

EFFECT OF DIFFERENT DRYING TECHNIQUES ON THE DRYING TIME AND ENERGY OF BLUEBERRY

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ABSTRACT

Blueberries (*Vaccinium corymbosum* L.) were dried combining vacuum, infrared, hot-air and freeze drying technologies. In this paper, examined the drying time and energy consumption of dewatering methods. The rehydration as a physical property were evaluated in dried blueberries. Combination of vacuum dried and freeze dried blueberries had higher rehydration ratio, followed by the single freeze drying, combination of hot-air drying and freeze drying, and infrared-freeze drying methods. The performance evaluation indicated that combination drying of blueberries at two-stage infrared-freeze drying with 60°C and 15 min pre-drying reduced the drying time by 53.4%, besides consuming less energy (52.9%) compared to single freeze drying. Based on the results, primarily vacuum pre-drying, infrared pre-drying and freeze finish-drying may be the economical and optimal solution for dehydrating blueberries.

Keywords: single- and two-stage drying, drying time, energy uptake, rehydration, blueberry

1. INTRODUCTION

The consumers are gradually interested in the health benefits of foods and have begun to look beyond the basic nutritional benefits to the potential illness prevention and health enhancing compounds contained in many foods. Fruits and vegetables are natural sources of healthy bioactive compounds and mineral nutrients, exhibiting significant health benefits [1]. Blueberries (*Vaccinium corymbosum* L.) have become very popular with purchaser because of the research results that associate their consumption with improvements in human health [2]. Nowadays, blueberry intake is of high interest due to its high content of antioxidant compounds (flavonoids and anthocyanins) and vitamin A, B, C and E. Blueberries are well known for their anticancer, anti-inflammatory and antidiabetic properties [3].

Drying of fruit and vegetables is one of the most common processes used to improve the stability, as it reduces the water activity of product, cut down on microbiological activity, reduces in weight and volume and minimizes physical and chemical changes during storage [4].

Nowadays, drying of fruits and vegetables principally accomplishing by hot-air drying (HAD). The high temperature of the drying method is an important cause of loss of chemical compounds and change in appearance. Some important physical properties of the final products are changed by this dewatering technique such as loss of color, change of texture, shrinkage, chemical changes affecting flavour and nutrients [5].

The infrared drying (IRD) occurs by the exposure of the raw matter to electromagnetic radiation. The infrared radiation energy is transferred from the heating element to the material surface. However, the surrounded air is not heated in the drying process [6]. Compared with HAD, the IRD heating offers many advantages such as greater energy efficiency, heat transfer rate, which results in decreased operational time and higher drying rate [7].

The vacuum drying (VD) is a remarkable procedure for heat sensitive substances. Under atmospheric pressure drying can be considered according to physical state used to add heat and remove water vapour. Low temperature can be used under vacuum for certain techniques that might discolour or degrades at high temperature [8].

Higher quality products can be obtained using more expensive freeze-drying (FD) process. The solid state of water during FD protects the structure and minimizes changes in the form of the final product, with

minimal shrinkage [9]. In addition, it contributes to preserve mineral nutrients and vitamins, as well as to retain original aroma and flavour [10].

Energy and working time efficiency are one of the most important design and operational parameters in food processing, so the importance of combined drying has increased. Combined, two-stage drying, or otherwise tandem drying, is a drying solution where one drying method is followed by another drying process. There are many combinations of drying techniques. Target to avoid the disadvantages of the single drying method, e.g. the long drying time, high energy consumption or unfavourable product quality [11].

No one has reported on the two-stage drying (HAD-FD, IRD-FD and VD-FD) of blueberries. The aim of the present study is to determine the combined drying program and to evaluate the effect of single- and two-stage drying on drying time, energy consumption, and rehydration.

2. MATERIALS AND METHODS

2.1. Materials

The blueberries were purchased from a local supermarket in Nyiregyhaza, Hungary. Before the experiments, initially the blueberry fruits were thoroughly washed. Before freeze drying the samples pre-treated with quick-freezing ($T = -25^{\circ}\text{C}$) in quick freezer (FT34MKII, Armfield Ltd., Ringwood, England).

The average diameter of a blueberry was $1\text{ cm} \pm 0.2\text{ cm}$. The samples were divided into thirteen groups, each group of samples weighed 100 g. Moisture contents of raw and dried blueberry samples was measured by the gravimetric method using a laboratory convection oven (model LP302, LaborMIM, Budapest, Hungary) at $105 \pm 1^{\circ}\text{C}$ until a constant weight was reached. Average moisture content of fresh blueberry was 88.1% in wet basis. The samples were dehydrated until they reached the final moisture content (2-3% w.b.).

