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Effect of foam-mat drying condition on physical properties and rehydration behavior of mushroom powder

S. Nejatdarabi[1], M. Mohebbi[2*]

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Abstract

In this study the effect of drying conditions on physical and rehydration properties of foam-mat dried mushroom powder was investigated. Physical properties included moisture content, a_w, hygroscopicity, particle size, flowability and cohesiveness, angle of repose, and T_g. The results showed physical properties of mushroom powder significantly ($p<0.05$) affected by dry temperature. The water activity of mushroom powder was below 0.3, which leads to stable conditions. As decreasing drying temperature, the particle size of mushroom powder increased and led to the increase moisture content and a_w. The mushroom powder showed better flowability as increased drying temperature. T_g of mushroom powder ranged from 41.3- 55.6°C. An increase in drying temperature led to increasing wettability and dispersibility. The drying condition had no-significant effect ($P<0.05$) on the solubility of mushroom powder.

Keywords: Mushroom powder, Flowability, Wetability, Dispersibility, Solubility.

Introduction

The white button mushroom (*Agaricus bisporus*) is one of the most important edible mushrooms. This is due to the high nutritional value, medicinal attributes, and lower prices (Meng *et al.*, 2017; Qin *et al*., 2015). Due to the lack of cuticle, high water content, and respiration rate, the shelf life of mushrooms has been limited to a few days. With consideration of beneficial properties and short shelf life of mushrooms, it is necessary to use an appropriate preservation method to extend the shelf life (Gholami *et al*,. 2017). Different methods have been used to improve the shelf life of mushrooms, such as film packaging (Gholami *et al.,* 2017; Salamat *et al.*, 2020), coating (Nasiri *et al*., 2018), drying (Carrión et al., 2018), and frying et al., 2011).

Nowadays, demand for food powders have increased due to various advantages such as stability and usability for a long period (Bhandari, 2013). In the food industry, drying is a common way to produce powdered food. Drying methods include spray drying, freeze-drying, air drying, and foam-mat drying. Among the methods of drying foam-mat drying is an economical and simple method. The porous structure of foam leads to a higher heat transfer rate and reduces drying time (Hardy & Jideani, 2017). Powdered food obtained by foam-mat drying can be used in beverages, meat and bakery products, ice cream, instant foods, and pasta (Hamzeh *et al.,* 2019). Foam mat drying technique has been successfully applied to many foodstuffs such as jambolan juice (Tavares *et al.,* 2020), lime juice (Dehghannya *et al*., 2019), grape juice (Maria de Carvalho Tavares *et al.*, 2019), fig (Varhan, Elmas, & Koç, 2019), strawberry and banana pulps (Guazi *et al*., 2019), yoghurt (Malik & Sharma, 2019), shrimp (Azizpour *et al*., 2016; Hamzeh *et al*., 2019), dates (Seerangurayar *et al*., 2017), cantaloupe pulp (Salahi *et al*., 2017), muskmelon (Asokapandian *et al.*, 2016), yacon juice (Franco *et al.,* 2016), and mushrooms (Pasban *et al.*, 2015).

Physical properties are used to define characteristics of powders and their behaviors

1 and 2. MSc Student and Professor, Department of food science & technology, Ferdowsi University of Mashhad (FUM), Mashhad, Iran.

(Corresponding Author Email:mohebbatm@gmail.com)
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during operation, transportation, and storage. Understanding these properties of powder can be useful to develop strategies for efficiency and reduces cost of powder processing (Jaya & Das, 2004). The physical properties of powders are divided into two groups: bulk and particle properties. Bulk properties of powder include flowability, bulk density, and mixture quality. Particle properties include size and shape, composition, and particle density (Fitzpatrick, 2013).

Rehydration is the critical quality of powders when focusing on standard benchmark for consumption. In most cases, food powders are dissolved in water or an aqueous system. The rehydration process of powder often includes three stages: wettability, dispersibility, and solubility. Among them, solubility is considered a rehydration quality of the powder (Hogekamp & Schubert, 2003).

Pasban (2012) investigated of foaming parameters of button mushroom. Mushroom puree: water ratio of 2:1 (w/w) and xanthan gum at a concentration of 0.17% (w/w) were selected to optimize foaming conditions for foam-mat drying of button mushroom. This study was done to investigate the effects of different levels of air temperature (50, 65, and 80°C), and foam thickness (3 and 5 mm) on physical and rehydration behavior of foam-mat dried mushroom powder.

Materials and methods

Button mushroom was purchased from a local market (Mashhad, Iran) and stored at 4°C. Xanthan gum as a foam stabilizer was purchased from Sigma-Aldrich Company.

Mushroom powder production

Sample preparation

The mushrooms were washed and cut into uniform pieces. To prevent browning, the pieces of mushroom were immersed in aqueous solution of sodium metabisulfite (2% w/w) for 10 minutes (Pasban, 2012). Then, they washed with water. After removing the excess water, the sliced mushrooms were homogenized by the kitchen blender (210 W; Tefal) at a maximum speed of 1500 rpm to obtain a homogenized puree. 100 mL of distilled water and 0.17 g of xanthan powder were mixed to obtain xanthan gum solution. The mixture stirred with a magnetic stirrer (Ray Noor Azma Company, Tehran, Iran) until a uniform solution was obtained. The solution was kept in the refrigerator at 4°C for 18– 24 h to make complete hydration.

Foam production

According to Pasban (2012), To prepare 100 g of foam, 33 g of xanthan gum solution with a concentration of 0.17% (w/w) and 67 g of mushroom puree were mixed. The mixture of gum and puree was stirred using a kitchen mixer (Sunny, SM88, maximum speed 1500 rpm) for 8 min.

