MICROWAVE-ASSISTED FOAM-MAT DRYING TECHNIQUE FOR PRESERVING THE PROPERTIES OF HONEYDEW MELON

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ABSTRACT: The paper presents a recent application of the fast nonconventional microwave heating a fruit (honeydew melon) for removing the high moisture content (above 90 %) in order to preserving its qualities. The fruit was prepared as a paste in which a foaming agent (egg white) and a foam stabilizer (carboxymethyl cellulose) were inserted for obtaining an expanded product, facilitating the removal of water. By drying and fast heating the fruit, the required conditions for its preservation are achieved, keeping ß-carotene and C-vitamin unchanged. The microwave heating parameters were: product temperature between 190-250 ºC, heating and drying time between 1.50-2.41 min, heating rate between 95.4-113.3 ºC/min, water amount removed by vaporization between 14.8-15.3 g and energy consumption for the water vaporization between 4-6.2 W/min.
KEYWORDS: foam-mat drying, food preservation, moisture, microwave heating, egg white, carboxymethyl cellulose.

1. INTRODUCTION

One of the major problems of fruit and vegetable producers is the preservation of their nutritional qualities by avoiding microbial and chemical spoilage. The microflora developed in altered products during storage can be transmitted to neighboring healthy products [1]. The availability for a long time of fresh food products is done through preservation techniques. The most effective way to reduce the water activity in the composition of fruits and vegetables is their drying (dehydrating), widely used.

Due to the stability of the products and the increase in their shelf life, dehydrated fruits and vegetables are increasingly sought after on the market. Various drying techniques for food products are known: use of solar radiation, freeze drying, and vacuum drying [2].

In the last decade, food engineering, including both food science and chemical engineering, is constantly evolving. Initially starting from the preservation and stabilization of food, now the emphasis is on maintaining a high level of product quality. Several preservation technologies developing the classic methods of food drying are in the interest area of research teams from different countries of the world, which have large fruit and vegetable productions. The work [3] critically analyzes the new techniques capable of increasing the drying rate in order to preserve the food quality with minimal losses. Pulsed electric energy, ultrasound, plasma, microwave heating, ultraviolet light microbial (only for liquid foods), pulsed light and infrared heating are analyzed in this book.

Due to the high water content (above 75 %) fruits and vegetables are very perishable. It is known that water creates ideal conditions for the growth of bacteria. Also, the enzymatic and microbial activity in these foods is due to the water content. Therefore, the elimination of water is equivalent to eliminating the possibility of the formation of microorganisms that cause food spoilage. The process of drying the fruits and vegetables is the solution to eliminate the conditions that favor the development of enzymes and microbes, increasing the stability of these products.

Foam-mat drying is a technique through which food concentrates in aqueous form can eliminate the water content in a short time with minimal quality changes. According to [2, 4], this process is most suitable for extracts from fruits and vegetables that are very sensitive to heat as well as those that are viscous, sticky, and difficult to dry by other methods (e.g. spray drying). In principle, fruit juices and aqueous vegetable solutions can be dried by this method without losing the initial nutritional qualities. Foam-mat drying with low thickness layer (about 1 cm) using air at 55-85 ºC, in presence of an expanding agent and a foam stabilizer incorporated into the food, forms a stable porous mass by growing the initial volume. The foam-mat drying method is more cost effective compared to vacuum drying, spray drying and freeze drying. The advantage of foam-mat drying is the significant reduction of the process time compared to foam-free drying methods. The resulting porous mass is then ground and thus preserved.

The process of expanding the food can be done by two usual methods: bubbling by introducing air into the aqueous mass containing a foaming agent and a foam stabilizer of fruit or vegetables, the aqueous solution being transformed into foam as well as continuous stirring with special devices of the aqueous mass (containing a foaming agent and a foam stabilizer), which allows the air infiltration in a more efficient way than the first method [4].

The main expanding agents used in the drying process of foods are egg whites and soy proteins and as foam stabilizers are often used carboxymethyl cellulose and glycerol monostearate. All these materials are organic and edible.