2.2. Methods

The hot-air drying (HAD) was realized in a cabinet drier (model LP305, LaborMIM, Budapest, Hungary). The drying temperature was fixed at 60°C . According to the previous literature, the optimum drying conditions of hot air drying for foods were 60°C hot air temperature [12, 13]. The weight of sample was measured (model JKH-500, Jadever Co., New Taipei, Taiwan), every 60 minutes, for a total duration of seven hours. A suitable blower was fitted for air circulation in the drying chamber which is leading to an air velocity of 1 m/s over the trays. The samples were placed in one layer on the sample holder.

A laboratory scale vacuum dryer (VD) was used for vacuum dehydration of the samples (model Kambic VS-50C, Kambic Lab. Eq., Semic, Slovenia). The vacuum pump provides pressure in the chamber 5000 Pa under the drying. The temperature in the chamber was set at 60°C for each treatment. Temperatures of the samples were monitored using type T thermocouples throughout the experiment. Blueberry mass was recorded with balance (model JKH-500) every 1 hours, which has a sensitivity of 0.1 g. The samples were uniformly spread in single layer on the tray.

Infrared drying (IRD) was performed in a laboratory digital infrared dryer (model Precisa HA60, Precisa Instruments AG, Dietikon, Switzerland). Two infrared heaters were operated at 230 V with a maximum power of 410 W. The sample tray was kept 15 cm below the infrared heater throughout the experiment. The drying air temperature was kept at 60°C , which corresponds to a heat intensity level of 4.5 kW/m^2 . The mass of the blueberry was measured using a digital electronic balance (model Precisa HA60) at intervals of 5 min during the drying experiment. Each 100 g samples were uniformly spread in single layer on a stainless steel tray.

Freeze drying (FD) was performed using a lab scale freeze dryer (model Christ Alpha 1-4 LSC Plus, Martin Christ GmbH, Osterode am Harz, Germany) (Fig. 1.). Heating shelf temperature was set at 20°C , and the cold trap temperature was maintained at -45°C . Samples temperatures were measured by the T-type thermocouples inserted into the samples. During drying, 100 g of samples were dehydrated in the chamber with an internal pressure of 50 Pa produced by the vacuum pump. The samples were uniformly spread in single layer on the tray.



Figure 1. Christ Alpha 1-4 LSC Plus laboratory vacuum freeze dryer with blueberry samples

The drying parameters of each drying conditions was listed in Tab. 1.

Table 1. Description of the drying programs

No	Acronym	Description	Air		Power (kW/m ²)	Pressure (Pa)
			T (°C)	v (m/s)		
1	HAD	Single-stage Hot-air drying	60	1	-	10 ⁵
2	IRD	Single-stage Infrared drying	60	-	4.5	10 ⁵
3	VD	Single-stage Vacuum drying	60	-	-	5 ³
4	FD	Single-stage Freeze drying	-20 - +20	-	-	50
5	HAD2-FD	Combined hot-air freeze drying	60; -20 - +20	1	-	10 ⁵ →50
6	HAD3-FD	Combined hot-air freeze drying	60; -20 - +20	1	-	10 ⁵ →50
7	HAD4-FD	Combined hot-air freeze drying	60; -20 - +20	1	-	10 ⁵ →50
8	IRD5-FD	Combined infrared freeze drying	60; -20 - +20	-	4.5	10 ⁵ →50
9	IRD10-FD	Combined infrared freeze drying	60; -20 - +20	-	4.5	10 ⁵ →50
10	IRD15-FD	Combined infrared freeze drying	60; -20 - +20	-	4.5	10 ⁵ →50
11	VD2-FD	Combined vacuum d. freeze drying	60; -20 - +20	-	-	5 ³ →50
12	VD3-FD	Combined vacuum d. freeze drying	60; -20 - +20	-	-	5 ³ →50
13	VD4-FD	Combined vacuum d. freeze drying	60; -20 - +20	-	-	5 ³ →50

The dried blueberry samples were packed immediately into PE bags after drying for further analyses. Combined or two-stage drying procedure: Experiments were performed using combined drying methods until the final sample moisture content. The settings for each stage are given in Tab. 2.

