S. dried fruit production and much of it is produced in counter-current tunnel dehydrators (11).

Most fruit juices are dried by spray-drying, vacuum puff foam-drying, or foam mat-drying (25). Raisins, figs, and dates are almost exclusively sun-dried. Many fruits are partially dried by solar energy, then finished in tunnel dryers. About 65% of all raisins are sun-dried, but all golden bleached raisin grapes are dehydrated in tunnel dryers.

Coffee. Considerable coffee is spray-dried, although vacuum and drum-drying are also used. Large hollow-sphere particles can be produced by dehydration in a vertical tower-type spray drier (11). Coffee is probably the most important item freeze-dried from liquid food extracts. Some coffee may also be vacuum puff foam-dried and foam spray-dried (50).

Eggs. Many kinds of driers have been used in producing egg solids. Drum driers probably were first (25), but they are not used extensively because high temperatures damage the heat-sensitive proteins in the egg. Spray-drying is now the most commonly used method of dehydrating eggs. Many types of driers are used, depending on the product, yolk, whole egg or white, to be dried. The cone-shaped Swenson Gray-Jensen spray drier was one of the first types used for whole egg and yolk. A flow diagram of Blaw-Knox Vertical Spray Drier is shown in Fig. 1. The exhaust air from the main chamber may be passed through several secondary collectors. The box-shaped Rogers spray drier (Fig. 2) uses bag filters extensively to dry egg whites (5). Some eggs are dried by foam mat-drying, and freeze-drying.

Dehydration of meats. Different degrees of drying as applied to meat products range from ordinary smoke-house treatment, through semi-dry and dry sausage, to dried beef (jerky), to complete lyophilization.

Cooked, ground meat can be dried in a hot-air dryer. Finely-divided meat can even be spray-dried. Pork fat tends to become rancid after hot-air drying. Nor is hot-air drying suitable for uncooked meat. Freeze-drying

Figure 1. Flow diagram of a Blaw-Knox vertical spray-drying system. (Courtesy of Blaw-Knox Food and Chemical Co.)

Figure 2. A Rogers spray drier. (Courtesy of C. E. Rogers Co.)
is the best method to dehydrate meats as far as rehydration and acceptability are concerned.

Beef is cooked on steam-heated drums or in steam-jacketed kettles, then dried further in tunnel dryers or in vacuum steam-jacketed melters. Beef is also freeze-dried in vacuum shelf dryers.

Chicken and turkey products are prepared in a variety of ways. Cooked, diced poultry is dried in tunnel dryers, in cabinet dryers, or on conveyor belt dryers. Finely-ground suspensions of poultry meat can also be spray-dried. Poultry skin is frequently spray-dried to be used in flavoring other food products. Poultry products are also freeze-dried (20).

Milk. A variety of milk products are spray-dried in dryers like the DeLaval Spray Drying System shown in Fig. 3. Whey is usually spray-dried; other milk products may be drum-dried, vacuum puff foam-dried, or foam mat-dried (25).

Seafoods. An infinite variety of seafoods are dehydrated without processing problems. Minced fish is dehydrated mostly in cabinet dryers (3). Surprisingly, a considerable amount of fish is still sun-dried (26).

Vegetables. There are innumerable articles dealing with the proper conditions for dehydrating vegetables (20,33,40), most of which are dehydrated in convection type machinery, as illustrated in Fig. 4. This dryer can dry sliced raw onions to a final 4% moisture at 10,000 lb/h.

### TABLE 2. Loss of β-carotene in drying carrots to 3% moisture.

<table>
<thead>
<tr>
<th>Drying process</th>
<th>Temperature-time</th>
<th>Average retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tray air-drying</td>
<td>200 F - 2 h</td>
<td>74%</td>
</tr>
<tr>
<td></td>
<td>150 F - 6 h</td>
<td></td>
</tr>
<tr>
<td>Explosion puff</td>
<td>200 F - 2 h in tray</td>
<td>81%</td>
</tr>
<tr>
<td></td>
<td>Exploded at 35 lb/in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Finished at 150 F</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total time 5.5 h</td>
<td></td>
</tr>
<tr>
<td>Freeze-dried</td>
<td>160 F 1000 μHg</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>4 to 5 h</td>
<td></td>
</tr>
<tr>
<td>Freeze-dried</td>
<td></td>
<td>90%</td>
</tr>
</tbody>
</table>

*aDella Monica and McDowell (14).
*bSweeney and Marsh (52).

**Nutritive value of dehydrated foods**

Considerable loss of vitamins can accompany fruit drying. When apricots are sun-dried, without sulfuring, 76-82% of vitamin A and nearly all vitamin C are lost. But when the fruit is treated with sulfur, much of both vitamins are retained (54). Ascorbic acid losses in drum-dried apples were reported to be 5% by Escher and Neukom (16). Labuza (34) reported that the overall loss of ascorbic acid in sun-dried peaches totaled 90%. Freeze-dried samples of fruit juices retained a high percentage of ascorbic acid. All samples retained 96-99% of their original ascorbic acid. During storage, however, considerable ascorbic acid was lost (7).

During moisture removal from vegetables, nutrient loss varies widely. During low-temperature drying, tomato concentrates lost no ascorbic acid. For air-dried rutabagas, Hein and Hutchings (24) reported some losses of thiamin (approximately 5%), the same as from air-dried snap beans, peas and corn, compared with 29% from carrots. Losses of beta-carotene from dehydrated carrots have been reported as high as 80% during vacuum-drying (54), 40% loss during explosion puffing and in ordinary air-drying (4), and as low as 13% for freeze-drying (6). Losses of beta-carotene from carrots during various drying methods are summarized in Table 2.

