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THEORETICAL RESEARCH REGARDING THE MASS BALANCE SHEET OF THE PRESERVATION OF BERRIES THROUGH DRYING/DEHYDRATION

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Abstract: *This paper presents some theoretical aspects regarding the mass balance sheet of the technological process of preserving berries, which are some of the main products in human alimentation, by means of drying. They are rich in sugar, vitamins, mineral substances, but also with a high content of water (75-92%) which can lead to conditions favouring the development of microorganism, responsible for their degradation. Starting from the main relation of the mass balance sheet from a technical equipment for drying berries and following the drying/dehydrating process which leads to the reduction of the water content through convective evaporation with the help of hot air, the necessary amount of hot air in order to remove a precise quantity of humidity.*

Key words: *berries, drying preservation, mass balance sheet.*

1. Introduction

Dried fruit are frequently used in the traditional Romanian alimentation. The climatic conditions in which Romania is situated, with 4 seasons (winter, spring, summer and autumn), with a harvest yield a year, has made it possible from ancient times for people to dry cure fruit in order to provide food in-between harvests, especially during winter.

The fruit which are conserved by drying are apples, pears, plums, apricots and grapes (without pits). They used to have the most diverse alimentary purposes. Later on, when the food industry started developing rapidly, other fruit were starting to get dried like, for example, berries: blackberries, raspberries, cranberries, blueberries etc.

Preserving food by drying, which at the beginning was done through sun drying, is a process which was enhanced by using technical equipment which used non-renewable heat sources.

Modern technology is based on forcing dehydration, which is a perfected drying technique. The dehydrated fruit, properly packed, can be kept for a long time, without the need of cold storage.

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The main methods of preserving fruit by eliminating the water are:
- natural drying;
- controlled dehydration.

The definition, specific elements, similarities and differences of the terms drying/dehydration are presented in Table 1.

Defining the notions: drying and dehydration respectively Table 1

	Drying	**Dehydration**
Purpose of the operation	Removal of the material's humidity, namely the increase of the concentration of solid substances until reaching values meant to assure the stability of food products when it comes to preserving them.	
Definition	= it is the ***natural process*** which, by means of ***heat transfer***, assures the ***evaporation of water*** at the surface of the product, which allows the removal of the humidity of materials which are in natural state, or exposed as paste, grains, slices.	= it is the ***artificial process***, carried out by means of ***controlled heat transfer and conducted by man***, the ***"vaporization" of water*** being practically made through the material which undergoes dehydration. This allows the removal of the humidity of materials exposed as paste, grains, sheets, plates, cubes, discs, etc. or even under the form in which they are found in nature.
The principle of the method	The evaporation of humidity at the surface of the material and the diffusion of humidity from the inner layers to the surface of the material.	
Particularities	To the drying process the following contributes: • the heat transfer from the naturally sun heated air to the material meant to dry; • the evaporation of the water from the surface of the material meant to dry; • entrainment and taking off the water vapours from the surface of the material; • migration of water from the inside to the surface; • the material which is meant to dry receives on its surface a certain quantity of heat, therefore a part of its humidity from the surface turns into vapours; • the air, when naturally heated by the sun, becomes a "heat-carrying gaseous agent", with a double role: - to bring the necessary heat for drying; - to take and remove the formed vapours from the system.	To the dehydration process the following contributes: • the heat transfer from the artificially heated air by using fuels or electric current to the material under dehydration; • the vaporisation of water from the material under dehydration; • leading a forced air circulation of the artificially heated air in order to assure the entrainment of water vapours emanated from the material meant to dry. There are two agents which participate in the process of dehydration: • the material under dehydration, which receives a quantity of heat, therefore the overall temperature increases, assuring the forced vaporization, total or partial of the contained humidity; • the heated air which is a • "heat-carrying gaseous agent" with a double role: to bring the necessary heat for water vaporization with the material, and to take and remove the formed vapours from the system.