In the paper [5], several experiments following the foam-mat drying for various types of fruits and vegetables (yacon juice, mango pulp, papaya powder, cherry powder, tomato powder, guava paste and banana paste) with expanded agents embedded in the food paste are shown. In these experiments the egg white was used as an expanded agent was used in all cases up to a maximum of 20 %, usually together with carboxymethyl cellulose (maximum 2 %). The thickness of the wet paste layer deposited in the trays was generally small (less than 1 cm) and the hot air temperature required for drying did not exceed 80 ºC. Higher amounts of hot air for drying the food mass led to structures with higher porosity, while the drying process has been reduced. Thin plates of dry porous food have been transformed into good quality powders, the initial product being able to be reconstituted of almost similar quality.

Another experiment on reducing the water content of onion paste for its preservation is presented in [2]. The foaming agent adopted was soy protein (between 0-12 %) and carboxymethyl cellulose was used as a foam stabilizer (0.5 %). Thickness of the wet paste layer including foaming and stabilizing agents was 3 mm and the air temperature for drying the food layer was between 55-75 ºC. According to the article, the drying times were 300 min at a temperature of 55 ºC, 240 min la 65 ºC and 300 min at 75 ºC corresponding to the proportion of soy protein of 12 %. By comparison, the drying time of un-foamed onion paste had values much higher than 600 min at 55 ºC, 420 min at 65 ºC and 480 min at 75 ºC. The optimal variant of the experiment included the use of 12 % soy protein and the hot air temperature for drying the foamed paste was 65 ºC.

The apple juice was treated by a foam-mat drying process according to [6] using egg white as a foaming agent (between 0.5-3 %) and carboxymethyl cellulose as a foam stabilizer (between 0.1-2 %), the method of incorporating the air into the liquid juice being its stirring with a special device. The optimal parameters of the process at which the highest expansion capacity was obtained were: 2-3 % egg white and 0.2 % carboxymethyl cellulose. The final product resulting from grinding the dry expanded plate had adequate characteristics.

An in-depth analysis of the foam-mat drying technique applied to melon is presented in [7]. The method applied by the authors consisted in using egg albumen (between 5-15 %) as an expanding agent and carboxymethyl cellulose (between 0-1 %) as a foam stabilizer added to the peeled and desesded fruit paste (to remove the soft central area). The pulp was blended for 1 min to obtain a homogeneous paste. The mixture composed of the melon pulp, expanding agent and foam stabilizer was whipped into a blender with the speed of 1.13 rot/min. Drying the mixture spread on a metal tray was performed into an enclosure with hot air at 50-70 ºC distributed with a constant rate of 1 m/s. The drying was intermittently carried out, every 30 minutes the mass of the expanded fruit being weighed, until it remained constant. The processed food was turned into a powder (with the bulk density between 0.3-0.6 g/cm^3) by a grinding process compared to the density of dried fruit without foaming of 0.68 g/cm^3. The results were satisfactory confirming the preservation of several initial features.

An innovation technique of combined use of infrared radiation and heating with hot air and heat pump for drying the longan fruit is shown in [8]. With an initial moisture content between 84-86 %, the fruit was dried up to 18 %, the drying temperature being 55 ºC in the case of combined infrared drying and heat pump and respectively, 65 ºC in the case of combined drying by infrared radiation and hot air with 80 % recirculated air. In both cases the electric power of the infrared heating system was set at 250-450 W. The experimental results showed that infrared radiation combined with hot air and heat pump drying leads to the increase of the drying rate of the longan fruit, reducing the time of drying and obtaining a higher porosity of the food. It has been determined that the total energy used for infrared drying has decreased as the power supplied to these heaters increases.

Another modern technique of combined fruit and vegetable drying with the microwave heating is presented in the paper [9]. The heat needed to dehydrate the food is provided by the microwave field, which comes in contact with the wet product and the elimination of water vapor resulted during the drying is achieved by a hot air stream, which circulates above the surface of the food. The heat transfer is mixed including a nonconventional microwave heating procedure combined with a conventional procedure based on the convective heat transfer of the hot air flow to the surface of the food.

