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Scientific Foundations, Educational Practices, and Culinary Applications
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Dehydration

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**Introduction**

Water is an important component of foods, even when they are “dry” (Table 29.1). Dehydration (or drying) is the application of heat under controlled conditions to remove by evaporation (or sublimation in the case of freeze-drying) most of the water normally present in a food. Although dehydration is an important unit operation in food engineering and in the food processing industry, it is not extensively practised as such in the kitchen (Guiné, 2018). In fact, there is no such kitchen apparatus as a “dehydrator”, even though some cooks utilize a sort of tray drier to remove the moisture from fruits and vegetables, as well as the kitchen oven (Boyer, 2018). This is unfortunate, since, among other things, the quality of a dry product or ingredient depends on a precise programming of the time–temperature conditions and the humidity of the air.

Dried products and ingredients are ubiquitous in our kitchens, e.g., most cereals and legumes, corn and wheat flour, spices, pasta products, etc. Partial loss of moisture occurs unnoticed in many culinary processes, such as frying, baking, toasting and roasting; on other occasions it is deliberately induced (e.g., stock reductions or oven-dried vegetables). Oftentimes, chefs collect fresh materials directly from the field (wild herbs, edible flowers and leaves, seaweeds, etc.) that need to be dried in their kitchens for later use.

An important characteristic of dry foods in gastronomy is that they become brittle, emit sounds on biting, and are sensed as “crispy” in texture (Tunick *et al.*, 2013). Today, some chefs are exploiting these properties to produce amazing products such as a crispy freeze-dried yogurt and crunchy fish flakes.

**Moisture in Foods**

Cooks have many problems in dealing with moisture in foods because recipes are usually expressed by weight of ingredients, and this includes the water content. Except for ingredients like salt, table sugar, fats and oil, most food ingredients and food have water in them. The common term to refer to how much water a food contains is the “moisture content” ($W$), which is defined in at least two ways:

\[
W_{wb} = \frac{\text{Wetweight} - \text{Dryweight}}{\text{Wetweight}} \times 100
\]

\[
W_{db} = \frac{\text{Wetweight} - \text{Dryweight}}{\text{Dryweight}} \times 100
\]

These definitions lead to much confusion, because moisture on a wet basis ($W_{wb}$) is numerically very different from moisture on a dry basis ($W_{db}$). For example, an apple has a $W_{wb} = 85\%$ and a $W_{db} = 567\%$ (for a quick moisture converter, see https://booksite.elsevier.com/9780123985309/content/calc/Chapter_1/Ex_1_4.html). The moisture of a food is usually determined by weighing a sample and exposing it in an oven to a high temperature (e.g., 105 °C) with circulating air or preferably, using a vacuum oven. The sample is removed after a couple of hours and cooled in a desiccator (to avoid moisture pickup) before reweighing. Moisture content is calculated as the difference between wet and dry weight (see formulae earlier). In food science, there are “official methods” for determining the moisture content of different foods (AOAC, 2016). In actual practice, laboratory moisture balances for routine moisture determination are fast and convenient.

The moisture of foods has major relevance for their chemical, microbiological and physical stability. In general, dry foods are quite stable at ambient temperature, while moist foods are not and need to be refrigerated. A few products, such as honey, jams, some sausages (e.g., salami) and hard cheeses, look moist but are stable at room temperature because they contain a combination of a high concentration of sugars or salt or have a low pH as well as a reduced moisture content. From the chemical and microbiological stability viewpoints, they are a separate class of foods known as “intermediate moisture foods”, or IMF.

**Moisture in Air**

Air on this planet contains water vapour that we cannot see. The amount of water vapour in the air is expressed as percentage relative humidity (% RH). The term “relative” means that it is in...
TABLE 29.1
Approximate Moisture Content of Some Foods and Food Products (on a Wet Basis)

<table>
<thead>
<tr>
<th>Food</th>
<th>Percent moisture (wb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk</td>
<td>87</td>
</tr>
<tr>
<td>Fish</td>
<td>80</td>
</tr>
<tr>
<td>Eggs</td>
<td>73</td>
</tr>
<tr>
<td>Wheat dough</td>
<td>55</td>
</tr>
<tr>
<td>Honey</td>
<td>23</td>
</tr>
<tr>
<td>Raisins</td>
<td>18</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>14</td>
</tr>
<tr>
<td>Rice (and other grains)</td>
<td>14</td>
</tr>
<tr>
<td>Dry pasta products</td>
<td>12</td>
</tr>
<tr>
<td>Nuts</td>
<td>5</td>
</tr>
</tbody>
</table>

reference to 100% RH, which corresponds to saturation or fog, the maximum amount of water that air can take at a given temperature. Interestingly, liquid water is constantly evaporating and being captured by the unsaturated air even at room temperature; otherwise, a floor mopped with water would never dry. This is due to a property called the “vapour pressure” of water in air, or the tendency of liquid water molecules to become vapour whenever they can. The higher the temperature of liquid water, the larger its vapour pressure, until it equalizes with the atmospheric pressure and water boils.

