ISSN 0798 1015

REVISTA ESPACIOS

HOME Revista ESPACIOS ÍNDICES A LOS AUTORES

Vol. 38 (Nº 52) Year 2017. Page 35

A review of techniques for drying food products in vacuum drying plants and methods for quality control of dried samples (Technical note)

Una revisión de técnicas para el secado de productos alimenticios en plantas de secado al vacío y métodos para el control de calidad de muestras secas (Nota técnica)

Natalya BUROVA 1; Nadezhda KISLITSINA 2; Faina GRYAZINA 3; Galina PASHKOVA 4; Albert Kuzminykh 5

Received: 09/10/2017 • Approved: 21/10/2017

Content

ABSTRACT:

Vacuum drying is a novel technology which allows for a high quality final product while retaining its original nutritive value. Combining various drying techniques with the use of vacuum as well as quality control in the food drying process are very important issues that have good potential for investigation. One of research directions involves quality assessment of dried products without employing complex technologies. A number of methods have been proposed by researchers from all over the world to assess the quality of dried products by indirect and organoleptic parameters. Such evaluation is necessary for getting the overall picture during the drying process since opening the drying plant will lead to the break of vacuum inside the facility and thus cause incremental costs and re-bringing of the dryer to the initially set parameters. This paper presents a review of various quality assessment methods for

RESUMEN:

El secado al vacío es una tecnología novedosa que permite obtener un producto final de alta calidad a la vez que conserva su valor nutritivo original. La combinación de varias técnicas de secado con el uso de vacío, así como el control de calidad en el proceso de secado de alimentos son cuestiones muy importantes que tienen un buen potencial para la investigación. Una de las direcciones de investigación implica la evaluación de la calidad de los productos secos sin emplear tecnologías complejas. Los investigadores de todo el mundo han propuesto una serie de métodos para evaluar la calidad de los productos desecados mediante parámetros indirectos y organolépticos. Dicha evaluación es necesaria para obtener una imagen general durante el proceso de secado, ya que la apertura de la planta de secado conducirá a la interrupción del vacío dentro de la instalación y, por lo

products dried in freeze-drying plants using diverse drying techniques that have been suggested by researchers from China, Mexico, Russia and other countries over the period 2010 to 2017. The analysis of proposed methods provides a basis for determining globally applicable criteria for selecting approaches and procedures for a particular vacuum drying technique.
Keywords: vacuum drying, quality, food products, methods, review.

tanto, causará costos incrementales y volverá a llevar la secadora a los parámetros establecidos inicialmente. Este documento presenta una revisión de varios métodos de evaluación de calidad para productos secados en plantas de secado por congelación utilizando diversas técnicas de secado que han sido sugeridas por investigadores de China, México, Rusia y otros países durante el período 2010 a 2017. El análisis de los métodos propuestos proporciona una base para determinar los criterios globalmente aplicables para seleccionar enfoques y procedimientos para una técnica particular de secado al vacío.
Palabras clave: secado al vacío, calidad, productos alimenticios, métodos, revisión

1. Introduction

From a physics perspective, drying is a complex diffusion process. The drying rate is determined by the rate of moisture diffusion from the interior of the material being dried into the external environment. In any type of drying, the material being dried is in contact with moist gas (most often atmospheric air). The method of drying materials including foods with infrared radiation has become widely used in industry over the last few decades. Infrared drying allows a several-fold reduction in the drying time as compared to drying with convective heat. Infrared rays provide and intensify the heating of the surface of foods being dried; infrared radiation also enhances heat transfer without using high temperatures of the drying agent. Therefore, the drying process involves a combination of two interrelated processes: heat transfer and mass transfer, or otherwise, moisture transfer. Moreover, there is a wide array of drying variations based on whether drying is performed under atmospheric conditions or by employing vacuum inside the drying facility [1].