The advantages of microwave drying compared to hot air drying only, according to the article mentioned above, are: fast volumetric heating, higher drying rate, reduced drying time, preservation of product quality (size and shape of food can influence the process efficiency), low energy consumption, low operating cost. As is known from the literature [10], not all materials can be efficiently microwave heated. The condition is that the targeted material to have in its composition at least one component that is microwave susceptible, i.e. to be a dielectric. The process parameters of the microwave field interaction with the material (in this case, the wet food product) are the dielectric constant and the dielectric loss factor. The dielectric constant characterizes the distribution of electromagnetic waves into the product being a measure of the product's ability to couple with the microwave energy, while the loss factor characterizes the interactions being a measure of the product's ability to dissipate the electricity into heat. By the direct contact of microwave field with the dielectric material, the microwave power is converted into heat. The initiation of this thermal process takes place in the core of the material and volumetrically propagates from the inside to the outside [10, 11]. The microwave heating is therefore a very fast process. The short duration of maintaining a relatively high temperature into the material to be dehydrated is one of the main conditions for keeping the initial qualitative characteristics of the food. The next step in the drying process should be the immediate removal of water vapor. The solution adopted and presented in [9] was to pass the hot air stream (at about 60 ºC) above the product. In this way, the combination of the two heating types (nonconventional with microwave and conventional through hot air convection) forms the so-called "convective microwave drying" proposed in the paper [9]. The food temperature control was performed by varying the power density (W/g-food) or the duty cycle. Various foods (banana slices, carrot slices, whole mushrooms, grapes) have been tested in the process of convective microwave drying, the result confirming the preservation of their initial characteristics.

Another recent paper [12] presents experimental results obtained by microwave-assisted foam-mat drying process of avocado paste. The avocado fruit was peeled and then processed into a domestic blender to obtain a fine paste. Egg white (30 %) as an expanding agent was added to the avocado paste, whose amount was limited to 20 g for each experiment. The samples were separately deposited in the form of a flat layer with a diameter of 10.5 cm and a thickness of 2 mm. In a first stage, the food was dried in a convective oven with hot air between 60-80 ºC ventilated above the pasta, checking at every 5 minutes the mass of the product until it is found that the mass remains constant. The second stage of the experiment was performed with the same dosage of food and foaming agent in a microwave oven for different microwave field powers: 120, 460 and 700 W. The time interval for checking the food mass was 10 seconds until the last difference between the values of the mass decreased to 0.01 g indicating the elimination of moisture. According to the results, the reduction of moisture decreased by increasing the temperature of the hot air and, respectively, by increasing the power of the microwave field. The time required to remove the moisture from the avocado paste was reduced from 150 min to 126 min in the case of hot air drying and from 22 min to 2.92 min in the case of microwave drying, respectively.

Benefiting from the previous experience of the foaming processes of glass waste by microwave heating, the authors of the current paper opted for the microwave-assisted foam-mat drying solution using egg white as a foaming agent and carboxymethyl cellulose as a foam stabilizer in the experimental process of preserving the initial qualities of a honeydew melon paste.

2. METHODS AND MATERIALS

2.1 Methods

The high proportion (over 90 %) of the moisture of the honeydew melon contributes decisively to ensure the dielectric properties of this fruit. Its dielectric constant as a measure of the ability of fruit to couple with the microwave energy has one of the highest values of all available fruits and vegetables (66, corresponding to the usual frequency of the 2.45 MHz microwave oven [9]). In fact, all fruits and vegetables have this characteristic being suitable for their microwave heating, the purpose of the operation being obviously the advanced reduction or elimination of moisture for the preservation of these foods.