Conclusions	• Sun-drying is one of the oldest methods of preserving fruit; • In the past, fruit used to be dried in the sun, in sunny and extremely airy places; • The sun-drying process can last a few days and the fruit had to be covered with a cloth with rare weaves in order to protect them from the insects.	• Modern technology allows the dehydration of fruit to take place at temperatures that get lower and lower.
Similarities	• They are procedures based on reducing the water content, which determines the concentration of soluble substances to increase until they reach the proper stability for preserving the fruit; • The removal of water from the fruit has to be done under supervision in order for the hydrophilic colloids to maintain their ability of rehydration. • Both processes have the same purpose, namely the partial or total removal of the exposed material's humidity; • Through sun-drying or through heat dehydration the weight of the fruit decreases 5-10 times in comparison with the fresh state that they are in; • Drying and dehydrating fruit is the technological process through which the natural content of water is reduced until it is reached a level that prevents the activity of micro-organisms without destroying the tissue or depreciating the alimentary value of products; • It is important to be specified on the label of the final product the way in which the water removal had been done; • On the label the following should be mentioned: - naturally dried product; - dehydrated product.	
Differences	• Drying is a natural process, realized in nature, without human intervention, while dehydration is an artificial process, conducted and controlled by man; • Recently, because of economic reasons, but also because of the product's safety, the removal of water from the fruit is done in the following way: - in personal households, but the sun-drying is less and less used, the process being considered "classic drying"; - in organizations specialized in preserving fruit by means of dehydration which is a process of forced drying, conducted and controlled by man.	

The transformations suffered by fruit during drying/dehydration are:

- *Structural transformations:* the shrivelling and volume reduction because of the decrease of water content and tissue contraction;

- *Colour transformation:* degradation of the fruit's colour depends on the temperature, on the time it takes to eliminate the water, on the presence of heavy metals, on the reduced sugar content, but also on the results of the oxidative processes that occur;

- *Flavour and savour transformations:* when it comes to dehydrating products by hot air, there is an entrainment with vapours of the specific flavours, therefore certain flavour losses occur. When it comes to drying, flavour losses are determined by the duration of the process and the relative humidity of the environment in which the raw materials are exposed.

- *Alimentary value reduction:* during the dehydrating process, in terms of the applied heat technique, there are some sensitive transformations in the chemical composition of the product, thing which influences their alimentary value.

When it comes to the drying process, but also to the dehydrating process there are some fruit modifications, such as:

- volume and weight are reduced;
- energy value is increased;
- they are easy to prepare;
- a part of the chemical components is lost (water, carbon dioxide, protein degradation, vitamin losses).

Generally, by heat treatments (heating, boiling) the initial quality of the fruit is lost, the carbohydrates and organic acids are preserved. As a result of the decreasing weight, the cost for transportation, moving and storing of fruit diminishes.

The technological flux of the drying/dehydration of berries is showed in Figure 1.

Preserving berries through drying/dehydration involves the following approach.

Drying or dehydration is the technological process through which, fruit which is considered raw material, and a certain quantity of water is removed through heat, after which a physico-chemical state meant to maintain their nutrient value, but also unfavourable conditions for the activity of microorganisms.

If for the removal of water *solar energy* is used, then it is a *drying process*, if it is by means of thermal energy and a *fuel or another energy source* is used, then it is a *dehydrating process.*

The movement of water in the raw material under dehydration is conditioned by the forms in which it is found in the products (free water, colloidally bound water and chemically bound water).

During the process, removing water from the products can be realized through diffusion, which can be:

- external (thanks to the evaporation from the product's surface);
- internal (it represents the phenomenon of the water's movement from the inner to the outer surface of the product).

In the dehydrating process a very special importance is that of the ratio between the internal and external diffusion.