Based on the data above, drying techniques can be classified according to the method of heat supply to the material being dried:

1. *Convective drying* is conducted by means of direct contact between the material being dried and the drying agent which is often hot air or fuel gases (usually mixed with the air). The heat needed to evaporate liquid is transferred from the hot air or overheated vapor to the material being dried by continuous or intermittent contact;
2. *Contact drying* is carried out by transferring heat from the heating agent to the material through a separation wall. In this case, the heat needed to evaporate liquid from the material is transferred to the latter from the hot surface which contacts the material;
3. *Infrared radiation drying* involves heat transfer by infrared rays; the heat needed to evaporate liquid from the material is transferred to the product by thermic (infrared) rays from the radiation generator installed inside the drying facility;
4. *Dielectric drying* is conducted by heating the product in the field of high-frequency currents;
5. *Vacuum drying* is performed under low pressure conditions. The heat transfer effect is produced by the convection or radiation method. The use of vacuum ensures a sparing effect on the product being dried due to the low values of drying temperatures.
6. *Sublimation drying, or freeze-drying*, is drying a product in a frozen state under high vacuum. According to the of heat transfer mechanism involved, freeze drying is similar to contact drying and is a variation of vacuum drying. However, due to the specificity of the freeze-drying process, it has been classified into a separate category [2].

Modern industry offers a wide variety of drying equipment which allows substantial intensification of the drying process without sacrificing the quality of the product being dried. This paper reviews existing techniques of drying food raw materials, as well as methods for quality control of the finished product.

2. Materials and Methods

Research into vacuum drying dates back to the end of the 20th century, while the formulation of the drying theory started in the early 20th century. Special attention has been given to the quality of the final product because it is the appearance of foods that primarily matters to the consumer. Fundamental aspects of the kinetics of the drying process were first articulated by Russian scientists P.S. Kosovich and A.V. Lebedev and related to soil evaporation. Approximately in the 1930s, American researchers W.K. Lewis and T.K. Sherwood used the apparatus of classical diffusion theory to describe the transfer of fluid in the interior of the material during drying. The next important stage in the development of the drying theory was associated with the discovery of the phenomenon of thermal diffusion of fluid (hygrothermal conductivity) in 1933 – 1935, which, alongside with the concentration diffusion theory, provided a basis for creating a system of differential equations of moisture and heat transfer in capillary-porous bodies [3].

The scope of research lines and methods for investigating vacuum drying is currently very large worldwide.

In 2010s, a group of scientists including R.M. Bórquez, E.R. Canales, and J.P. Redon conducted a study on drying raspberries at low pressure. First, previously frozen raspberries were thawed in sucrose solution at low pressure (1.33kPa for 8min), then the process continued at atmospheric pressure for four hours. Moisture content decreased from 84% to 49% (wet basis); removal of almost one half of water occurred during the vacuum period. Two different transport coefficients were obtained: 19.9×10^{-10} m^2/s for water transport under vacuum and 3.2×10^{-10} m^2/s for moisture transport at atmospheric pressure. Losses of vitamin C were high (80%) and for reutilization, microwave-vacuum drying (1.33kPa for 40min) was suggested to be performed under temperature control by varying setting parameters of the microwave oven. As a result, an undamaged dried product (7.8% wet basis) of high organoleptic quality was gained [4].

Another study was conducted in 2010 by Chinese scientists Shen Pingniang, Liu Zhiyuan, Huang Kaizhong, and Xiao Qiong who explored the efficiency of vacuum drying. According to the research, drying is a key process for the pharmaceutical industry and traditional Chinese medicine. The relevance of drying technologies stimulates ongoing systematic research into processing of products using vacuum drying as well as the investigation of engineering technologies. On the basis of the fundamental research undertaken by the scientists, factors affecting the moisture evaporation rate in the vacuum drying process and principles of vacuum drying were explored. Regularities of vacuum drying were investigated; techniques for implementing continuous process of vacuum drying were proposed with regard to various products [5].

The effect of vacuum drying on the nutrient content of peppermint was explored by scientists Elsa Uribe, Daniela Marín, Antonio Vega-Gálvez, Issis Quispe-Fuentes, and Angela Rodríguez in 2016. The findings of the study imply that peppermint can be considered a valuable source of biologically active compounds, and vacuum drying preserves certain quality parameters of dried peppermint. Vacuum-dried peppermint can potentially be used as an ingredient of functional food. The purpose of the research was to study the effect of temperature on the process of vacuum drying of peppermint. Vacuum drying was performed at temperatures ranging from 50 to 90 °C. As a rule, the drying process affects the quality of products, but during drying at a pressure below atmospheric pressure many processes in the interior of the product occur differently. After drying, peppermint quality parameters were examined such as color, chlorophyll content, phenolic content, flavonoid content; vitamin C and sugar levels were estimated as well. Insignificant changes of the color and chlorophyll content were observed in all samples. The highest scores regarding the above listed indicators were recorded after drying at 50 and 70 ° C, whereas vitamin C level went down. The research suggests that peppermint can be used as a natural antioxidant in its both fresh and dried form, the latter obtained by means of vacuum drying [6].