Table 2. Description of drying treatment combinations

No	Acronym	First drying stage (m. c. in w.b.)	Second drying stage (m. c. in w.b.)
1	HAD2-FD	60°C for 2h until the moisture c. was 54.5%	20°C until the moisture c. below 2.6%
2	HAD3-FD	60°C for 3h until the moisture c. was 40.3%	20°C until the moisture c. below 2.4%
3	HAD4-FD	60°C for 4h until the moisture c. was 33.7%	20°C until the moisture c. below 2.9%
4	IRD5-FD	60°C for 5 min until the moisture c. was 46.9%	20°C until the moisture c. below 2.1%
5	IRD10-FD	60°C for 10 min until the moisture c. was 35.4%	20°C until the moisture c. below 2.2%
6	IRD15-FD	60°C for 15 min until the moisture c. was 26.5%	20°C until the moisture c. below 2.6%
7	VD2-FD	60°C for 2h until the moisture c. was 59.2%	20°C until the moisture c. below 3.0%
8	VD3-FD	60°C for 3h until the moisture c. was 44.4%	20°C until the moisture c. below 2.7%
9	VD4-FD	60°C for 4h until the moisture c. was 36.2%	20°C until the moisture c. below 2.8%

The specific energy consumption during dehydration was measured by an energy-cost-checker (model EKM 265, Conrad Electronic GmbH, Hirschau, Germany), and the energy consumption required to remove 1 kg of water was calculated. The specific energy consumption (SEC) in MJ/kg_{water} was estimated as follows (1):

$$SEC = \frac{E \times 3,6}{W_0 - W_f}, \quad (1)$$

where E is the electrical power consumption [kWh], W_0 is the initial mass of the raw material [kg], W_f is the final mass of the dried sample [kg].

Description of rehydration procedure: The dried samples were soaked in 30°C ± 1°C distilled water for 1 h, then the free water on the surface of the samples was removed with a filter paper. The rehydrated samples weighed with an electronic digital balance having a sensitivity of 0.01 g. The rehydration ratio (RR) was calculated according to Eq. (2):

$$RR = \frac{W_r}{W_d}, \quad (2)$$

where W_r is the drained weight of the rehydrated sample [g], W_d is the weight of the dry sample used for rehydration [g].

Statistical analysis was conducted by analysis of variance (ANOVA) using Duncan's test to detect the differences among drying methods (SPSS 20.0, IBM Inc., USA). All drying condition were replicated three times.

3. RESULTS AND DISCUSSION

3.1. Drying time

The Fig. 2 shows the significant effect ($p < 0.05$) of different drying techniques on the drying time. Drying (initial moisture content, 88.1% w.b.) continued until the final moisture content was ca. 2-3% (w.b.). It is observed that the drying time for HAD, IRD, VD, FD, HAD2-FD, HAD3-FD, HAD4-FD, IRD5-FD, IRD10-FD, IRD15-FD, VD2-FD, VD3-FD and VD4-FD was 420, 75, 480, 1320, 1080, 960, 1320, 1080, 960, 900, 785, 670, 615, 1140, 960 and 900 minutes, respectively.

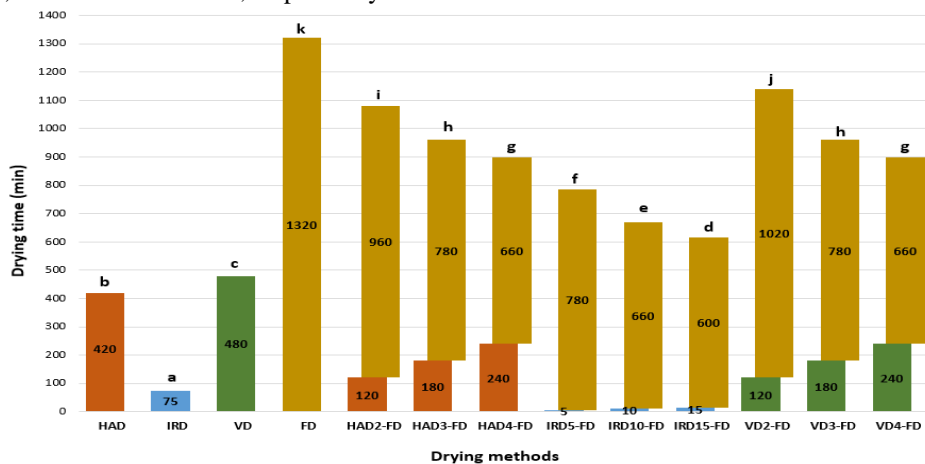


Figure 2. Results of drying time of dried blueberry samples under different drying techniques
 Bars with different letters differ significantly from each other as determined by Duncan's test.

Lyophilization (FD=22h) has the longest treatment time at blueberry, in agreement with previous studies [14, 15]. Pre-freezing of the blueberry sample has a good effect on the operating time of lyophilization as it reduced the drying time from 26 to 22 hours. Compared to FD, the IRD15-FD significantly ($p < 0.05$) reduced drying time by 53.4%.

