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Opinion

Discussion of Interaction of Foods and their Main Components with Water

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Abstract

This article discusses the interaction of foods and their main components with water. In particular, the processes of sorption and desorption of water vapor, as well as the role of moisture in food storage are considered.

Opinion

It is known that food products consist of three main components - fats, proteins, and carbohydrates. Fats or lipids are triglycerides of saturated or unsaturated fatty acids. Fats perform a variety of important functions. They are involved in the formation of the phospholipids of cell membranes and in the synthesis of specific lipids of a given organism. Fats regulate the production of hormones, dissolve and help the absorption of vitamins A, D, E, and K, increase skin elasticity, protect the body from hypothermia in the form of subcutaneous, partially supply energy for cells, etc. Although the calorific value of fats is quite high, about 9 kcal per gram, their need for the human body is relatively small and normally does not exceed 65 g per day. Therefore, fats are inferior in supplying the body with energy to carbohydrates, the daily intake of which is much higher. Proteins are macromolecular compounds consisting of residues of amino acid linked in chains through peptide bonds, -CO-NH-. Proteins have a complex structural organization. Along with the primary molecular structure, they have a secondary helical structure, which in turn forms a spatial tertiary structure; in addition, there is a quaternary structure, which is formed by combining several tertiary structures into a final form that determines the biological functions and properties of a given protein. The main purpose of food proteins is to supply the body with amino acids that are used for the synthesis of all specific proteins and enzymes of this organism. Being low-caloric, proteins have a small contribution to supplying the body with energy. The recommended daily intake of food proteins is about 91g.

Carbohydrates are a broad class of organic substances, which include monosaccharides, oligosaccharides, and polysaccharides. A typical example of a food monosaccharide is glucose; the example of an oligosaccharide is the natural trisaccharide raffinose, while examples of polysaccharides are starch and glycogen. A characteristic feature of all oligo- and polysaccharides is that, as a result of complete hydrolysis, they give monomeric sugars. Although the average calorific value of carbohydrates is about 4 kcal per gram, their recommended daily intake should be 4.0-4.5 times higher than fats. Therefore, carbohydrates are the main energy source for the organism, generated by the complete oxidation of glucose into water and carbon dioxide in living cells. The unused part of glucose is poly-condensed into glycogen, which is a reserve source of energy and is consumed as needed, turning back into glucose, the oxidation of which to water and carbon dioxide provides energy. When carbohydrate and therefore glucose intake greatly exceeds the body's need, the liver converts glucose into fats, which are stored as a reserve in fat depots. Therefore, in order to prevent obesity, it is necessary first of all to reduce the intake of carbohydrates. It is known that the production, processing, and storage of food products are directly related to their interaction with water. For example, flour should be stored at low air humidity to prevent moisture, swelling, clumping, and spoilage, while vegetables should be stored at high air humidity to prevent them from drying out.

Sorption and desorption processes of water are described by isotherms expressing the amount of sorbed or desorbed water (W) versus relative air humidity (RH) at a constant temperature, for example at 298 K. To study sorption, a dry sample is placed in a sealed vessel and evacuated, and then the vessel is filled with a small amount of water vapor with a given RH value, maintained until equilibrium is established, after which the amount of water W, g, sorbed by 1 g of dry sample is measured. In the desorption process, on the contrary, the RH value is gradually decreased in the vessel that contains the wet sample, and the equilibrium value of W is measured [1-4].

Fats are hydrophobic substances that practically do not sorb water. In contrast, proteins and especially carbohydrates are hydrophilic substances due to the presence of such polar groups as peptide, amino, and hydroxyl groups. Therefore, food products containing a significant amount of these hydrophilic components are able to absorb water vapor (WV) when stored in a humid atmosphere. Since isotherms of WV sorption for proteins and carbohydrates have sigmoidal shapes, a food product containing these components also has a sigmoidal isotherm (Figure 1).

This isotherm can be divided into four main areas: the initial section I, where the main components of the product having low water content are in a glassy state; the middle linear section II, where the gradual absorption of VW occurs and the transition of moistened loose-packed amorphous regions to the highly elastic state begins, and the final section III, where the wet amorphous regions of all components completely turn to the highly elastic state, which contributes to a sharp increase in the further sorption of WV. In addition, in section IV, at very high values of relative air humidity, RH>0.9, the process of WV sorption in the amorphous regions of the components can be accompanied by WV condensation in nanosized capillaries. An example of the VW isotherm for a dry food product, wheat flour (WF) containing 74 wt. % of carbohydrates (CH), 11wt. % of proteins (PR), and 15 wt. % of hydrophobic components (lipids, minerals, etc.) is shown in Figure 2. As can be seen, the isotherm of this food product (WF) is a superposition of isotherms of its hydrophilic components, CH and PR.