In 2016, scientists Yuan-Yuan Pu and Da-Wen Sun conducted a study on the effect of the product shape on the quality of the microwave-vacuum dried product. Inconsistent results were obtained after drying mangos of four different shapes which was estimated visually. Higher consistency was observed in regard to round-shaped slices as compared to other samples. The aim of the work was to study moisture content and homogeneity of mango slices of four different shapes (square, rectangle, regular triangle, and round) in microwave vacuum drying. Infrared hyperspectral imaging in combination with chemometric multivariate data analysis was applied to perform the study. Seven wavelengths were used (951, 977, 1138, 1362, 1386, 1420, and 1440 Nm). Based on an optimized model and selected wavelengths, a multivariate linear regression was developed with high forecasting precision values of Tp2 = 0.993 и RMSEP = 1.282%. As indicated by the moisture distribution map, similar non-uniform drying pattern was observed on the mango slices shaped as rectangles and right triangles, while round-shaped mango slices demonstrated the best results of drying. The study suggested that the proposed quality assessment method has potential for predicting moisture content of mango slices dried in microwave vacuum drying plants. The non-uniformity of moisture distribution and the influence of the sample geometry should be taken into account when utilising the microwave vacuum drying technique [7].

In 2011, German scientists Katrin Burmester, Arne Pietsch, and Rudolf Eggers studied instant coffee production in vacuum belt drying facilities. This work presented a basic investigation of soluble coffee production by vacuum belt drying. A set of experiments on drying instant coffee was conducted in a lab-scale drying facility. Changes in technological parameters of the product's properties were detected. Density, structure and flavor of the product were subject to assessment. The parameters were assessed and compared to commercial products produced by means of freeze or spray drying. The study revealed the fact that by optimizing the process parameters instant coffee can be produced by vacuum belt drying as well. The obtained product meets up-to-date product requirements. Additionally, mass transfer occurring during drying was analyzed, the effective diffusion coefficient was determined using a thin film measurement technique. Furthermore, the sorption behavior of instant coffee was systematically studied and could be described using a sorption isotherm [8].

In 2011, a group of researchers comprising B. Zecchi, L. Clavijo, J. Martínez Garreiro, and P. Gerla examined the process of combined convective and vacuum drying of mushrooms and parsley. The work aimed to develop an easy-to-perform and economical alternative for mushroom and parsley dehydration through combining convective and vacuum drying. Depending on the product, such a combination of technologies allows minimization of the total drying time as well as excludes negative effect on the quality of thermo-sensitive products during drying. Experimental drying curves were determined in a cross-flow convective drying unit and also in a cabinet vacuum dryer at the temperatures of 35, 45 and 55º C. The most appropriate theoretical models were applied to the combined processes to minimize the overall drying time and avoid damage of the finished product. In regard to parsley, the combined drying process performed at the highest temperature value (45º C), made it possible to reduce the drying time by 63% and 16% as compared to the convective drying alone and vacuum drying alone, respectively. For mushrooms, the highest temperature for combined drying was 55ºC which ensured the best visual quality and minimized the drying time for the product [9].

In 2013, scientists from Poland Zdravko Šumić, Aleksandra Tepić, Senka Vidović, Stela Jokić, and Radomir Malbaša published the outcomes of their study on vacuum drying of frozen sour cherries. The purpose of the research was to optimize the vacuum drying process of frozen sour cherries in order to preserve health-beneficial phytochemicals and textural characteristics. The drying was conducted within the temperature range of 46–74°C at a pressure of 17–583mbar inside the vacuum-dryer equipment. Moisture content, content of phenolic compounds, vitamin C, antioxidant activity, anthocyanin content, total colour change and firmness were investigated after drying. These parameters were used as indicators for evaluating the quality of dried sour cherries. Within the experimental range of studied variables, the optimum conditions of 54.03°C and 148.16mbar were determined for vacuum drying of sour cherries. Additional experiments were conducted separately under optimum conditions to verify predictions and adequacy of the second-order polynomial model. Under those optimal conditions, the predicted amount of total phenolic compounds was 744mg CAE/100 dw, vitamin C 1.44mg/100g per dry weight, anthocyanin content 125mg/100g dw, total solids 70.72%, total colour change 52.61 and firmness 3395.4g. The investigated parameters had significant influence on the quality of dried sour cherries. Thus, a new prototype of a vacuum dryer was proposed in this study. In order to preserve anthocyanins and vitamin C, the process parameters were optimized. Furthermore, regular temperature and pressure were determined which allowed to achieve the best quality of the dried product [10].