Foam drying

Mushroom puree foam was poured into an aluminum plates of diameter 9 cm in a thin layer with a thickness of 3 to 5 mm. The plates were placed in a dryer (Pars Azma Company, Tehran, Iran) at a constant speed of 1.5 m/s at three temperatures of 50, 65, and 80°C. Drying of the samples was continued until reaching a constant weight. A certain amount of dried foam was removed from the dryer and pulverized by a kitchen miller. The samples were poured into glass containers after passing through a sieve (Mesh No.50) and stored at ambient temperature until further analysis.

properties

Moisture content

The moisture content of the powder was determined by using an oven (AOAC, 1995). The samples were dried at 105°C to a constant weight. Moisture content was calculated by the difference between the weight of powder before and after drying.

Water activity

A water activity meter was used to measure a_w of samples. Powder samples were poured into the device and the a_w was recorded.

Hygroscopicity

To measure the hygroscopicity of mushroom powder, 1 g of the powder samples was poured into a glass plate. The plates were then placed in a desiccator containing a saturated solution of sodium chloride at 25°C. After a week, the plates were removed from the desiccator and weighed. Hygroscopicity was calculated by weight differences between samples (Tonon *et al.*, 2008).

Particle morphology and microstructural properties

The microstructure of the samples (i.e. size and shape) was evaluated by using a scanning electron microscope (SEM) model XL 30 (manufactured by Philips, Netherlands). The required amount of mushroom powder was covered with gold. Imaging was performed at two magnifications (500 and 1000) and particle size was calculated with ImageJ 1.51p software.

Bulk and tapped densities

To determine the bulk density, a quantity of mushroom powder was poured into a glass cylinder. Bulk density was calculated considered as the ratio of mass to volume according to equation 1. The glass cylinder was then tapped from a height of 15 cm (30 taps) to obtain a constant volume. Tapped density was calculated considered as the ratio of mass to the final volume according to equation 2.

$$\rho_b = \frac{m}{V} \quad (1)$$

$$\rho_t = \frac{m}{V_f} \quad (2)$$

m= quantity of mushroom powder (g)
V= volume of mushroom powder (cm^3)
V_f= final volume of mushroom powder after mechanically tapping (cm^3)

Flowability and Cohesiveness

Classification of flowability and cohesiveness of mushroom powder was done by using the Carr index (CI) and Hausner ratio (HR) according to equations (3, and 4) respectively.

$$CI = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (3)$$

$$HR = \frac{\rho_t}{\rho_b} \quad (4)$$

Angle of repose

A glass funnel and graph paper were used to measure the angle of repose. The funnel of diameter 10 cm and a base with 7 cm length and 1 cm diameter were held by a suspension clamp. The distance between the end of the funnel base and the graph paper was 3 cm. The powder was poured on the graph paper until it touched the end of the funnel base. According to the radius and height of the powder (3 cm), the angle of repose was calculated according to equation (5) (Alanazi, 2010).

$$\theta = \tan^{-1}\left(\frac{h}{r}\right) \quad (5)$$

h= Height of the powder
r= Radius of the powder

Glass transition temperature

The glass transition temperature was measured using a differential scanning calorimetry (DSC, OIT-500 Sanaf Electronic Co.). After calibration, about 10-12 mg of the powder was placed inside the sample pan; an empty aluminum pan was used as a reference. All experiments were performed with the same heating rate of 10°C/min in the temperature range of 25-150°C.

Rehydration behavior

Wettability

To measure the wettability, 100 ml of distilled water was poured into a 250 ml beaker. A glass funnel was placed on top of the beaker using a clamp. The distance between the end of the funnel bottom and the surface of the water was 10 cm. A test tube was inserted into the funnel to block its end. 1g of mushroom powder was poured around the test tube. Then the test tube was removed and the time was recorded using a stopwatch, simultaneously. The wettability is equal to the time of wetting of the powder particles (Jinapong *et al.*, 2008).

Dispersibility

To measure the dispersibility, 10 ml of distilled water was poured into 50 ml beaker. 1g of powder was added to the beaker and the solution was stirred for 15 seconds by a spoon.

The solution was passed through a sieve (212 μm); after weighing, 1 ml of the solution dried in an oven at 105°C for 4 hours. The dispersibility was calculated according to equation (6) (Jinapong *et al*., 2008).

$$\text{Dispersibility}=\frac{(10+a)\times \%\,TS}{a\times\frac{100-b}{100}} \quad (6)$$

a= amount of powder (g)

b= moisture content in the powder

%TS= percentage of dry matter in the reconstituted mushroom powder after it has been passed through the sieve.

Solubility

To measure the solubility of the samples, 1 g of powder was poured into a 50 ml beaker. Ten ml of distilled water was added to the beaker. The solution was stirred by a magnetic stirrer for 60 seconds at a constant speed. Then, 1 ml of the solution was weighed (m_1) and dried in an oven at 105°C to a constant weight. After cooling inside the desiccator, the sample was reweighed (m_2). Solubility (%) was calculated according to equation (8) (Zhang *et al*., 2013).

$$\text{Solubility}=\frac{10\times m_2}{m1}\times 100 \quad (8)$$

Statistical analysis

The effect of drying conditions on physical and dehydration properties of mushroom powder analyzed by the SPSS software (SPSS 22.0; IBM SPSS Statistics, Chicago, IL, USA). Duncan’s test was used to establish the multiple comparisons of the mean values that were considered at 95% significance level ($P<0.05$).