The equipment used in the experimental process is, as in the case of expanding glass waste, a domestic microwave oven constructively adapted for operation at much higher temperatures compared to the temperature range required in this experiment (below 400 ºC). The fruit in the form of paste with a diameter of about 30 mm and a maximum thickness of 20 mm placed on a 1 mm-stainless steel plate is protected against too intense microwave radiation with a ceramic tube from a 80/20 weight mixture of SiC and Si_3N_4 with 125 mm-outer diameter, 100 mm-height and 5 mm-wall thickness, purchased from China. The material from which the tube is made contains high microwave susceptible materials capable to absorb the electromagnetic waves, which are converted into heat. Thus, most of the microwave radiation is transmitted to the food paste in the form of thermally radiated heat by the wall of the ceramic tube. The outer surface and the bottom of the crucible are thermally insulated with ceramic fiber mattresses to avoid the heat loss from the intensively microwave heated core of crucible wall to the outside. The very high level of moisture in the fruit paste ensures it dielectric properties favorable to microwave absorption, because the water is known as a good microwave susceptible chemical compound. However, the predominant heating of the food is not carried out by direct microwave heating, but by the conventional method of thermal radiation from the crucible wall to it. A low proportion of the microwave field penetrates through the crucible wall coming into direct contact with the honeydew melon paste, the initial heating being achieved in the core of the fruit according to the peculiarities of this nonconventional heating type mentioned above.

The constructive and functional scheme of the experimental equipment is shown in Figure 1.

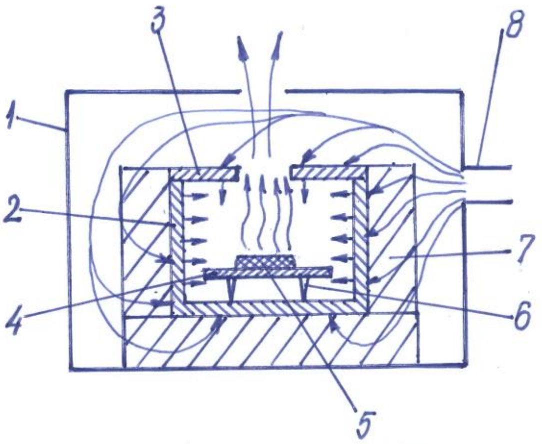

Figure 1. Constructive and functional scheme of the equipment 1 – microwave oven; 2 – ceramic tube; 3 – ceramic lid; 4 – stainless steel plate; 5 – food paste; 6 – metal support; 7 – thermal insulation; 8 – waveguide.

The working method of the authors' paper included the fruit processing procedure. It was peeled off and its central area was removed. It was then cut into small pieces and ground as a paste into a common household blender. Egg whites in weight proportions of 7, 11, and 15 % as a foaming agent and carboxymethyl cellulose (3, 6, and 9 %) as a foam stabilizer were chosen to be incorporated into the paste mass. The three components were mixed in the same blender for 5 min. The wet paste was hand-modeled in cylindrical pieces with a diameter of about 30 mm and a height of 20 mm, which were successively placed on the stainless steel plate and also successively introduced in the microwave oven.

The electrical power dissipated inside the oven by means of the microwave field was previously experimentally determined at the value of 625 W in the concrete case of the adapted domestic oven of 800 W used in the experiments. The microwave power of 625 W corresponds to a thermal energy of 2250 kJ/h. The wet mass of each sample subjected to microwave drying was about 17 g. Given the moisture content of melon at least 90 % [9], it follows that the amount of water to be removed by drying is 15.3 g. Theoretically, the heat need for water vaporization at 100 ºC under normal pressure conditions is 2.26 kJ/g [12], which means that the energy required to remove the 15.3 g of a fruit sample is 34.6 kJ. Reporting this value to the 2250 kJ/h provided by the oven heating system it can calculate the time required for food dehydration of 0.015 hours (or 0.9 min). This preliminary calculation did not take into account the energy consumption required to heat the water to 100 ºC, the heating of the metal plate that supports the sample and heating the solid part of the food, but these are significantly lower compared to the energy consumption of water vaporization. In order to control the loss of melon moisture, it was necessary to weigh it at very short intervals (about 15 seconds) to identify the time of the end of the drying process.