In 2014, scientists Manish Dak, N.K. Pareek investigated the effects of microwave drying in combination with vacuum drying on pomegranate arils. Drying of pomegranate arils was performed by means of microwave-vacuum technique. The input data of the experiment were as follows: microwave power of 25- 95 W, vacuum pressure of 25-195 mm Hg, and sample mass of 65-235 g. Effective moisture diffusivity values increased as microwave power increased in parallel with a decrease in sample mass for constant values. Meanwhile, changes of pressure inside the vacuum drier had slight effect. A correlation between the effective moisture diffusivity and moisture content was established. Moreover, multivariate polynomial models were also developed for estimating the moisture diffusion coefficient as a function of microwave-vacuum drying [11].

In 2014, Japanese researchers Takahiro Orikasa, Shoji Koide, Shintaro Okamoto, Teppei Imaizumi, Yoshiki Muramatsu, Jun-ichi Takeda, Takeo Shiina, and Akio Tagawa conducted a study on vacuum drying of kiwi slices. Physical and chemical properties of dried kiwi slices were evaluated. The properties were analysed using the reaction rate theory. The drying was performed with hot air under vacuum. The changes in moisture content, hardness, l-ascorbic acid level value, and antioxidant activity as well as the surface color of kiwifruit samples were investigated during the drying process at temperatures of 50, 60, and 70 °C, a vacuum drying pressure being of 3.00 kPa. The residual ratio of ASA and the antioxidant activity in the dried kiwifruit samples constituted 0.75–0.99 and 4.3–5.5, respectively. L-ascorbic acid changes in the kiwifruit samples during hot air drying were discovered. The colour of the sample surface was also found to change after drying. Those changes were also measured, and the total color change (ΔE) of the samples at all temperatures and for each drying process exceeded 12. Color changes of the samples after vacuum drying at each temperature level were significantly ($p < 0.01$) lower than those after hot air drying [12].

In 2014, scientists Bussaya Mee-ngern, Seung Ju Lee, Jinnipar Choachamnan, and Waraporn Boonsupthip studied the possibility of penetration of juice into rice grains followed by vacuum drying. Vacuum drying was used to enrich rice with additional nutrients. The penetration of nutrients into rice kernels was enhanced due to the cracking of the kernel surface. Thus, an effective approach (cost- and time-efficient) for enriching rice with nutrients was proposed. The studies involved vacuum drying which was performed to saturate rice with vegetable juice. Red beetroot juice was used as a good source of color and functional compounds. After mixing with beetroot juice and vacuum drying, cracks were formed on the surface of rice kernels which changed in colour to red-violet. The degree of kernel surface cracking, assessed visually, as well as antioxidative activity increased with increasing amounts of added juice. The visually detectable kernel surface cracks were necessary for deeper penetration and juice accumulation within rice kernels. Three different rice varieties were used in the experiment; their characteristics were assessed after two months and one year of storage, respectively. The final moisture content of rice kernels after vacuum drying was low enough for good storage quality. Heat treatment was not required. The results obtained imply that it is possible to use other functional liquids /solutions followed by vacuum drying of rice grains. Functional properties of rice could be effectively improved by vacuum drying technology [13].

In 2014, Lin Liu, Ya Wang, Daidi Fan, and Yu Mi used phenolphthalein as an indicator that has good potential for monitoring the vacuum freeze-drying process. Since the degree of dissociation of phenolphthalein is closely related to the structure of the water state, phenolphthalein can be used as an indicator for monitoring freeze-drying under vacuum. During the three stages of freeze-drying, colour changes of phenolphthalein indicated its high sensitivity to structural changes of water. In terms of product quality improvement, a critical aspect of vacuum freeze-drying is accurate monitoring of the state of water at its freezing stage and that of the residual water at its drying stage. The study resulted in suggesting an easy-to-perform method for monitoring the state of water throughout the entire freeze-drying process (i.e. the state of water at the freezing stage and of residual water at the drying stage) based on colour changes of phenolphthalein. A sample prepared with phenolphthalein appeard to be sensitive to structural changes of water and reflected the changes due to colour-changing effect. This make it possible to accurately trace the dynamics of the freeze-drying process thus providing a valuable tool for preparing high-quality products [14].