Results and discussion

Moisture content

Moisture content is one of the important properties of the powder, which indicates the drying efficiency (Shrestha, Howes, Adhikari, & Bhandari, 2007). The average moisture content of mushroom powder ranged from 2.46- 6.04 g/100 g. As shown in Table 1, increasing drying temperature led to a significant effect ($p<0.05$) on moisture content. At higher drying temperature, the greater temperature difference between foam and drying air led to an increase in heat penetration into foam and accelerated removal of moisture (Hamzeh *et al.*, 2019). Moreover, at the same drying temperature, decreasing in foam thickness led to reduction in the moisture content of the mushroom powder. This might be due to the increase in drying time. Salahi et al. (2017) reported that with increasing foam thickness, drying time increases. With the increase in drying time, the foam structure decomposes and a weak structure is formed. Therefore, drying process is difficult and more water remains in the foam. This observation is in agreement with many studies using different materials such as lime juice, shrimp, fig, cantaloupe, and yacon juice. The moisture content values of lime juice, fig, cantaloupe, and yacon juice powders ranged from 1.02-9.55 g/100 g (Dehghannya *et al.*, 2019), 7.65-8.27 g/100 g (Varhan *et al*., 2019), 4.59-8.02 (Salahi *et al.*, 2017), and 4.33-4.91 g/100 g (Franco *et al*., 2016) respectively. Based on the results, the best drying condition in terms of storage and stability included combination of higher drying temperature and lower thickness (80°C- 3mm).

Table 1- Moisture content of foam-mat dried mushroom powder

Drying conditions	Moisture content (g/100g, wb)
3 mm- 50°C	5.34 ± 0.13^{b}
5 mm- 50°C	6.04 ± 0.12^{a}
3 mm- 65°C	4.09 ± 0.10^{d}
5 mm- 65°C	4.72 ± 0.10^{c}
3 mm- 80°C	2.46 ± 0.03^{f}
5 mm- 80°C	3.05 ± 0.05^{e}

Mean with different letters in the same column indicate significant differences at $p<0.05$.

Water activity

The water activity of mushroom powder is illustrated in Table 2. It was in the range of 0.12-0.28. The lowest water activity was obtained at 80°C- 3 mm, whereas the highest water activity was for sample prepared at 50°C-

5 mm. Powders with water activity less than 0.3, prevents the growth of microorganisms, reduces enzymatic and biochemical reactions and delays the non-enzymatic browning (Belitz *et al.*, 2009). All powder samples have a_w below 0.3, which leads to stable conditions during storage. The a_w of foam-mat dried product such as shrimp, fig, cantaloupe, and yacon juice powders was reported as 0.13- 0.29, 0.21- 0.39, 0.14- 0.28, and 0.10- 0.22 by Hamzeh et al. (2019), Varhan et al. (2019), Salahi et al. (2017), and Franco et al. (2016) respectively.

Table 2- Water activity (a_w) of foam-mat dried mushroom powder

Drying conditions	Water activity (a_w)
3 mm- 50 °C	0.26 ± 0.00^{a}
5 mm- 50 °C	0.28 ± 0.00^{a}
3 mm- 65 °C	0.20 ± 0.00^{c}
5 mm- 65 °C	0.22 ± 0.00^{b}
3 mm- 80 °C	0.12 ± 0.00^{e}
5 mm- 80 °C	0.15 ± 0.00^{d}

Mean with different letters in the same column indicate significant differences at $p<0.05$.

Hygroscopicity

The hygroscopicity of mushroom powder is presented in Table 3. It was in the range of 3.94-6.77 g/100 g. At the same foam thickness, increasing the drying temperature had a significant effect ($P<0.05$) on hygroscopicity of samples. The highest hygroscopicity wasobtained at 80°C- 3 mm, whereas the lowest hygroscopicity was for sample prepared at 50°C- 5 mm. The results showed an increase in moisture content of the samples caused an increase in hygroscopicity. This is due to the difference in moisture content between the powder samples and the environment because the samples absorb water until they reach equilibrium with ambient humidity. Therefore, increasing the difference in moisture content between the powder samples and the environment led to an increase in moisture absorption (Tonon *et al.*, 2008).

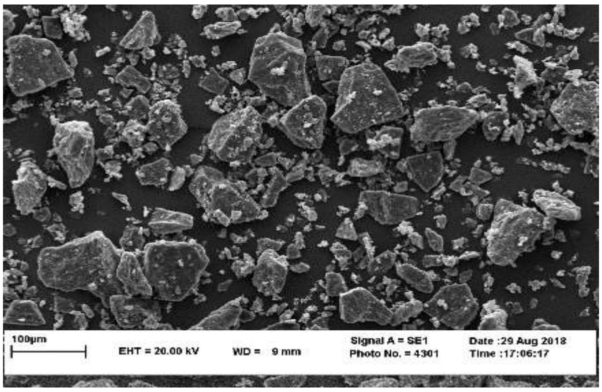
Our results are in agreement with the other studies (Franco *et al.*, 2016; Moghbeli *et al.*, 2020; Salahi *et al.*, 2017). The hygroscopicity of date, feijoa, cantaloupe, yacon juice, and acai powder was reported as 25- 29% (Moghbeli *et al.*, 2020), 19.8-27.2% (Henao-Ardila *et al.*, 2019), 16.73-20.76% (Salahi *et al.*, 2017), 15.24-22.31% (Franco *et al.*, 2016), and 12.54-15.79% (Tonon *et al.*, 2008).

