STUDY OF COMBINED MICROWAVE VACUUM DRYING OF APPLE RAW MATERIAL

Sándor Ferenczi, Bálint Czukor
Department of Technology
Central Food Research Institute, H-1022 Budapest, Herman Ottó út 15, Hungary
e-mail: s.ferenczi@cfri.hu

ABSTRACT

A widespread and simple method for preserving fruits and vegetables is drying. Hot-air-, freeze-, vacuum- and dielectric drying are the most common methods. In this work, the microwave-vacuum drying combined with hot-air pre-drying was investigated for apple. This combined drying method produces a snack-like product with crisp and puffed structure, preferred by consumers. It can be an alternative to products like deep-fried potato, or fruit chips. The ovary of the raw apple was removed, and then the apple was cut into slices. After the preparation, the sample was hot-air dried, and then microwave vacuum-dried for 60, 70 or 80% and 97-98% dry basis, respectively. During microwave vacuum drying, the rapid evaporation of residual moisture of raw material causes the fruit tissue to expand, creating a porous crunchy texture with low mass density. In the course of the drying process, pulsed microwave energy is used, with radiation, and relaxation times. The microwave energy is provided by two magnetrons, with severally 850Watts nominal, 450Watts effective output.

Our aim is to investigate the technology-related properties of microwave vacuum drying combined with hot-air pre-drying. The experimental pilot plan consists of 3 independent variables (factors) and 2 dependent variables. The mass load of the pre-dried fruit was 200g and the applied vacuum was 50 mbar. The independent factors were investigated in 3 levels: pre-dried dry mass content, (60, 70, 80%) the specific energy input (12, 14, 16 minutes of total microwave radiation, which equals 1.62, 1.89, 2.16 kJ/g specific energy) and the ratio of double-magnetron treatment and total radiation. (0.5, 0.75, 1) Two of the product's measurable properties as dependent parameters were analyzed; the burning ratio and the mass density. Our goal was to create product with minimal burning ratio and minimal mass density.

After performing the experiments, the following conclusions can be taken. The mass density and the burning ratio of treated apple are directly proportional to the energy input. Within the studied range, at low initial dry matter content of the pre-dried product (60% dry matter content) with intense energy input, desirable product can be achieved. The ultimate optimum occurs at medium initial dry matter content (70%), 0.8 double magnetron-treatment ratio, and 1.755 kJ/g energy radiation.

1. INTRODUCTION

Dried food products have always had stable marketability, and nowadays the demand for these dried food products is continuously growing. With new technologies, it is possible to create new dried products, with unique characteristics, excellent rehydration rate, sensorally preferred properties, and high nutrition value. These methods are expected to be energy efficient, and rapid. Most commonly used technologies for drying are hot-air drying, freeze drying, osmotic dehydration, microwave-, and vacuum drying. Using these methods in

different combinations can result advantageous properties, for example higher drying rate, or increased quality product.
The microwave vacuum drying (MVD) is a rapid and efficient dehydration method, which can yield unique characteristics, improved product appearance and quality, compared to conventionally dried products. This improved quality is achieved by the combination of microwave energy and vacuum. The electromagnetic microwave radiation penetrates the interior of the food, where it is converted to thermal energy and causes rapid warming. However, the vacuum reduces the boiling point of water, keeping the product temperature low, as well as creating a pressure gradient that enhances the drying rate. The microwave vacuum drying is less time-consuming, compared to air-and freeze-drying, which can take up to several days. The microwave radiation is being applied cyclically, with moderately strong vacuum, which results in better product quality and energy efficiency. The unique, crispy, open cellular structure of the dried product, related to MVD is created by an expansive force by the *in situ* vaporization of water. Because of the low temperature, and the low oxygen pressure during the drying process, higher degree of remained nutritional and aromatic components sensitive to oxidation and thermal degradation can be achieved than by air-drying. Although, the investment, operating and energy costs of microwave-vacuum drying are higher than the conventional air-drying costs, the higher quality end product results greater benefit. The microwave vacuum driers use more electric energy than the conventional hot-air driers; however, the efficiency of the microwave vacuum drying is better, especially towards the end of the drying process. This motives the spreading usage of new combination drying processes, such as MVD combined with hot-air drying. There is a research and development project takes place in this topic in the Central Food Research Institute. Because of the regularities of atmospheric hot-air-drying are thoroughly explored, this article deals primarily with the MVD operation within the combined process.