In early 2017, findings of the research conducted by Kamilla Soares de Mendonça, Jefferson L.G. Corrêa, João Renato de Jesus Junqueira, Marcelo Angelo Cirillo, Fabiano Vicente Figueira, and Elisângela Elena Nunes Carvalho were published. Their study focused on the effects made by convective and vacuum drying on the pequi slices. The results showed that vacuum and low drying temperature contributed to the retention of ascorbic acid and carotenoid content. Product shrink and color changing reduced with increasing pressure and decreasing drying temperature. The rehydration coefficient increased under vacuum and at lower drying temperature. Pequi is a fruit from Brazil. Regardless of its ascorbic acid and carotenoid contents, the consumption of pequi is limited to its region of origin. The study aimed to explore the process of drying pequi slices (convective or vacuum drying at 40 °C and 60 °C) preceded or not preceded by osmotic pre-treatment (sucrose solution at concentrations of 40% and 60%). It was found that that prior osmotic dehydration significantly decreased moisture content, duration of the drying process, and the volumetric ratio of the dried product. However, the pretreatment also promoted the leaching of bioactive components such as ascorbic acid and carotenoids. Low temperature vacuum drying not preceded by dehydration was preferable because the ascorbic acid and carotenoids were retained, the rehydration coefficient was higher, and the volume and the color and volume change was minimal. [15].

In 2016, Zhi-Gang Chen, Xiao-Yu Guo, and Tao Wu proposed a new technique for dehydrating carrot slices which used ultrasound and vacuum drying methods. The novel drying technique involving a combination of ultrasound and vacuum dehydration was developed to shorten the drying time and enhance the quality of carrot slices. Carrot slices were dried with ultrasonic vacuum (USV) drying and vacuum drying at 65 °C and 75 °C. The duration of drying was dependent upon the drying technique and temperature. As compared to vacuum drying, USV drying resulted in a 41–53% decrease in the drying time. The drying time for the USV and vacuum drying techniques at 75 °C was determined to be 140 and 340 minutes for carrot slices, respectively. The dehydration rate, nutritional value (retention of β-carotene and ascorbic acid), color, and textural properties of USV-dried carrot slices were found to be better as compared to vacuum-dried carrot slices. Furthermore, lower energy consumption associated with the use of the USV technique was recorded [16].

In 2016, Dragana Šoronja-Simović, Zita Šereš, Nikola Maravić, Marijana Djordjević, Miljana Djordjević, Jadranka Luković, and Aleksandra Tepić published the outcomes of their study on improvement of physicochemical properties of sugar beet fibers affected by chemical modification and vacuum drying. The experiments led to the conclusion that chemical modification of the fibers increases the content of soluble dietary fiber, and chemical modification in combination with vacuum drying results in an increase in brightness and changes of fiber properties. The effects of chemical modification with hydrogen peroxide as well as different temperatures of vacuum drying (55, 65 and 75°C) on the content of soluble and insoluble dietary fibers were examined. Physicochemical properties (colour, structure, water binding and swelling capacity) and the drying kinetics of sugar beet fibers were also explored. Compared to non-modified fibers, chemical modification allowed for a 20–40% increase in the ratio of soluble and insoluble fibers and approximately a 25% increase in fiber brightness. The swelling and water binding capacities of fibers exposed to chemical modification were three to four times higher than those of non-modified fibers. The specified effects are explained by changes in fiber structure due to chemical modification. In general, the research showed that chemical modification and vacuum drying are suitable for sugar beet fibers and that modified fibers can be used as an additive in the food industry [17].