The differences between our results and other studies could be related to the nature of mushroom. Mushrooms are low in sugar content (0.16-0.42 g/100 g) (Kalač, 2013). In food powders, sugar-rich products, due to the ability of the sugar hydroxyl group to create hydrogen bonds with water molecules, have a higher moisture absorption ability (Jaya & Das, 2004). Moreover, Our results are very close to ideal hygroscopicity for instant products which outlined by Jaya and Das (2004) (5.13-9.38 g/100 g). Powders with hygroscopicity below 20% are not very hygroscopic during storage (Henao-Ardila *et al.*, 2019), thus, the foam-mat dried mushroom powder can be considered quite stable during storage.

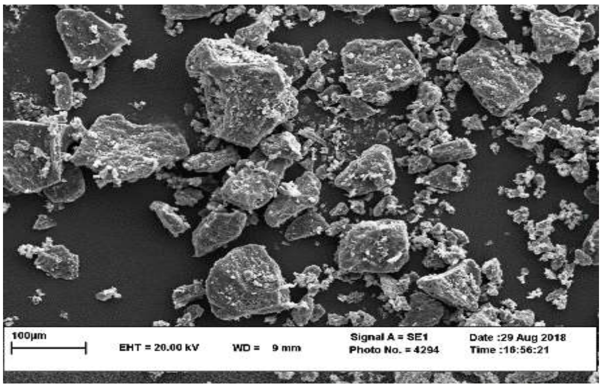
Table 3- Hygroscopicity of foam-mat dried mushroom powder

Drying conditions	Hygroscopicity (g/100g)
3 mm- 50°C	4.63 ± 0.08^{c}
5 mm- 50°C	3.94 ± 0.06^{d}
3 mm- 65°C	5.55 ± 0.08^{b}
5 mm- 65°C	5.16 ± 0.06^{b}
3 mm- 80°C	6.77 ± 0.12^{a}
5 mm- 80 °C	6.38 ± 0.12^{a}

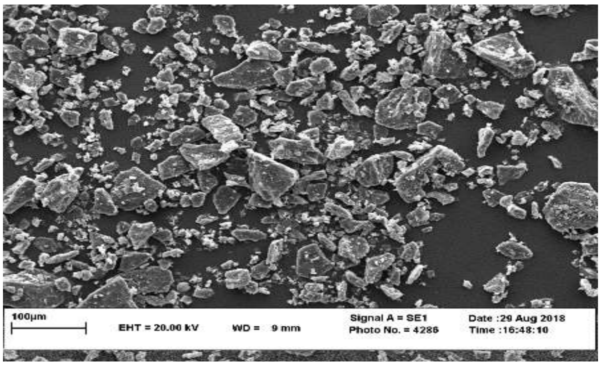
Mean with different letters in the same column indicate significant differences at $p<0.05$.