2. MICROWAVE VACUUM DRYING

2.1 Microwave properties

Microwaves are electromagnetic radiation with frequencies from 300 MHz to 300 GHz, and wavelengths from 1 mm to 1 m. Two designated and approved frequency is used for heating in households and industry, 915 and 2450 MHz. The electromagnetic waves react in different ways with the objects encountered; they are reflected from metallic substances, absorbed by some dielectric material, or transmitted without significant absorption. Water, carbon and high moisture-content materials are good microwave absorbers, while glass, ceramic and most thermoplastic materials let the waves pass through them with negligible absorption.
Microwaves can be created by different devices, but magnetrons are used almost exclusively in the industrial and the culinary practice.
Microwaves don't carry real heat, but as the electromagnetic radiation with rapidly changing polarity contacts with the food material, the microwave energy transforms into kinetic energy, then heat. The electromagnetic field of the microwaves affects the ionic-, and also the polar/dipolar molecules. It forces the ionic compounds to accelerate in the direction of the field, while the polar components start to vibrate due to the changing polarity of the electromagnetic field. This is how the microwaves' energy dissipates. The friction of these moving compounds generates heat, which is equalized by conduction.

Water is a constantly present molecule in foodstuff in large quantities. It is good microwave absorber, because of its permanent dipole. The absorption rate depends on the physical-chemical status of water molecules. Free water bonds to each other with hydrogen bonds, which is easily broken by microwaves. The dipole rotation of water molecules bond to peptides, or carbohydrates is inhibited, so the absorption of microwaves is much less.
In the case microwaves approaches the food from several directions, inner reflections can come up, thus the energy of the rays adds and „hot spots" are created. Hot spots cause inhomogeneous heating and increasing chance of damaging the product. Hot spots can be avoided by moving the sample, or increasing the homogeneity of the field, but the latter is a difficult and complex task.

2.2 Properties of microwave vacuum drying

Drying rate

At foodstuff, the simultaneous usage of microwaves and vacuum causes faster drying rate compared to conventional drying methods, because of the same direction of heat-, and mass transfer. The process of MVD can be divided into three periods.
At the beginning, the microwave radiation almost completely turns into heat, causing continuously warming sample. The warming keeps going until the boiling point of the water, which is determined by the ambient pressure. The evaporation in this period is negligible. Compared to the hot-air drying, this phase is very rapid. The next period is the drying. The temperature of the sample is approximately constant, while the energy of radiation is being consumed by the moisture evaporation. During hot-air drying, the dying rate decreases continuously, while the MVD has no, or minimal drying rate reduction. The third period is characterized by decreasing intensity drying. The drying rate decreases, while the more strongly bond water also leaves the sample. In the conventional hot-air drying method, this is the most time-consuming period, taking away two-thirds of the total drying time. MVD has two significant advantages in this period: most of the moisture leaves in the isothermal period, and the diffusion of the evaporated moisture inside the sample is much faster than the diffusion of liquid moisture.
During MVD, the drying rate is affected by the total irradiated energy, the applied vacuum value, the sample mass is the vacuum chamber and their relations. High energy input and low pressure increases the rate of mass transfer, thus the drying rate, while more weight of sample per treatment decreases the drying rate.

Quality of product

With microwave vacuum drying, a popular crunchy product with puffy texture and low mass density can be created. It is suitable for direct consumption as a smack, or can be consumed after storage and rehydration. The texture is created by the overheated moisture, which caused by microwave heating, and reduced boiling temperature by the vacuum. Steam is generated inside the material, which creates inner pressure, thus the puffing of the product. During drying, this process is somewhat controllable, because the strength of the structure-keeping force depends on the evaporation rate (thus indirectly on the energy input) and the pressure of the vacuum chamber. This puffing phenomenon occurs more intensively when the MVD process is preceded by hot-air drying.