For the combined drying methods, the pre- and finish-drying are marked with different colours. Fig. 2 shows that the drying time in the IRD-FD method (785, 670 and 615 min) was the shortest among hybrid drying techniques. Reyes et al. [16] dried the blueberries in a freeze dryer equipped with a 150 W infrared halogen lamp. It was found that the IRD application accelerated the drying process. The operating time of freeze-drying was reduced to 12 hours with this solution. In particular, the drying time required for dehydration with IRD15-FD to reach a moisture content of 2.6% (w.b.) was 1.46 times less than HAD4-FD and VD4-FD methods, respectively. The increase in heat intensity level at IRD might have caused a rapid rise in the temperature at surface of product, resulting into an increase in the water vapour pressure inside the material and thus in higher drying rates [17].

It was found, that the drying time decreased significantly ($p < 0.05$) with increased a pre-drying time (2-3-4 h and 5-10-15 min) under a constant drying temperature (60°C) and infrared power (4.5 kW/m²). Furthermore, it was found that 5 hours of pre-drying for VD and HAD and 20 minutes of pre-drying for IRD cause a noticeable browning (so called Maillard reaction) on the surface of the products, so the results of these settings are not reported.

3.2. Specific energy consumption (SEC)

Effect of single and two-stage drying methods on the specific energy consumption (MJ/kg_{water}) are given in Fig. 3. As it can be seen there, the SEC for HAD, IRD, VD, FD, HAD2-FD, HAD3-FD, HAD4-FD, IRD5-FD, IRD10-FD, IRD15-FD, VD2-FD, VD3-FD and VD4-FD was 73, 40.7, 167, 496.1, 360.8, 293.2, 248, 293.2, 248, 225.5, 383.4, 293.2, 62.6, 248 and 83.5 MJ/kg_{water}, respectively. It can be seen that as the drying time decreases, the total specific energy consumption decreases. In the case of combined drying, the energy consumption of the given method decreases significantly ($p < 0.05$) with the increase of the pre-drying time (from 2 to 4 hours and from 5 to 15 min). The highest SEC was recorded in the FD compared to other drying methods (SEC=496.1 MJ/kg_{water}). So it is very important that improve freeze-drying – very energy intensive process – by reducing energy consumption and drying time.

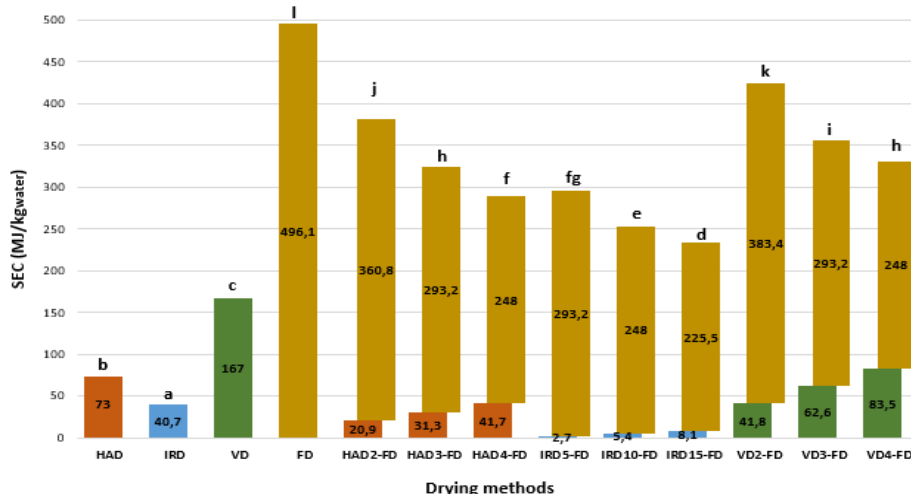


Figure 3. Effects of different drying techniques on the specific energy consumption (SEC) of dried blueberries
 Bars with different letters differ significantly from each other as determined by Duncan's test.

The reason for the high energy consumption of lyophilization is that, it usually uses electric heating plates to provide the heat required for ice sublimation, with low heat conductivity [18]. In freeze-drying, the basic energy, which required to remove 1 kg of water is almost double that of conventional drying (e.g. HAD) [19]. In this study, the specific energy consumption of the FD is about 6.8 times the energy consumption of the HAD. The lowest SEC was related to the IRD-FD technique. The energy consumption of the IRD15-FD is 52.9 % lower than the energy consumption of the FD, there is a significant difference between them.