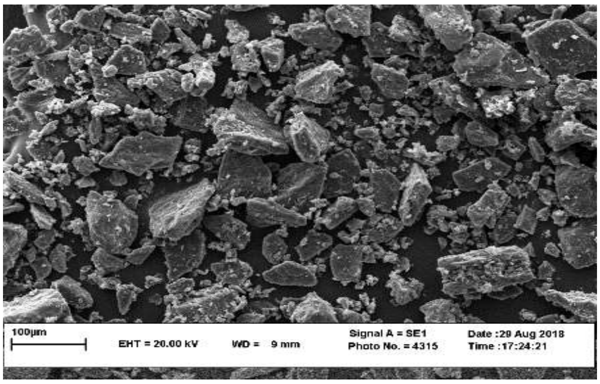
3mm-50×500



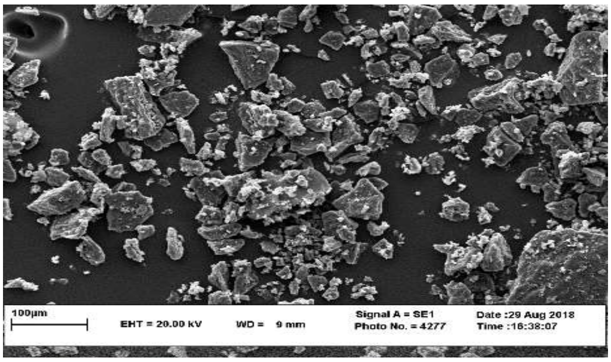
5mm-50×500



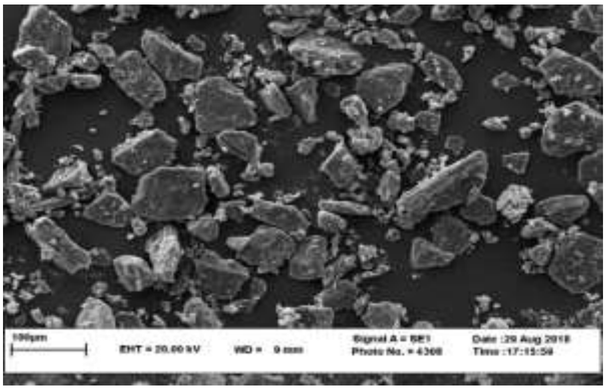
3mm-65×500



5mm-65×500

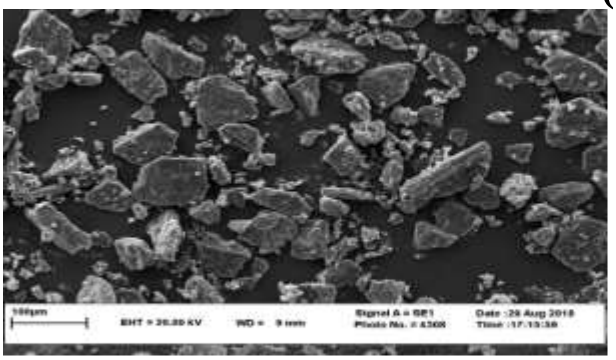


3mm-80×500

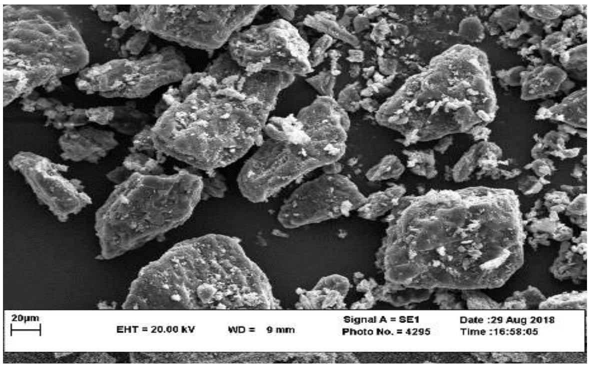


5mm-80×500

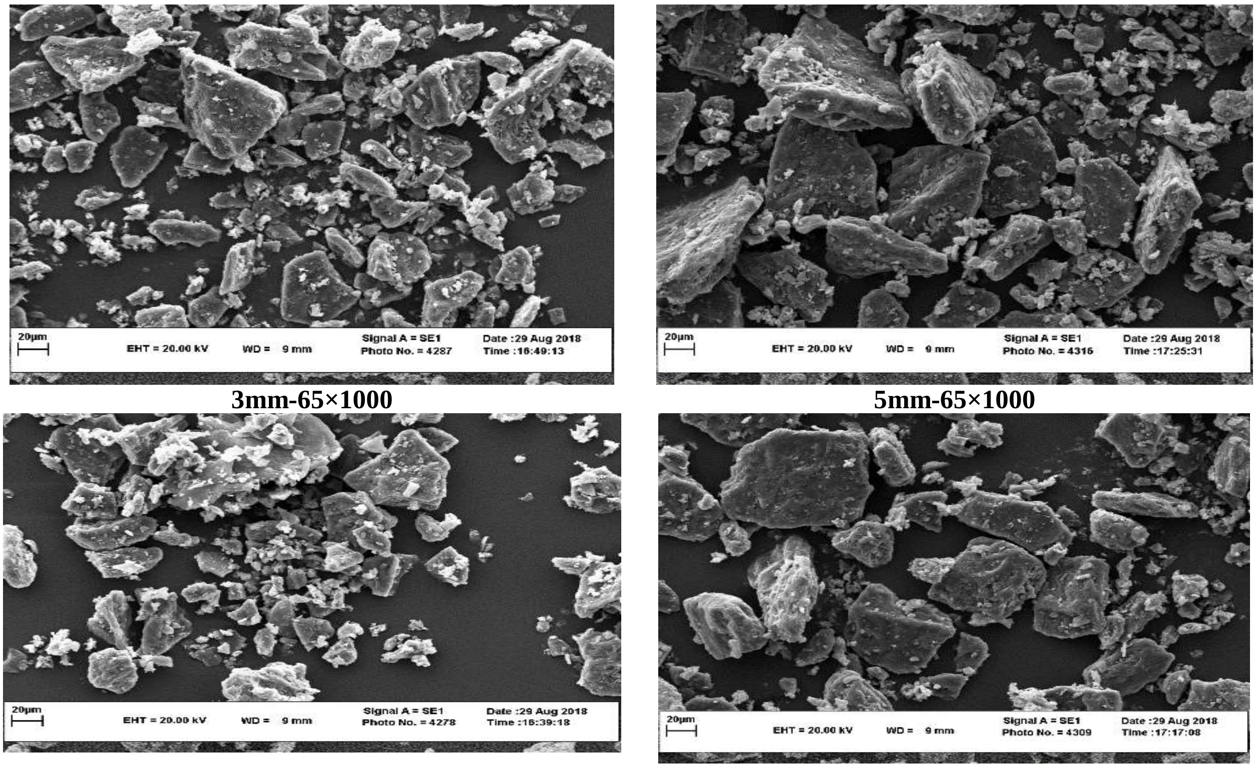
(a)



3mm-50×1000



5mm-50×1000



3mm-65×1000 5mm-65×1000

3mm-80×1000 5mm-80×1000

(b)

Fig. 1. SEM images of mushroom powder at magnification of ×500 (a) and ×1000 (b)

Particle morphology and microstructural

Particle size is one of the important properties of food powder as it plays a role in determining the behavior and properties of powder such as density, flowability, rate of solubility, and food formulation (Fitzpatrick, 2013). The SEM images of the samples are shown in Fig. 1. According to Table 4, The lowest particle size was obtained at 80°C- 3 mm (120 µm), whereas the highest particle size was for sample prepared at 50°C-5 mm (282 µm). According to the results, particle size of samples decreased as increasing drying temperature. Moreover, at the same drying temperature, thinner foam layers produced powders with lower particle size. According to this study, particle size of samples was correlated with the moisture content.

Table 4- Particle size of foam-mat dried mushroom powder

Drying conditions	Particle size (µm)
3 mm- 50°C	282.49± 8.19^{a}
5 mm- 50°C	279.20± 10.68^{a}
3 mm- 65°C	212.23± 9.84^{b}
5 mm- 65°C	262.41± 6.38^{ab}
3 mm- 80°C	120.20± 11.66^{c}
5 mm- 80°C	161.55± 8.43^{c}

Mean with different letters in the same column indicate significant differences at $p<0.05$

The lowest moisture content was obtained at 80°C-3 mm, whereas the highest moisture content was for sample prepared at 50°C-5 mm. The rate of heat transfer declines as the temperature decreases and the foam thickness increases, which increases the drying time. In this case, the foam moisture remains for a long time, as a result, the number of liquid bridges between the foam particles increases. The cohesion between the particles increases as the number of bonds between the foam particles increases, then, larger particles produced. The same result were reported for cornmeal (Chinwan & Castell-Perez, 2019), jamun juice (Santhalakshmy, Don Bosco, Francis, and Sabeena, 2015), and acai powder (Tonan, 2008).