Also in 2016, Gabriella Dias da Silva, Zilmar Meireles Pimenta Barros, Rafael Augusto Batista de Medeiros, Carlos Brian Oliveira de Carvalho, Shirley Clyde Rupert Brandão, and Patrícia Moreira Azoubel explored the possibility of using ultrasound and vacuum for drying melons. Ultrasound, osmotic dehydration and vacuum were employed as pre-treatment for drying melons. Samples pretreated with ultrasound alone or in combination demonstrated faster drying rates when dried under vacuum. Dried melons exposed to combined ultrasound and vacuum pretreatment presented higher total carotenoids content and softer texture. The purpose of the study was to evaluate the effects of ultrasound, osmotic dehydration and vacuum as a pretreatment on melon drying and product quality. The pretreatment consisted in four processing conditions utilizing vacuum and/or ultrasound and a control sample without application of ultrasound and vacuum. Melon samples were immersed in a liquid medium (distilled water or sucrose solution) and pretreated for 10, 20 and 30 minutes. The drying process was carried out in a fixed bed at 60 °C and air velocity of 2 m/s. The dried samples pretreated with ultrasound and with a combination of ultrasound and vacuum showed faster drying rates. The assessment of the final product was implemented with regard to total carotenoid content, texture, color as well as by means of sensorial testing. Dried melon pretreated with ultrasound in combination with vacuum showed higher total carotenoids content, softer texture and total color difference similar to the untreated dried fruit. The sensory test revealed good taste of the dried product. Thus, the use of ultrasound or a combination of ultrasound and vacuum as a pretreatment impacts the efficiency of melon drying and can be considered suitable for industry as an alternative to traditional drying techniques [18].

---

3. Results and discussion

The analysis of a number of studies carried out by researchers from different countries indicates the undeniable advantage of vacuum drying over other food dehydration technologies. Great advances have been achieved in investigating vacuum drying within the last 5-7 years. Based on the results of the analysis, the following aspects that have good potential for further research have been identified:

1. The possibility of utilizing vacuum drying or freeze drying, the latter also implemented under vacuum for most food crops.

2. The use of vacuum drying allows for higher efficiency of drying as well as the retention of nutritional composition and attractive appearance of dried samples.

3. For a number of crops that have hard structure, chemical preparations (e.g., solutions of sucrose, hydrogen peroxide) can be used as pre-treatment before drying to facilitate further processing.

4. Vacuum drying can also be used to increase the nutritional value of the product being dried.

5. Evaluation of the final product requires assessment of the product appearance, i.e. attractiveness of the product is an essential evaluation parameter.

6. Antioxidant activity and, for some products, ascorbic acid content, are necessary parameters to be used for assessing the product quality.

7. It is recommended that vacuum drying is conducted at lower temperatures in order to retain high organoleptic properties of the product being dried.

8. Additional treatment with ultrasound is possible during or prior to vacuum drying of food products.

9. It is possible to estimate the dryness of products placed inside a freeze-dryer by using

phenolphthalein as an indicator of ongoing drying processes.

4. Conclusions

The present technology review focuses on the analysis of studies that have been carried out in the area of vacuum drying of food products. The research findings showed that scientist have a strong interest in vacuum drying and e ways to improve this method of product dehydration. Vacuum drying can be used for drying unique plants grown in a particular geographical area as well as processing food products and, most probably, medicinal plant raw material.

Bibliographic references

Burova N.O., Kislitsyna N. A., . Gryazina F. I., Elchaninova N. V.(2016) Features of production of dry germinated grains and rye. Bulletin of the Mari state university. Series: Agricultural sciences. Economic sciences.T. 3. No. 7. Page 10-15.

Lykov A. V. (1968) Theory of drying, 471 p.

Burova N.O. (2011) Technology of dry germinated wheat grain and its use in the bakery production. Abstract of the thesis of the candidate of technical science. 05.18.01. 24 p.

R.M. Bórquez, E.R. Canales, J.P. Redon (2010). Osmotic dehydration of raspberries with vacuum pretreatment followed by microwave-vacuum drying. Original Research Article. Journal of Food Engineering, Volume 99, Issue 2, July 2010, Pages 121-127

Shen Pingniang, Liu Zhiyuan, Huang Kaizhong, Xiao Qiong (2010). An Engineering Study and Analysis of the Factors Affecting Evaporation Rate Under the Vacuum Drying Process. Original Research Article.World Science and Technology, Volume 12, Issue 1, February 2010, Pages 118-121

Elsa Uribe, Daniela Marín, Antonio Vega-Gálvez, Issis Quispe-Fuentes, Angela Rodríguez (2016).Assessment of vacuum-dried peppermint (Mentha piperita L.) as a source of natural antioxidants. Original Research Article. Food Chemistry, Volume 190, 1 January 2016, Pages 559-565