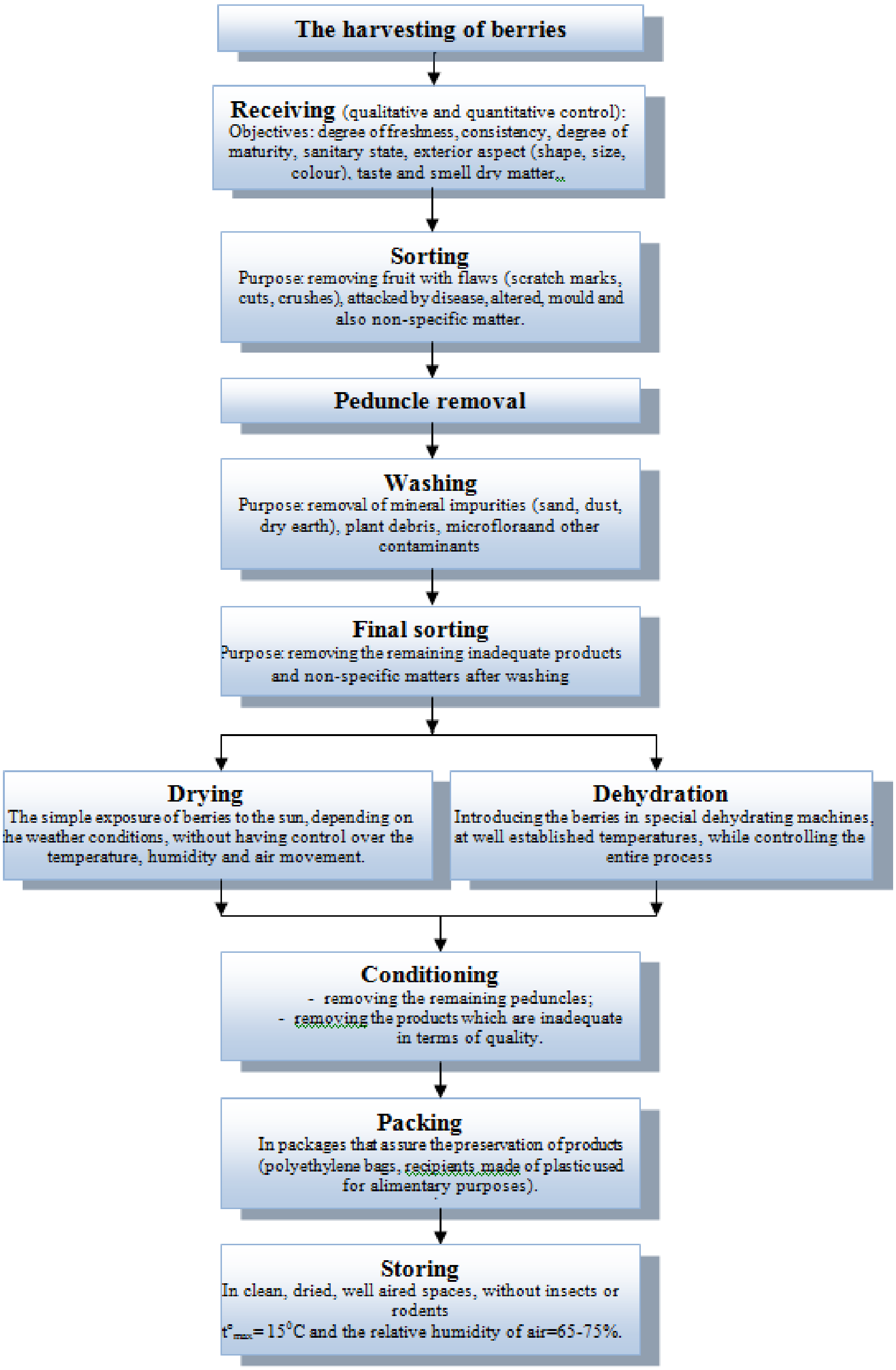

Fig.1. *Technological figure of the drying/dehydration process of berries*

A big speed of external diffusion and a small speed of internal diffusion influence the drying of the product's surface, determining the appearance of a shrivelling phenomenon. This will make it more difficult to continue the process, determining under some conditions the appearance of cuts on the product's surface, with important losses of cell fluids.

The drying / dehydration process takes place in three successive phases (Figure 2).

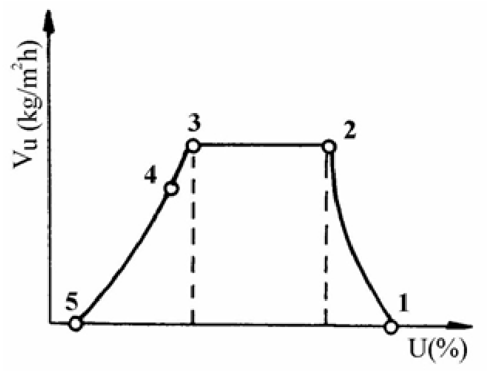

Fig. 2. *Product humidity variation in terms of drying/dehydration speed*

- Phase I represented by curb 1-2: the product is heating and only a part of the heat is used in water evaporation;
- Phase II represented by curb 2-3: the dehydration speed is constant and the water from the product is removed; the phase lasts until internal diffusion stops;
- Phase III represented by curb 3-5; on the 3-4 zone a part of the colloidal water is eliminated, and on the 4-5 a part of the absorption water.

The dehydration speed increases once the temperature gets higher, the diffusion resistance and thickness of the product decrease, the ratio between the product surface and its water content is higher and the moving speed of hot air is also higher.

The relative humidity of air has a great influence on the dehydration speed. The increase of the relative humidity of air reduces its capacity of absorbing the water vapours from the product, while the low relative humidity determines a forced removal of water from the product, with ruptures the cell membranes.

The dehydrated fruit are kept in special packages, fit for each product, in well aired spaces, at the temperature of 15-18 ^{0}C and the relative humidity of air between 70-75 % [6].

The dehydrated products differ from the raw material in the concentration of dry substance (it determines the decrease of volume, the increase in volume, the increase of the energy and plastic value), the modification of the ratio between the main components of the dry substance, the quantitative decrease of some, the increase of others, the partial or total disappearance of some components and the appearance of others.