Bulk and tapped density

The bulk and tapped densities provide a perspective from packing and the compaction profile of a material (Asokapandian *et al.*, 2016). According to Table 5, increasing drying temperature led to a decrease in the density of mushroom powder. The bulk density of mushroom powder was in the range of 0.54-0.70 g/cm^3. Both densities of mushroom powder increased as an increase in the moisture content of powder samples. Due to the higher density of water than dry particles, bulking weight of powder increased as increasing moisture content (Chegini & Ghobadian, 2005). The bulk density of shrimp, fig, date, and muskmelon powder were reported as 0.56-0.79 g/cm^3, 0.36-0.50 g/cm, 0.56-0.70 g/cm^3, and 0.51-0.54 g/cm^3 by Hamzeh et al. (2019), Varhan et al. (2019), Seeranguravar et al. (2017), and Asokapandian et al. (2016) respectively.

Tapped density of samples ranged from 0.63-0.85 g/cm^3. The tapped density of mushroom powder was larger than bulk density due to make denser packing conditions during tapping, which is in agreement with other studies *(Seeranguravar et al., 2017; Varhan et al.,* 2019). The tapped density for foam-mat drying of fig, date, and muskmelon were reported as 0.57-.069 g/cm^3 (Varhan *et al.*, 2019), 0.75-0.90 g/cm^3 (Seeranguravar *et al.*, 2017), 0.54-0.64 g/cm^3 (Asokapandian *et al.*, 2016) respectively.

Table 5- Bulk and tapped density of foam-mat dried mushroom powder

Drying conditions	Bulk density (g/cm^3)	Tapped density (g/cm^3)
3 mm- 50°C	0.68± 0.00^a	0.91± 0.02^a
5 mm- 50°C	0.70± 0.00^a	0.95± 0.01^a
3 mm- 65°C	0.63± 0.01^b	0.77± 0.01^b
5 mm- 65°C	0.63± 0.00^{ab}	0.80± 0.01^b
3 mm- 80°C	0.54± 0.01^c	0.63± 0.02^d
5 mm- 80°C	0.55± 0.01^c	0.65± 0.02^c

Mean with different letters in the same column indicate significant differences at $p<0.05$.

Flowability and cohesiveness

Flowability is defined as a relative movement of particles between adjacent particles or along the wall surface of a container (Peleg, 1977). As illustrated in Table 7 the range of variations was 13.18-26.82% for the Carr index and 1.15-1.36 for the Hausner ratio. According to this study higher drying temperatures improved powder flowability. Moreover, increasing foam thickness led to increase in the Carr index and Hausner ratio, which indicating reduced flow ability. This is might be due to the reduced drying time at higher drying temperature which prevents foam collapse. The same results were reported for fig (Varhan *et al.*, 2019) and muskmelon (Asokapandian *et al*., 2016). As shown in Table 2, drying conditions have a significant effect ($p<0.05$) on flowability and cohesiveness of mushroom powder.

Higher HR and CI values indicate reduced flowability. In general, the results showed that the Carr index and Hausner ratio increased as moisture content increased. This is probably due to the increase in the number of liquid bridges in the powder samples. Increasing moisture content causes an increase in the number of liquid bridges and reduces the flowability of powders (Kim *et al.*, 2005).

Based on Carr (1965) mushroom powder had fair flowability at 50°C and 65°C- 5 mm. The samples produced at 65°C-3 mm and 80°C-5 mm showed good flowability. The mushroom powder produced at 80°C- 3 mm showed very good flow ability. According to Hausner (1967) cohesiveness of mushroom powder produced at

80°C was low and the other sample was intermediate.

This study showed that the flowability of mushroom powder is inversely proportional to the particle size content of samples. The results showed that the larger particle size was worse in flowability. This is due to the increase in contact surface between powder particles due to the decrease in the inter-particle voids at smaller particle sizes, resulting in better flowability (Seerangurayar *et al.*, 2017). The same results were reported for the other powders such as cornmeal (Chinwan & Castell-Perez, 2019), fig (Varhan *et al.*, 2019), and date (Seerangurayar *et al*., 2017).

Table 7- Flow ability, cohesiveness of mushroom powder obtained by foam-mat drying

Drying conditions	Carr Index (CI) (%)	Flowability	Hausner ratio (HR)	Cohesiveness
3mm- 50°C	24.5± 0.91[a]	fair	1.32±0.01[a]	Intermediate
5mm- 50°C	26.82± 0.37[a]	fair	1.36±0.00[a]	Intermediate
3mm- 65°C	18.90± 0.59[b]	good	1.23±0.00[b]	Intermediate
5mm- 65°C	21.02± 1.50[b]	fair	1.26±0.02[b]	Intermediate
3mm-80°C	13.18± 1.05[c]	Very good	1.15±0.00[c]	Low
5mm-80°C	15.24± 0.96[c]	good	1.18±0.01[c]	Low

Mean with different letters in the same column indicate significant differences at $p<0.05$.