Yuan-Yuan Pu, Da-Wen Sun (2016).Prediction of moisture content uniformity of microwave-vacuum dried mangoes as affected by different shapes using NIR hyperspectral imaging. Original Research Article. Innovative Food Science & Emerging Technologies, Volume 33, February 2016, Pages 348-356

Katrin Burmester, Arne Pietsch, Rudolf Eggers (2011).A basic investigation on instant coffee production by vacuum belt drying. Original Research Article. Procedia Food Science, Volume 1, 2011, Pages 1344-1352

B. Zecchi, L. Clavijo, J. Martínez Garreiro, P. Gerla(2011).Modeling and minimizing process time of combined convective and vacuum drying of mushrooms and parsley. Original Research Article. Journal of Food Engineering, Volume 104, Issue 1, May 2011, Pages 49-55

Zdravko Šumić, Aleksandra Tepić, Senka Vidović, Stela Jokić, Radomir Malbaša (2013).Optimization of frozen sour cherries vacuum drying process. Original Research Article.Food Chemistry, Volume 136, Issue 1, 1 January 2013, Pages 55-63

Manish Dak, Pareek, N.K. (2014).Effective moisture diffusivity of pomegranate arils under going microwave-vacuum drying Original Research Article. Journal of Food Engineering, Volume 122, February 2014, Pages 117-121

Takahiro Orikasa, Shoji Koide, Shintaro Okamoto, Teppei Imaizumi, Yoshiki Muramatsu, Jun-ichi Takeda, Takeo Shiina, Akio Tagawa (2014). Impacts of hot air and vacuum drying on the quality attributes of kiwifruit slices. Original Research Article.Journal of Food Engineering, Volume 125, March 2014, Pages 51-58

Bussaya Mee-ngern, Seung Ju Lee, Jinnipar Choachamnan, Waraporn

Boonsupthip(2014).Penetration of juice into rice through vacuum dryingOriginal Research Article. LWT - Food Science and Technology, Volume 57, Issue 2, July 2014, Pages 640-647

Lin Liu, Ya Wang, Daidi Fan, Yu Mi (2015).Using phenolphthalein as a promising indicator to monitor the vacuum freeze-drying process. Materials Letters, Volume 139, 15 January 2015, Pages 245-248

Kamilla Soares de Mendonça, Jefferson L.G. Corrêa, João Renato de Jesus Junqueira, Marcelo Angelo Cirillo, Fabiano Vicente Figueira, Elisângela Elena Nunes Carvalho(2017).Influences of convective and vacuum drying on the quality attributes of osmo-dried pequi (Caryocar brasiliense Camb.) slices. Original Research Article. Food Chemistry, Volume 224, 1 June 2017, Pages 212-218

Zhi-Gang Chen, Xiao-Yu Guo, Tao Wu(2016).A novel dehydration technique for carrot slices implementing ultrasound and vacuum drying methods Original Research Article. Ultrasonics Sonochemistry, Volume 30, May 2016, Pages 28-34

Dragana Šoronja-Simović, Zita Šereš, Nikola Maravić, Marijana Djordjević, Miljana Djordjević, Jadranka Luković, Aleksandra Tepić(2016). Enhancement of physicochemical properties of sugar beet fibres affected by chemical modification and vacuum drying. Original Research Article. Food and Bioproducts Processing, Volume 100, Part A, October 2016, Pages 432-439

Gabriella Dias da Silva, Zilmar Meireles Pimenta Barros, Rafael Augusto Batista de Medeiros, Carlos Brian Oliveira de Carvalho, Shirley Clyde Rupert Brandão, Patrícia Moreira Azoubel (2016) Pretreatments for melon drying implementing ultrasound and vacuum drying. Original Research Article. LWT - Food Science and Technology, Volume 74, December 2016, Pages 114-119.

---

1. Mari State University, Yoshkar-Ola, Russian Federation; E-mail: natsta@mail.ru

2. Mari State University, Yoshkar-Ola, Russian Federation

3. Mari State University, Yoshkar-Ola, Russian Federation

4. Mari State University, Yoshkar-Ola, Russian Federation

5. Mari State University, Yoshkar-Ola, Russian Federation

Revista ESPACIOS. ISSN 0798 1015
Vol. 38 (Nº 52) Year 2017

[Index]