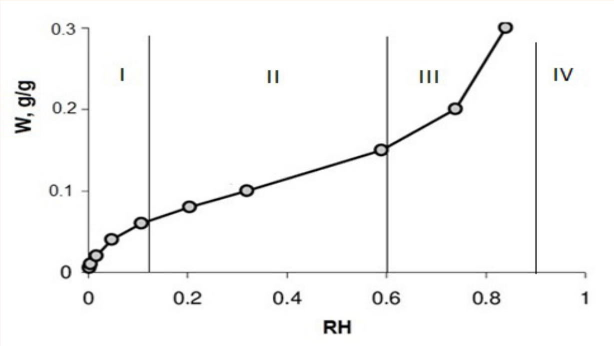

Figure 1: Typical sigmoidal isotherm of VW sorption by a dry food product.

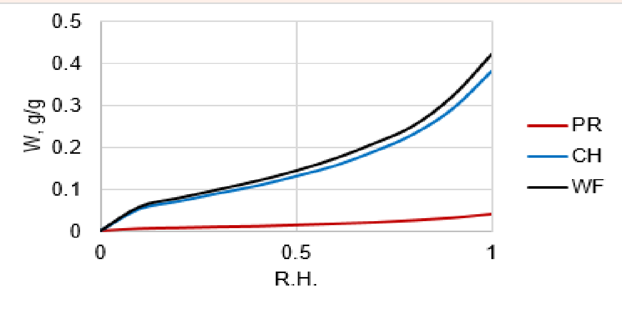

Figure 2: Sigmoidal isotherms of VW sorption by dry wheat flour and its hydrophilic components.

It was proved that the sorption of WV by food products and their hydrophilic components, proteins, and carbohydrates, occurs according to the absorption of water molecules by polar groups located in the volume of the amorphous domains of the components. It is also known that the real specific surface area of dry food products and their components, measured by the adsorption of inert gases and vapors, is very small and does not exceed a few square meters per g. As a result, such popular sorption models as mono- and multimolecular adsorption of WV on the surface of pores should be excluded from consideration. For the same reason, it makes no sense to use various equations of surface adsorption to calculate the isotherms of WV sorption by food products and their hydrophilic components. Moreover, such equations do not allow one to adequately calculate the entire sorption isotherms and found sorption parameters.

In our studies, based on the absorption mechanism and thermodynamics of interaction, the following simple equation of sigmoidal isotherm was derived:

$$W = Wo / [1 - K \ln(RH)] \quad (1)$$

where Wo is the maximum sorption value at RH =1.

To find the value of Wo and the coefficient K, this equation must be presented in a linear form:

$$W^{-1} = Wo^{-1} - (K / Wo)\ln(RH) \quad (2)$$

For example, for such carbohydrate as amorphized starch, the isotherm of WV sorption indeed is straightened in the coordinates of eq. (2) (Figure 3).

Extrapolating the dependence 1/W= f[-ln(RH)] for amorphized potato starch to the value of the corresponding -ln(RH) =0, the value of 1/Wo and its reciprocal, Wo= 0.5 were found, while from the slope coefficient, K/Wo, the parameter K=2.7 was calculated. It was shown, that after excluding a small amount of capillary-condensed water, the experimental sigmoidal isotherm almost completely coincides with the calculated isotherm, which indicates the adequacy of the calculating method based on the WV absorption mechanism. The isotherms of WV desorption from wet food products and their hydrophilic components also have a sigmoidal shape. However, for the same sample, the desorption isotherm is higher and therefore does not coincide with the sorption isotherm. This phenomenon is called hysteresis of sorption-desorption (Figure 4).

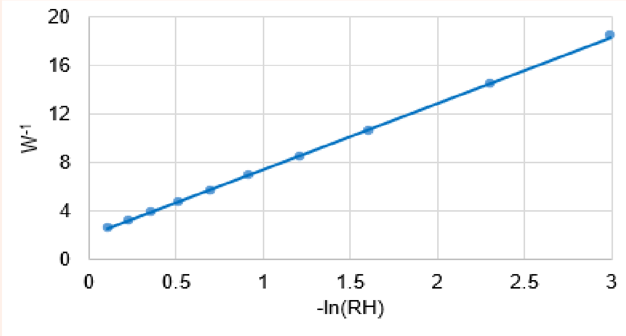

Figure 3: Linearized isotherm of WV sorption by amorphized potato starch at 298 K.