Angle of repose

The mean angle of repose of mushroom powder ranged from 23.13- 39.23θ°. The mushroom powder produced at 80°C showed lower angle of repose followed by samples produced at 65°C and 50°C. The lowest angle of repose was shown at 80°C- 3 mm, whereas the highest angle of repose was shown at 50°C- 5 mm. Variation of angle of repose could be related to microstructure (size and shape) of particles of powder samples which shown at Fig1. Kim et al. (2005) reported that flow properties of a powder mainly depends on the size and shape of powder particles. According to our results, angle of repose is directly proportional to the particle size of mushroom powder. Decreasing particle size led to surface contacts between powder particles, resulting in lower angle of repose. Similar observation was reported by Seerangurayar et al. (2017).

Flow properties of the powder are inversely proportional to the cohesiveness of powder particles such that an increase in the angle of repose leads to reduced flowability *(Geldart et al*., 2009). Based on Carr (1976), samples showed fairly cohesive at 50°C and the other samples showed free-flow ability. According to our results, the angle of repose increased as moisture content increased, indicating reduced flowability. This is might be due to the increasing the cohesiveness of particles which caused by increasing liquid bridges. The same observation was reported by other researchers (Chinwan & Castell-Perez, 2019; Suleiman *et al*., 2019; Vashishth *et al.*, 2020).

Table 8-Angle of repose of mushroom powder obtained by foam-mat drying

Drying conditions	Angle of repose (θ°)	Flowability
3mm- 50°C	37.30± 0.73[a]	fairly cohesive
5mm- 50°C	39.23± 0.61[a]	fairly cohesive
3mm- 65°C	33.03± 1.59[b]	free-flow
5mm- 65°C	35.53± 0.93[b]	free-flow
3mm-80°C	23.13± 1.15[c]	free-flow
5mm-80°C	25.13± 1.30[c]	free-flow

Mean with different letters in the same column indicate significant differences at $p<0.05$.

Glass transition temperature

The mean glass transition temperature of mushroom powder is presented in Table 9. It was in the range of 41.67-55.33°C. As shown in Table 9, glass transition temperature increased as drying temperature increased. Tg is mainly related to moisture content and the chemical structure of food material (Hamzeh *et al.*, 2019). According to our results, the glass transition temperature of mushroom powder increased as moisture content decreased. As the increasing moisture content of powder, water acts as a plasticizer and leads to decreasing Tg of powder (Jaya & Das, 2004).

Roos (2003) pointed out that structural and physicochemical properties are proportional to Tg. These properties include stickiness, crispness, collapse, and amorphous-to-crystalline transformations. Food materials are shelf stable when stored below Tg due to reduction in chemical and microbial reactions, thus, the foam-mat dried mushroom powder can be stable from production to consumption.

Caparino et al. (2012) reported that Tg of mango powder ranged from 18-26°C. The high glass transition temperature of mushroom powder might be due to the low sugar content of mushrooms. The amount of sugar compounds is one of the main factors affecting the glass transition temperature. These compounds are one of the most important hygroscopic compounds that reduce the Tg and cause adhesion by absorbing water (Roos, 2003).

Table 9- Glass transition of mushroom powder obtained by foam-mat drying

Drying conditions	T_g (°C)
3mm- 50°C	44.00 ± 1.15^{bc}
5mm- 50°C	41.67 ± 0.57^{c}
3mm- 65°C	50.33 ± 0.88^{b}
5mm- 65°C	44.33 ± 0.88^{bc}
3mm-80°C	55.33 ± 1.76^{a}
5mm-80°C	53.00 ± 0.83^{a}

Mean with different letters in the same column indicate significant differences at $p<0.05$.

Rehydration properties

Wettability

The mean wettability of mushroom powder is presented in Table 10. It was in the range of 317.33– 412.33 s. Wettability of powder samples is significantly ($p<0.05$) affected by drying temperature. The variation of wettability of mushroom powder might be due to the microstructure of powder particles. According to the results, the wettability of mushroom powder decreased as increasing powder particle size. Increasing the particle size enhances the free space between the particles, therefore, water penetrated faster into powder particles, and the time required for wetting the powder particles reduced. Similar results were reported for date (Seeranguráyar *et al.*, 2018), and fig powder (Varhan *et al*., 2019).

Fitzpatrick et al. (2016) investigated the wettability of twelve different powders. Their results showed that the powder structure, especially its surface compounds, play an important role in the wettability of a powder. High wettability of mushroom powder might be due to the lower sugar content of mushroom. Seeranguráyar et al. (2018) studied foam-mat drying of date at three ripening stages include khalal, rutab and tamr. The tamr powder was shown lower wettability. They conclude that it might be due to the variation of sugar content at ripening stages of date, since tamr had higher sugar content compare to the other ripening stages. The same result was reported for cocoa powder (Shittu & Lawal, 2007).

Hogekamp and Schubert (2003) reported that powder particles larger than 250 μm are usually have shown low wettability. Samples produced at 50°C and 65°C showed particles larger than 250 μm. Our results are different from Hogekamp and Schubert (Hogekamp & Schubert, 2003). This is might be due to the irregular and non-uniform of mushroom powder particles which caused an increase in mechanical interlocking and cohesiveness of powder.

Table 10- Wettability of mushroom powder obtained by foam-mat drying

Drying conditions	Wettability (s)
3mm- 50°C	327.00± 9.82[c]
5mm- 50°C	317.33± 13.69[c]
3mm- 65°C	394.00± 6.40[ab]
5mm- 65°C	382.66± 7.80[b]
3mm- 80°C	412.33± 8.21[a]
5mm- 80°C	402.00± 5.68[a]

Mean with different letters in the same column indicate significant differences at $p<0.05$.