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2.2 Materials

The materials used in the process of preserving the specific properties of melon are egg white as a foaming agent and carboxymethyl cellulose as a foam stabilizer. Egg white is an organic compound that includes several protein types, of which ovalbumin accounts for over 50 % being widely used in many applications, especially in the food and pharmaceutical industries. In the process of food drying for its preservation, egg whites are the most frequently used foaming agent [14].

Carboxymethyl cellulose, commonly known as CMC, is a water soluble polymer $[C_6H_7O_2(OH)_2OCH_2COONa]n$ based on renewable cellulosic raw material. It is a stabilizer and thickener type used in food industry (although is not digestible) and also in chemical industry for detergents and chemicals. The product was purchased from the market being made in China (over 99.5 % purity).

As mentioned above, the fruit was a honeydew melon (over 90 % moisture) which was processed up to the paste state, the egg white and carboxymethyl cellulose (CMC) being added into the paste mass.

The experiment consisted of drying each sample of melon paste by microwave heating in the oven described above. The experimental variants were constituted with the dosages shown in Table 1.

Table 1. Experimental variants composition

Variant	Melon paste (wt. %)	Egg white (wt. %)	CMC (wt. %)
1	90	7	3
2	83	11	6
3	76	15	9

3. RESULTS AND DISCUSSION

3.1 Results

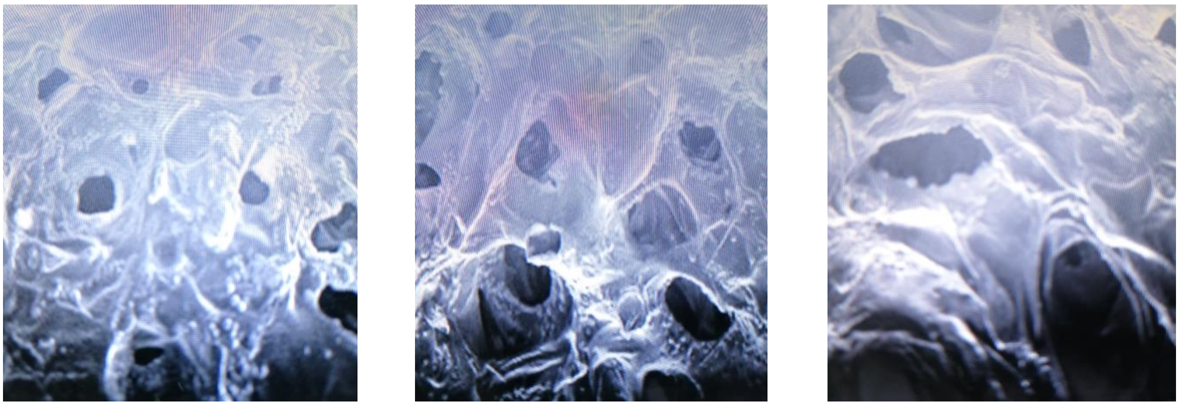
Starting from the constant amount of wet samples (17 g) and moisture content (15.3 g) of melon used in the experiment, the parameters of the drying process performed by microwave heating are presented in Table 2. The three samples processed by increasing the proportion of the foaming agent and respectively, the foam stabilizer from variant 1 to variant 3 were successively heated to 190, 220 and 250 ºC, exceeding in all cases the temperature of 100 ºC required for water vaporization at the pressure of 1 bar. Thus, the drying rate had high values between 95.4-113.3 ºC/min. The moisture control in the fruit mass performed by weighing the solid sample at intervals of about 15 seconds showed that in variant 1 its final value was 0.5 g, in variant 2 it was 0.3 g and in variant 3 it was not identified. The water amount removed by vaporization was calculated at 14.8 g (variant 1), 15.0 g (variant 2) and 15.3 g (variant 3). The energy consumed in these experiments as nonconventional form had net values between 33.4-34.6 kJ and reported to time unit between 14.4-22.3 kJ/min or between 4.0-6.2 W/min. Appearance of the microwave-assisted foam-mat dried honeydew melon samples is shown in Figure 2 and corresponding pictures of the microstructural configuration of dried samples by foaming are presented in Figure 3.