During the time in which the dehydrated products are kept the following important modifications might appear:

- discoloration: 'browning';
- becoming sugared: especially when it comes to whole or cut fruit.

Water content of fresh and dried/dehydrated berries Table 2

Species	Water content	
	In the fresh product [%]	In the dehydrated product [%]
Blueberries	79-84	16-20
Red berries	83-86	16-22
Strawberries	83-93	20-25
Sea buckthorn	84-94	8-14
Black currants	75-86	18-20
Red currants	79-88	20-22
Rose hip	32-47	8-12
Raspberry	75-94	22-24

2. Material and Method

Mass transfer is a physical transformation based on the transfer from a phase to another, using differences of vapour pressure, solubility, concentration, along with a chemical gradient. It is known that the basis of the transfer of substances from a phase to another is represented by the diffusion phenomenon, therefore:

- mass transfer is a field that studies the laws and phenomena of separating homogeneous mixtures through diffusion;
- mass transfer operations are those physical operations which use diffusion (the most important ones are: absorption, adsorption, extraction, rectification, drying and crystallisation).

In the study of mass transfer there are two ways of expressing the composition of phases: fractions or mass, volume or molar ratio calculation [5].

The molar fraction (C_M) is the ratio between a component's total number of moles and the mixture of the components' total number of moles. For a mixture with *n* components, each with N_1, N_2, ... N_n moles, the molar fraction for the *I* component will be:

$$C_{Mi} = \frac{N_i}{N_1 + N_2 + \ldots N_n}, \tag{1}$$

component moles/mixture moles, if it is expressed under the form of mass concentrations (C_{m1}, ... C_{mn}), the result is:

$$C_{Mi} = \frac{\dfrac{C_{Mi}}{M_{0i}}}{\dfrac{C_{m1}}{M_{01}} + \ldots \dfrac{C_{mn}}{M_{0n}}}, \tag{2}$$

component moles/mixture moles, in which M_0 is the molar mass.

It should be mentioned that only when it comes to gaseous substances the molar fractions are numerically equal with the volume fractions (C_M=C_V).

The molar ratio (C_M^0) represents the ratio between the number of moles with two components. When it comes to a mixture with *n* components, it can be written as:

$$C^0_{Mi,1} = \frac{N_i}{N_1};...;C^0_{Mi,n}\frac{N_i}{N_n}. \quad (3)$$

The mass fraction (C_m) represents the number kilograms of the substance of a component, found in a kilogram of mixture:

$$C_{mi} = \frac{M_i}{M_1 + M_2 + ...M_n}, \quad (4)$$

component kg /mixture kg

In practice, the mass ratio is especially used to express concentrations of binary solutions of salt in the water or other solvents.

The volume fraction (C_V) represents the ratio between the number of units of the volume of a component found in the volume unity of the mixture:

$$C_{Vi} = \frac{V_i}{V_1 + V_2 + ...V_n}, \quad (5)$$

$m^3$of component/$m^3$of mixture

The volume ratio (C_V^0) is similarly expressed as the molar and mass ratio:

$$C^0_V = \frac{V_i}{V_1};...;C^0_{Vi,n} = \frac{V_i}{V_n}. \quad (6)$$

Materials with fibrous, porous, gelatinous structure, of organic nature, in which the bond of the humidity with the material is strong, present low values of equilibrium humidity, the migration of the humidity throughout them taking place through diffusion. The percentage of the drying zone with constant speed is low or completely missing. When the drying speed is too forced, the difference between the humidity of the superficial layers and that of the core can provoke the irreparable deterioration of the product by cracking, twisting, exfoliation. That is why the drying speed of these materials is limited and the intensity of the heat transfer should not go beyond its bearing grade [1], [3], [4].

The mass balance sheet of the drying room is expressed by the formula:

$$G_1 - G_2 = w_1G_1 - w_2G_2 = L \cdot \left(x_2 - x_1\right) = \Delta W \quad (7)$$

where:

- G_1: represents the humid mass material [kg];
- G_2: dried mass material, in [kg];
- w_1: the relative humidity of the material when entering the drier [%];
- w_2: the relative humidity of the material when exiting the drier [%];
- L: dried air flow [kg/s];
- x_1: the absolute humidity of the air when entering the drier [%];
- x_2: the absolute humidity of the air when exiting the drier [%];
- ΔW: the quantity of humidity evacuated from the material [kg/s].

Replacing the terms with known values, for example*,* for *100 g of rose hip* with an *initial humidity of 94%*, and the *final one of 8%*, at *a flow of dry air of 0,481 kg/s*, the quantity of humidity evacuated from the material is *ΔW= 0,009 kg/s*.