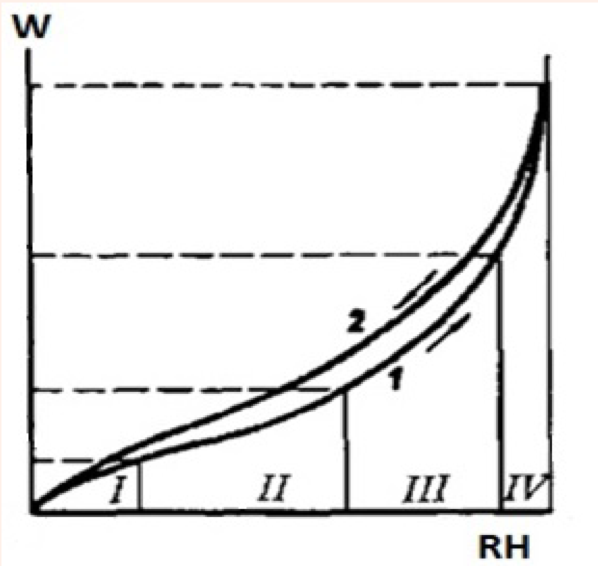

Figure 4: Hysteresis of sorption-desorption.

The most likely explanation for this phenomenon is that the wet components of the food product - proteins and carbohydrates, at high RH values are highly elastic and therefore their sorption centers are completely accessible to water molecules. On the other hand, dry hydrophilic components are in a glassy state, which limits the accessibility of water molecules to polar groups - sorption centers. Thus, the number of sorption centers available for WV during desorption will be higher than during sorption, which causes the hysteresis phenomenon. After excluding capillary condensed water, the desorption isotherm can be calculated using an equation similar to the eq. (1), but with a smaller parameter K. For example, for amorphized potato starch, the parameter K in eq. (1) during WV desorption will be 2.2 instead of 2.7 during sorption. Relative humidity of air plays a decisive role in the preservation and spoilage of food during storage. Numerous studies have shown that oxidation of fats can occur even at room temperature if the RH value exceeds 0.25 (at the beginning of section II of the isotherm in Figure 1). If the food product has an acidic pH value, then its oligomeric and polymeric carbohydrates may hydrolyze at room temperature if this product has been stored in humid air with RH>0.3 (in the middle of section II of the isotherm in Figure 1). To prevent enzymatic hydrolysis, storage of the product in an atmosphere of low humidity, RH<0.4, is required (in section I and at the beginning of section II of the isotherm in Figure 1), while to prevent the growth of microorganisms in food products, it is sufficient that the RH value during storage does not exceed 0.6 (lower than section III of the isotherm in Figure 1). For a finished food product containing a constant standard amount of water (W_c), it is also important to know the relative humidity (RH_c), when stored in a sealed package at a constant temperature (for example, at 298 K). For this, a series of products with different W_c values is taken, placed in sealed packages equipped with a hygrometer, and after exposure, the relative air humidity, RH_c, is measured. It has been shown that in this case, for different products with different standard water contents, W_c, the following general Γ-shaped plot of RH_c versus W_c can be obtained (Figure 5).

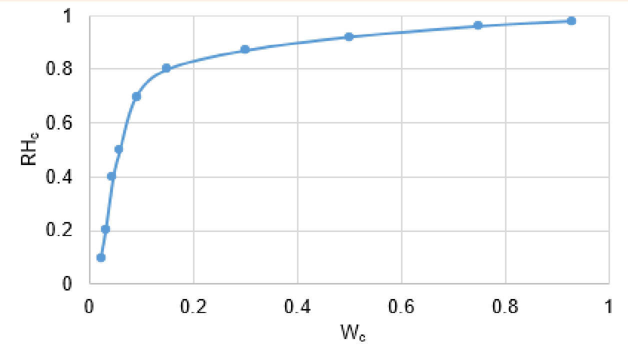

Figure 5: Dependence RH_c on W_c for various food products.

This dependence can be expressed mathematically using the following equation:

$$Y = 1 - Ae^{-kx^n} \quad (3)$$

where $Y=RH_c$, $X=W_c$, A=3.9, k=4.93, n=0.3, e is Euler's constant.

The left steep branch of the graph in Figure 5 applies to products having only bound absorbed water, the standard water content of which does not exceed 0.2 g/g; these products can be, for example, crackers, flour, baked goods, cereals, pasta, nuts, tea, coffee, etc. The middle flat part of the graph includes products with higher standard water content, from 0.2 to 0.6, for example, feta cheese, marmalade, jam, etc. These products may contain bound water, absorbed, hydrated and capillary, as well as a relatively small amount of free water. The end of the graph refers to foods with high free water content, such as fresh meat, fresh fruit, milk, juices, etc.

Thus, in this article, the processes of sorption and desorption of water vapor by food products and their hydrophilic components - proteins and carbohydrates, were discussed. The important role of moisture in food storage is shown.

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