Dispersibility

The mean dispersibility of mushroom powder is presented in Table 11. It was in the range of 78.53- 93.76%. The dispersibility of powder samples is significantly ($p<0.05$) affected by drying temperature. Higher dispersibility was shown by a combination of higher foam thickness and lower drying temperature. As shown in Table 3 the highest dispersibility was obtained at 50°C- 5 mm and the lowest dispersibility was obtained at 80°C-3 mm.

Table 11- Dispersibility of mushroom powder obtained by foam-mat drying

Drying conditions	Dispersibility (%)
3mm- 50°C	91.20± 0.55[a]
5mm- 50°C	93.76± 0.47[a]
3mm- 65°C	84.83± 0.79[b]
5mm- 65°C	86.10± 0.60[b]
3mm- 80°C	78.53± 0.92[c]
5mm- 80°C	80.00± 0.45[c]

Mean with different letters in the same column indicate significant differences at $p<0.05$.

Table 12- Solubility of mushroom powder obtained by foam-mat drying

Drying conditions	Solubility (%)
3mm- 50°C	72.00± 0.90[a]
5mm- 50°C	72.06± 0.72[a]
3mm- 65°C	73.36± 1.43[a]
5mm- 65°C	72.67± 1.24[a]
3mm- 80°C	74.06± 1.24[a]
5mm- 80°C	74.23± 1.26[a]

Mean with different letters in the same column indicate significant differences at $p<0.05$.

The variation of dispersibility might be due to the difference in the particle size of samples. Particle size and morphology are two most important factors affecting dispersibility (Ding *et al.*, 2020). The largest particle size of mushroom powder was observed at 50°C- 5 mm, whereas the smallest particle size of mushroom powder was observed at 80 °C-3 mm. According to our results, powder dispersibility is inversely related to particle size.

The dispersibility of food powder depends on the ability of the powder dispersed in the solution. The rate of dispersion indicates whether a food powder can be categorized as an instant powder (Hogekamp & Schubert, 2003). Ding et al. (2020) reported that the optimal powder particle size for the best dispersibility in the medium range (180 μm< diameter< 355 μm). So, the mushroom powder produced at 50 and 65°C has a good potential to explore instant properties.

Solubility

The mean solubility of mushroom powder is given in Table 12. It was in the range of 72-74%. As shown in Table 3 the drying condition had no-significant effect ($P<0.05$) on the solubility of samples. This can be due to the fact that solubility is affected by physicochemical properties of food powdered rather than processing conditions (Fitzpatrick, 2013). Similar observations were reported for yacon juice and cantaloupe powder (Franco *et al*., 2016; Salahi *et al*., 2017).

In other studies, the solubility of date, lime juice, cantaloupe, and yacon powders ranged from 66- 89%, 66- 69%, 81- 82%, and 80- 84%, respectively.

Conclusions

In this study, the effects of three temperatures of 50, 65 and 80°C with two thicknesses of 3 and 5 mm on physical and rehydration properties of foam-mat dried mushroom power were investigated using a hot air dryer. At constant foam thickness, moisture content, and a_w of mushroom powder decreased as increasing drying temperature. However, their hygroscopicity and particle size increased significantly. Based on this study, moisture content, a_w, and hygroscopicity of foam-mat dried mushroom powder were decreased to a stable condition to prevent chemical and microbiological reactions. By increasing drying temperature, the flowability of mushroom powder improved. The mushroom powder produced at 80°C- 3 mm showed very good flowability with high stability. Powders produced at higher drying temperatures had lower wettability and higher dispersibility. Thus, lower drying temperature could be more desirable for production mushroom powder with instant food application.

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نشریه پژوهشهای علوم و صنایع غذایی ایران
جلد ۱۷، شماره ۳، مرداد - شهریور ۱۴۰۰، ص. ۱۶-۱

اثر شرایط خشک کردن کف‌پوشی بر خصوصیات فیزیکی و رفتار بازجذب آب پودر قارچ

سعید نجات دارابی[1] - محبت محبی[2*]

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چکیده

این پژوهش با هدف بررسی شرایط خشک کردن بر خصوصیات فیزیکی و بازجذب آب پودر قارچ دکمه‌ای که با روش خشک کردن کف‌پوشی انجام شده است خصوصیات فیزیکی پودر قارچ شامل: مقدار رطوبت، فعالیت آبی، قابلیت جذب آب، اندازه ذرات، جریان‌پذیری و پیوستگی، زاویه ریپوز و دمای گذار شیشه‌ای بررسی گردید. دمای خشک کردن اثر معناداری (P<۰/۰۵) بر اکثریت خصوصیات فیزیکی پودر قارچ داشت. نمونه‌های پودر دارای فعالیت آبی کمتر از ۰/۳ بودند که منجر به ایجاد شرایط پایدار می‌شود. کاهش دمای خشک کردن منجر به افزایش رطوبت و تشکیل ذرات بزرگتر گردید. پودر قارچ تولید شده در دمای بالاتر دارای جریان‌پذیری بهتری بود. دمای گذار شیشه‌ای در محدوده ۵۵/۶-۴۱/۳ درجه سانتی‌گراد بود. افزایش دمای خشک کردن موجب افزایش ترشوندگی و پخش‌شوندگی گردید.

واژه‌های کلیدی: پودر قارچ، جریان‌پذیری، ترشوندگی، پخش‌شوندگی، حلالیت.

۱و ۲- دانش‌آموخته کارشناسی ارشد و استاد، گروه علوم وصنایع غذایی، دانشکده کشاورزی، دانشگاه فردوسی مشهد.
(*- نویسنده مسئول : Email: mohebbatm@gmail.com)