3.3. Rehydration ratio (RR)

Rehydration ratio (RR) is important quality evaluation index for dehydrated products. This means that the higher the RR, the better the quality of the dried material. The Fig. 4. showed the RR of blueberry samples under different drying methods. The rehydration ratio values obtained in this work varied from 1.43 to 3.67. The maximum rehydration rate (3.67) was obtained for VD2-FD, the RR value of FD was 3.54, but there was no significant difference ($p > 0.05$) between them. The rehydration rate of the vacuum pre- and freeze-dried product is particularly high, differing significantly ($p < 0.05$) from the RR of the other combined dried samples. It was observed that rehydration ratio of IRD-FD and VD-FD decreased with increasing of drying time at pre-drying, with the exception of HAD-FD.

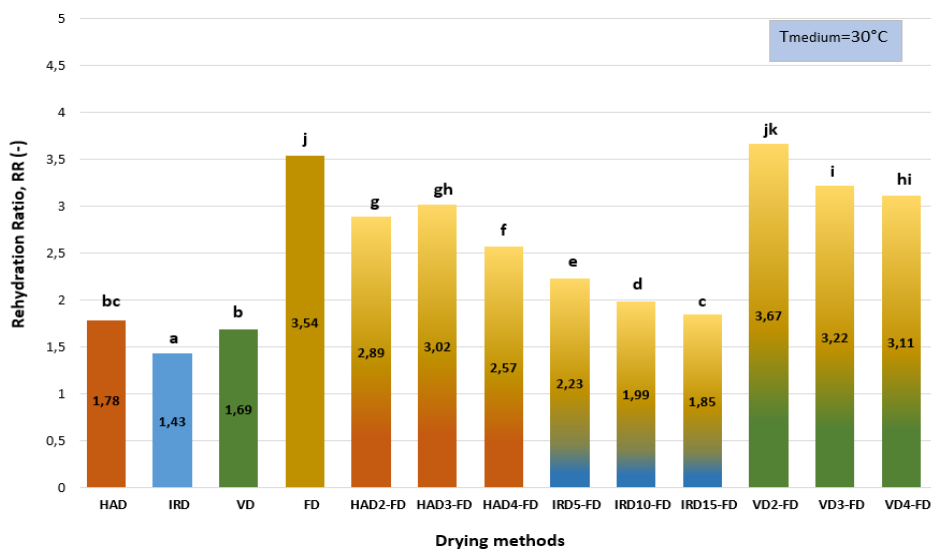


Figure 4. Effects on different drying methods on the rehydration ratio of dried blueberry samples
 Bars with different letters differ significantly from each other as determined by Duncan's test.

Dried blueberries with single-stage IRD, characterized by the lowest rehydration rate (1.43) compared to other single-stage (HAD: 1.78, VD: 1.69) methods used in the present study. After 3 h of soaking in water, the rehydration capacity of blueberries dried by single-stage HAD at 60°C and 1 m/s was 2.30 [20]. The relatively low rehydration ability of single-stage infrared-, vacuum-, and hot-air dried blueberries is primarily due to collapse structures and shrinkage [21, 22]. Based on the results, it is not surprising that the rehydration index of freeze dried blueberries is high. Similar finding has been reported by Rajkumar et al. [23] on carrot drying. This can be caused by porous structure, and surface micro capillaries as a result of the freeze dried (FD) method [24]. As a result, the freeze dried material can be quickly restored to its original, raw state. In addition to FD products, the same can be said for VD-FD materials.

4. CONCLUSIONS

In this study, whole blueberries were dehydrated by single-stage hot air-, vacuum-, infrared-, and freeze-drying, and these drying methods were also combined. Compared with freeze drying (FD), the infrared-freeze drying (IRD-FD) could effectively lower the drying time and total energy consumption, especially IRD15-FD. The IRD15-FD reduced the drying time by 53.4%, besides consuming less energy (52.9%) compared to single-stage freeze drying. It was found that the drying time of the HAD-FD material was similar to that of the VD-FD samples. The specific energy consumption (SEC) of HAD4-FD was the same as IRD5-FD. Vacuum pre- and freeze-dried (VD2-FD) blueberries have a water absorption capacity better than FD, IRD-FD and HAD-FD were dried. Although the rehydration of lyophilized blueberries (RR=3.54) is almost the same as that of vacuum pre- and freeze-dried blueberries (RR=3.67), its energy consumption is 1.17 times. The rehydration rate (RR) of the HAD-FD samples were close to the VD-FD samples. Taking into account the economic and quality factors, the VD4-FD, HAD3-FD and IRD5-FD a good option for use in the food industry. Further experiments are needed to optimize the combined drying.

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