Other advantage of the MVD over traditional drying methods is the greater retention of bioactive components of foods, for example antioxidants or vitamins, which are – as is well known – easily inactivated by oxidation or thermal degradation.
Attention should be paid to the smooth heat treatment and the drainage of the generated vapor. Their absence could result in unfavorable burning. The phenomenon starts with browning, presumably the Maillard-reaction, but finally results burnt, inedible products. The burning always starts from the inner material, reaching the surface only in a few cases, makes it hard to sense. The burning of the product can be avoided by moving the sample during drying, reducing its size, or reducing the intensity of the microwave energy.

Economy
Experience suggests that the investment-, operating-, and energy costs are higher at a microwave vacuum drying equipment, than a hot-air dryer. MVD requires more energy, but the energy is used more efficiently, especially at the end of the process. For the economical and quality production, it is important to determine the optimum point for the microwave energy, and the applied vacuum. With this knowledge in possession, the energy usage for MVD can be lower than the hot-air drying. The ideal combination of these two drying processes also decreases the overall energy consumption for drying.

Combined drying method
For the fruits and vegetables, there is a critical point of dry mass content during drying. If the moisture content is removed by conventional drying until this point, where only the free water leaves the sample, then the quality parameters of the product doesn't change. So, the combination of hot-air-, and microwave vacuum drying is more energy-efficient, and creates better quality product than using the technologies alone.

The aim of this present work was to study the effect of MVD parameters, in microwave vacuum combined drying process combined with hot-air drying, namely microwave power, intensity and initial dry matter content on the products burning ratio and mass density, and to determine optimum values for obtaining high-quality dried apple chips.

3. MATERIALS AND METHODS

3.1 Raw material and drying preparations

As raw material, Jonathan apple was used, because of its pleasant aroma and prosperous puffing tendency. The ovary of the apple was removed and then cut into 8mm thick slices. Pre-drying operation was done by a laboratory-scale hot-air drying equipment. The pre-drying was done until 60, 70 or 80% dry matter content.
The microwave vacuum drying equipment has a cylindrical stainless steel vacuum chamber, with a conical dome for better vapor removal. The samples are hold in a rotary teflon tray. Microwaves are generated by two, 850W nominal efficiency magnetrons. The vacuum is kept constant at 50 mbar by a vacuum pump, connected to the heat exchanger for vapor condensation. The cooling water for the heat exchanger is cooled by a compressor and kept circulating by a pump. For each treatment, 200 grams of pre-dried apple was dried. Intensive

radiation was used in the beginning of the treatment, and then the intensity was continuously reduced. The radiation (active) and relaxation (passive) time was equal.

3.2 Experimental design

For the experimental design, 3 independent variables with 3 levels, and 2 dependent variables were used. The independent variables (factors) was the dry mass content of the pre-dried sample, (at 60, 70, 80%) the specific amount of energy irradiated (12, 14, 16 minutes of magnetron radiation) and the ratio of double magnetron-minutes and total magnetron-minutes (intensity) (0.5, 0.75, 1). The dependent variables were the burning ratio and the mass density of the product. These two quality parameters can determine the sufficiency of the treatment. For better quality product, lower mass density and lower burning ratio is desirable.
Box-Behnken experimental design was used. The changing of the independent variables (factors) causes the changing of the two quality variables; these correlations were evaluated. Quadratic model was used with interactions.

3.3 Measurement

The determination of the moisture content was done by a KERN MLB 50-3 type rapid moisture content analyzer.
The burning ratio was calculated from the weight of the burned pieces, divided by the weight of all pieces in one treatment cycle.
The mass density was measured via volume-displacement method, with mustard seeds.

4. RESULTS AND DISCUSSION

4.1 Burning ratio analysis

The results of the burning ratio are shown in figure 1.