Nutritional qualities of drum-dried bean powders were determined (38) to be 20% of thiamin, pyridoxine, niacin and folic acid. And losses of folic acid from dried beans can be as high as 50% (31).

De Groot (12), who compared drying techniques, reported no damage to the protein in lima beans.

Considerable information is available on the nutritional value of dried potatoes. Ascorbic acid losses during processing can be quite high (Table 3). The low retention of ascorbic acid and folic acid are thought to stem from heat destruction and leaching during blanching. During the entire process of potato dehydration, total retention averages 9% thiamin, 83% protein and B6, and less than 50% of ascorbic and folic acids (2). Nutrient losses are significant during both blanching and
dehydration, but more during blanching than dehydration (2). For air-dried potatoes, Hein and Hutchings (24) reported 25% losses of thiamin. When potatoes are steamed and dehydrated, no vitamin C can be recovered (54).

During drying of dairy products, protein quality is generally not affected. In comparing hot air-drying, vacuum-drying, and accelerated freeze-drying, de Grott (12) reported that protein quality was not significantly altered, but freeze-drying produced the best results. Although milk is not an important source of thiamin, 10% is lost during spray-drying and 20 to 30% during roller-drying (32, 54). There is no loss of riboflavin with drying of milk so long as light is excluded. With spray-drying 20% of vitamin C is lost, and slightly more with roller-drying.

It is not clear whether drying effects essential fatty acids. Pol and de Groot (46) found a decline of 30 to 40% fatty acids in spray-dried compared with freeze-dried milk. But other work reported no loss of fatty acids in roller-dried milk (4).

During spray-drying or drum-drying, milk loses very little of vitamins A or D (22, 23).

The effects of drying method on eggs have also been studied. When hot air-drying, vacuum-drying, spray-drying and freeze-drying were compared, insignificant changes occurred in the biological quality of the egg protein (12). Drying does not destroy vitamin A, thiamin or riboflavin in eggs, but dried eggs lose vitamin A (54).

It is generally agreed that drying does not affect the protein quality of meat. In comparing hot air-drying, vacuum-drying and freeze-drying, de Groot (12) found no damage to the proteins in chicken meat with hot air-drying. Accelerated freeze-drying had no affect on protein of beef or fish (4).

Thiamin losses of meats and vegetables are shown in Table 4. Riboflavin losses average 4 to 6% in freeze-dried chicken cubes (34). Schroeder (49) summarized the losses for water-soluble vitamins during drying of foods. Nutrient losses from dehydration are usually a small part of the total loss (16). Hein and Hutchings (24) reported riboflavin, niacin and pantothenic acid losses for 9 vegetables and in only 2 instances did the loss exceed 10% when the blanched product was considered 100%. In general, losses of thiamin and other water-soluble vitamins, except ascorbic acid, were less than 10% during conventional drying (6).

Freeze-drying yields the highest possible quality and maintains the highest nutritional value of any drying method.

### TABLE 3. Ascorbic acid loss in drying potatoes (22).

<table>
<thead>
<tr>
<th>Tray</th>
<th>Air temperature (°F)</th>
<th>Drying time (h)</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>First stage</td>
<td>Second stage</td>
</tr>
<tr>
<td>Wood</td>
<td>200 → 170</td>
<td>0.92</td>
<td>4.08</td>
</tr>
<tr>
<td>Metal</td>
<td>100 → 130</td>
<td>1.05</td>
<td>2.28</td>
</tr>
<tr>
<td>Metal</td>
<td>200 → 170</td>
<td>0.63</td>
<td>2.47</td>
</tr>
</tbody>
</table>

### TABLE 4. Thiamin losses in drying.

<table>
<thead>
<tr>
<th>Product</th>
<th>Conditions</th>
<th>Loss</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeze-dried pork</td>
<td></td>
<td>30%</td>
<td>Karmas et al. (38)</td>
</tr>
<tr>
<td>Freeze-dried chicken</td>
<td></td>
<td>5 to 6%</td>
<td>Roew et al. (48)</td>
</tr>
<tr>
<td>Freeze-dried pork</td>
<td>-40°C</td>
<td>5%</td>
<td>Thomas and Calloway (53)</td>
</tr>
<tr>
<td>Freeze-dried chicken</td>
<td>1000 μHg</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Freeze-dried beef</td>
<td></td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Vegetables-beansa</td>
<td>Air-dried</td>
<td>5%</td>
<td>Harris and von Loesecke (22)</td>
</tr>
<tr>
<td>Vegetables-cabbagea</td>
<td></td>
<td>9%</td>
<td></td>
</tr>
<tr>
<td>Vegetables-corna</td>
<td></td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>Vegetables-peasa</td>
<td></td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Air-dried pork</td>
<td></td>
<td>50 to 70%</td>
<td>Calloway (6)</td>
</tr>
</tbody>
</table>

*a*Does not include blanching losses.
procedure (9). Fat-soluble vitamins are not usually lost during dehydration. Modern dehydration processes offer good nutrient retention, except for ascorbic acid and beta-carotene. Protein quality deteriorations are minimal in food products currently in production (6).

Bluestein and Labuza (6) reviewed the effects of moisture removal on nutrients. Nutrients that are heat labile and sensitive to oxidation (vitamins A and C) have been investigated most. Losses of 5 to 40% have been reported although there is such a wide variety of processes (e.g., freeze-drying, roller-drying, spray-drying, air-drying) that it is difficult to compare losses. But dehydration processes generally cause nutrient losses similar to those from freezing.

REFERENCES


con't. p. 491


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Cunningham, con’t from p. 483