Table 2. Drying process parameters using the microwave heating technique

Variant	Wet sample amount (g)	Moisture content (g)	Drying time (min)	Dry melon temperature (ºC)	Drying rate (ºC/min)	Moisture content at the end (g)	Water amount removed by vaporization (g)	Energy consumption for water vaporization		
								kJ	kJ/min	W/min
1	17.0	15.3	1.50	190	113.3	0.5	14.8	33.4	22.3	6.2
2			2.00	220	100.0	0.3	15.0	33.9	17.0	4.7
3			2.41	250	95.4	-	15.3	34.6	14.4	4.0

a b c

Figure 2. Appearance of the microwave-assisted foam-mat dried honeydew melon samples
a – variant 1; b – variant 2; c – variant 3.



a b c **500 µm**

Figure 3. Pictures of the microstructural configuration of microwave-assisted foam-mat drying samples
a – variant 1; b – variant 2; c – variant 3.

According to the images in Figure 2, the pieces of melon paste with an initial layer thickness of 20 mm were expanded due to the different weight proportions of egg white as a foaming agent and the drying temperature reached in a very short time as a microwave heating feature. Dry stable foams with the contribution of CMC as a foam stabilizer were obtained in the three variants of the experiment differing by the size of generated pores.

Suggestive images regarding the distribution of pores in the dried fruit section obtained with a Smartphone Digital Microscope were identified and shown in Figure 3. Especially in the case of the sample obtained in variant 3, but also in the case of the other two samples to a lesser extent, the existence of quite consistent struts between the pores of the foamed fruit representing a solid fibrous structure was observed. The pore size in the dried fruit was determined according to images of Figure 3 at 80-160 µm in variant 1, 130-270 µm in variant 2 and 190-450 µm in variant 3.

According to the usual technique of preserving the food properties, the foamed solid mass of each sample was ground in an electric household blender obtaining a concentrated powder of honeydew melon.

3.2 Discussion

As mentioned above, the main role in the technique of preserving fruits and vegetables is to remove the water from their composition by foaming and heating. It is also very important to be very quickly heated the food to avoid losing its specific qualities. The solution adopted by the authors and presented in this paper involves a very high heating rate (around 100 ºC/min), the fruit reaching temperatures of 190-250 ºC in 1.50-2.41 min, so that in terms of quality the microwave heating process is suitable for achieving the objective.

Given the physical characteristics of the products dehydrated by rapid heating and foaming in the three experimental tests, variant 3 was chosen as the optimal variant. The heating time was 2.41 minutes and the temperature of the fruit reached 250 ºC safe for vaporizing the 90 % water of its composition. The final moisture content of the dried fruit was determined to be zero. The pore size in the porous structure of the processed fruit was between 190-450 µm, considered optimal for the chosen technology.

The energy consumption for the water vaporization was 14.4 kJ/min (4.0 W/min), i.e. 0.63 W/g-water.

The honeydew melon in form of dry powder has a much longer durability compared to the fresh fruit and keeps ß-carotene and C-vitamin unchanged in its composition. Due to the ability of this even heat-processed fruit to provide flavour and water binding properties, it can be used for instant beverages, ingredient in bakery, yogurt, ice cream and even pharmaceuticals in the form of tablets [15].

4. CONCLUSION

Recently, several modern technical solutions have been tested in the world to dehydrate fruits and vegetables by drying and their fast heating for preservation. One of these techniques is the use of microwave power converted into heat. The microwave heating ensures the very fast heating of food and removing its high moisture content. The experiment presented in the work tested preserving the properties of honeydew melon paste containing egg white as a foaming agent (7-15 %) and carboxymethyl cellulose (CMC) as a foam stabilizer (3-9 %). The fast heating of fruit at 190-250 ºC in 1.5-2.41 min allowed obtaining dehydrated foamed pieces preserving their basic qualities. The dried melon was ground as a powder. In this state, the fruit has a much longer durability keeping ß-carotene and C-vitamin unchanged in its composition and it can be used for instant beverages, ingredient in bakery, yogurt, ice cream, etc.

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