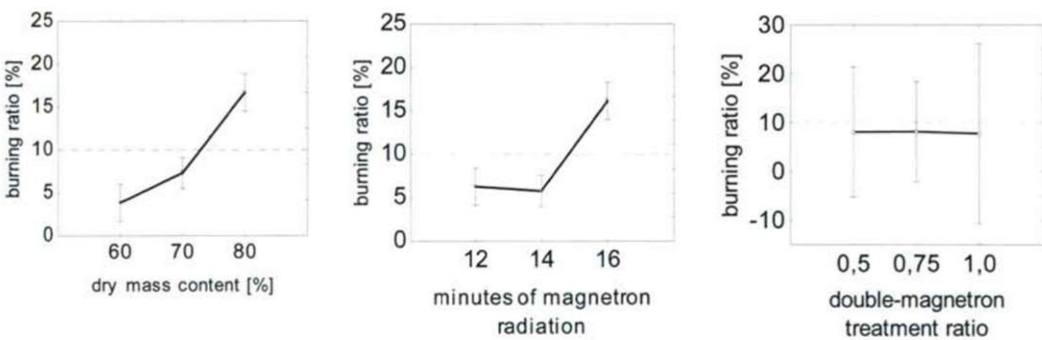

Figure 1. Burning ratio over dry mass content, magnetron-minutes and double-magnetron treatment ratio

Increasing dry mass content and increasing magnetron-minutes also results increasing burning ratio. The double-magnetron treatment ratio has no significant effect on the burning ratio due to its high standard deviation. Technologically acceptable burning ratio is determined at 10%, shown in Figure 1 with a red dashed line.

4.2 Mass density analysis

The results of the mass density are shown in figure 2.

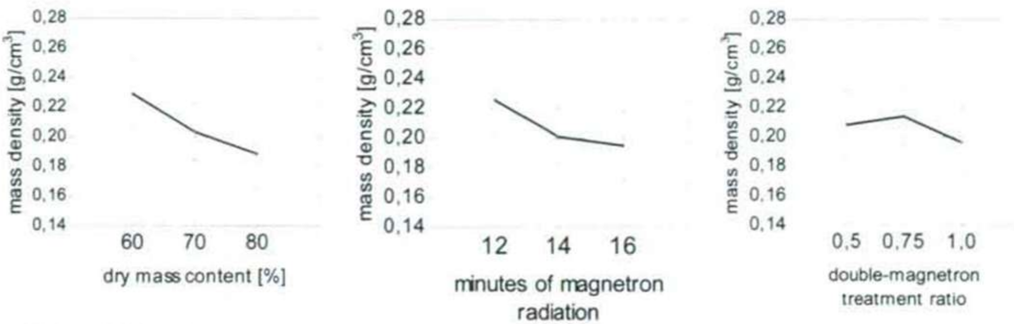

Figure 2. Mass density over dry mass content, magnetron-minutes and double-magnetron treatment ratio

Increasing dry mass content and increasing magnetron-minutes results decreasing mass density. The double magnetron treatment ratio has no significant effect on mass density. The desirable lowest mass density occurs at the maximum of the two parameters, but every product is acceptable under 0.2 g/cm^3. This acceptance limit is shown in Figure 2 with a red dashed line. From this point of view, similar quality product can be achieved by different combinations of treatment time and pre-dried sample mass content.

4.3 Combined analysis

At the maximum values of the two significant parameters, the magnetron-minutes and the dry mass content of the pre-dried sample, the mass density is low as desired, but the burning ratio is the highest under these circumstances, so an optimum range must be found.

The experimental parameters, where the burning ratio does not exceed 10%, and mass density is under 0.2 g/cm^3, are as follows: 14.5 minutes with 64% dry mass content; 14.0 minutes with 68% dry mass content; 13.0 and 12.5 minutes with 72% dry mass content. It is apparent, that the appropriate minutes of treatment and pre-dried sample dry mass content needed to produce quality products are inversely proportional to each other.

The intensity of irradiated energy (double magnetron-treatment ratio) had no significant effect on either the mass density or the burning ratio within the examined range (0.5-1).

5. SUMMARY

Our goal was to prepare the production technology of a crunchy fruit snack by examining the microwave vacuum drying technology on apple raw material. The burning ratio and the product mass density – the two most important quality parameters - were studied depending on the initial dry matter content of the pre-dried product, the specific energy input and its intensity. The initial dry matter content of the pre-dried product and the irradiation time had significant effect on forming a non-burnt and low mass density crunchy dried product. Quality product can be achieved by different inverse combinations of initial dry matter content of the pre-dried product and the irradiation time. (12.5 to 14.5 minutes with 64-72% dry matter content)

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