The decrease of humidity can be calculated with the formula:

$$U = \frac{W_1 - W_2}{100 - W_2} \cdot 100 = 93{,}47\left[\%\right]. \quad (8)$$

When there are no material losses, *the quantity of dry substance* remains constant before and after drying. This can be mathematically expressed with the help of the formulae:

$$G_U = G_1 \frac{100 - W_1}{100} = G_2 \frac{100 - W_2}{100} = 0{,}006 \ [kg] \quad (9)$$

Therefore, $G_2 = 0{,}0065$ *kg*.

The values of G_1, respectively G_2 can be expressed as such:

$$G_1 = G_2 \frac{100 - W_2}{100 - W_1} = 0{,}099 \left[kg\right],$$

$$G_2 = G_1 \frac{100 - W_1}{100 - W_2} = 0{,}0065 \left[kg\right]. \quad (10)$$

The removed humidity by drying represents the difference between the mass of the humid material and the mass of the dried material:

$$W = G_1 - G_2 = 0{,}0925 \ [kg]. \quad (11)$$

By replacing the value of G_2 the obtained result is:

$$W = G_1 - G_1 \cdot \frac{100 - W_1}{100 - W_2} = 0{,}0925 \left[kg\right],$$

or (12)

$$W = G_1 \frac{W_1 - W_2}{100 - W_2} = 0{,}0925 \left[kg\right].$$

Similarly, by replacing the value of G_1 the obtained result is:

$$W = G_2 - G_2 \cdot \frac{100 - W_2}{100 - W_1} = 0{,}0931 \left[kg\right]$$

or (13)

$$W = G_2 \frac{W_1 - W_2}{100 - W_1} = 0{,}0931 \left[kg\right]$$

Air consumption when dehydrating berries:

In a dehydrator without losses, the quantity of completely dried air which goes through, as well as the quantity of completely dried material remain unchanged.

Therefore, when it comes to a stationary process, *the total quantity of humidity* is formed of:

- *the humidity of the dehydrating material*: $G_1 \cdot \frac{W_1}{100} = 0{,}09306 \left[\%\right]$;
- *the humidity of the air when entering the dehydrator*: $Lx_1 = 0{,}36075 \left[\%\right]$;
- *humidity of the dehydrated material*: $G_2 \cdot \frac{W_2}{100} = 0{,}00052 \left[kg\right]$;
- *air humidity when exiting the dehydrator*: $Lx_2 = 0{,}45695 \left[\%\right]$.

If there are no losses, the total humidity remains constant and the equality is respected:

$$G_1 \frac{W_1}{100} + Lx_1 = G_2 \frac{W_2}{100} + Lx_2 \quad (14)$$

The humidity removed from the material is:

$$W = G_1 \frac{W_1}{100} - G_2 \frac{W_2}{100} = 0{,}09254 \left[kg\right] \quad (15)$$

By comparing equations (14) and (15) it results that:

$$W = L \cdot \left(x_2 - x_1\right) = 0{,}09254 \left[kg\right] \quad (16)$$

Therefore, *the total consumption of air* which is needed for the dehydration is expressed through the relation:

$$L = \frac{W}{x_2 - x_1} = 0{,}4627\left[\text{kg/s}\right] \qquad [17]$$

The particular air consumption, *l*, meaning the ratio of the air consumption and 1 kg humidity:

$$l = \frac{1}{x_2 - x_1} = 5\left[\text{kg/kg umiditate}\right]. \ (18)$$

3. Conclusions

Drying is a process of diffusion through which, with the help of thermal energy, water is removed from the solid or liquid material, through the evaporation of humidity and the removal of the formed vapours. In the food industry drying is used as a method of preserving different products. Being a transfer process, simultaneously by heat and mass, drying is influenced by factors dependent upon:

- the material exposed to drying: flow, initial and final humidity, nature and presentation form, heat sensitivity;
- the drying agent: temperature, relative humidity, pressure;
- the drying operation: drying temperature, drying duration, ways of carrying out the drying process (continuous or discontinuous).

Food drying is known as the oldest preservation method. Initially practiced in the households from the country-side for personal needs, the method extended at an industrial level, therefore dehydration method is a perfected procedure for drying fruit which is permanently improved and continuously modernized.

The quality of the dried fruits is mostly dependent on the way in which the drying/dehydration is done, that is why the entire process should be intensely monitored.

The stability of preserving dried/dehydrated fruit for a long time offers the possibility of commercializing them at any moment and throughout the entire year, contributing to a diversified fruit consumption throughout the entire year.

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