So, exposing “dry foods” to air usually results in the uptake of moisture (see later). This has important consequences when it comes to crispness. A food may be crisp coming out of the oven or fryer and become “soggy” if left in a humid environment.

Hygroscopicity of Foods

Another concept that cooks can use is hygroscopicity, or the capacity of a food to exchange water with air. This means that, for most foods, there is not a “single” moisture content; it depends on the % RH of the air in which they are allowed to equilibrate. Moreover, within a food there may be a moisture gradient between the outside and the interior. Think of fresh bread right out of the oven and French fries just removed from the fryer. In the latter case, while the crust is dry and crispy (moisture around 10%), the mealy interior may have a moisture of 80%. Eventually, the whole fried potato piece will come to an equilibrium moisture content and become limp (Miranda et al., 2005).

The Engineering Approach

From an engineering viewpoint, dehydration involves heat transfer and mass transfer. For water to become a vapour (or steam), heat has to be supplied to account for the sensible heat (increase in enthalpy due to temperature) and latent heat (enthalpy needed for a phase change at a constant temperature). Mass transfer refers to how moisture migrates from the interior of the food to its surface and then is captured by air that is hot and dry, and carried away from the product. Thus, in most dehydration processes, we need a heat source and a moisture sink. The subject of food dehydration methods and industrial equipment was reviewed by Fellows (2017).

Methods for Dehydrating Foods

For a comprehensive review on the subject, the reader is referred to an article by Maisnam et al. (2017), but key points are as follows:

- **“Natural” drying:** sun drying of foods has been practised since ancient times. Most grains are dried in the field by direct exposure to the sun (e.g., beans, lentils, corn, wheat, etc.). Dry grains become brittle and can be ground into flours and meals (e.g., wheat flour, corn meal, etc.) that are widely used as convenient ingredients by chefs. The same can be said for some fruits and vegetables (e.g., sun-dried tomatoes and raisins). Other naturally dried products have found their way into several local gastronomic dishes. Charqui is a typical IMF product ($a_w$ of 0.70–0.75) obtained by salting and sun-drying meat from different sources and used in soups or dishes or as a snack (Torres et al., 1994). The Incas of the highlands of Peru froze potatoes during the cold nights and let them thaw in the sunny days while exuding the water. The resulting naturally freeze-dried chuño (black dried potatoes) or tuna (white dried potatoes) were later ground into a flour (Peñarrieta et al., 2012).

- **Air drying** is the process of controlled water removal, usually by circulating hot and dry air over a piece of food in a chamber (Figure 29.1a). In high-moisture cellular material such as plant and animal tissues, it is common to observe shrinkage of food pieces during air drying (e.g., as happens to a grape when it becomes a raisin). Product shrinkage is mainly due to the existence of moisture gradients within a product, which generate structural stresses leading to contraction and collapse of the cellular structure (Aguilera et al., 2003). Rehydration of dried fruits and vegetables does not locate the water where it was in the fresh tissue and generally leads to poor quality (or different) products (e.g., raisins, charqui).

- **Spray drying** is a method for drying liquid foods (fluid milk) or extracts (coffee), in which a nozzle distributes the liquid as droplets (like the spray nozzle of a garden hose) that fall into a chamber with circulating hot air (between 120 °C and 180 °C) (Figure 29.1b). Interestingly, as long as there is liquid water present in the falling particle, the temperature will remain much lower than that of the surrounding air (i.e., at the so-called wet-bulb temperature). The droplets continuously lose water to the warm air and become dry particles at the bottom of the chamber, from where they must be quickly removed to avoid excessive heating and browning of the dry powder. Although this would be an attractive method for cooks to prepare dry ingredients
from liquid extracts and juices, it has not found its way into modern kitchens. However, there are several models of lab bench spray driers available for research and product development.

- **Drum drying** takes place when a thin layer of a wet and viscous paste is dried over a hot surface and continuously removed as a sheet of dry product. This may be accomplished in the kitchen by contacting a wet food mix or a slurry with a hot metal surface (Figure 29.1c). The final products are dried flakes, as is the case with instant mashed potatoes and gelatin sheets.

- **Freeze-drying, or lyophilization,** involves removing water in the form of vapour from a frozen product (e.g., at –40 °C) held under high vacuum (e.g., at less than 5 Pa, or 5 millionths of atmosphere), a process called sublimation. As water sublimes (passes directly from ice to vapour), the boundary separating a nearly dry outer layer from the remaining central frozen portion moves to the interior of the product (Figure 29.1d). Since there is never any liquid water present, the product’s matrix does not collapse, and the original structural appearance is preserved. Also, micropores are formed in places occupied by tiny ice crystals, facilitating fast and homogeneous rehydration. Moreover, the food never reaches very high temperatures, so freeze-dried foods maintain the shape, texture, colour and flavour of the natural product much better than with any other method of food drying. The main applications are freeze-dried instant coffee, berries and small fruit pieces, and vegetables for high-quality foods.

**REFERENCES**


**FIGURE 29.1** Main modes of drying foods.