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Short Communication

The Impacts of Fluidized and Static Bed Drying Methods on Bio-active Compounds and Antioxidant Properties of Saffron Petal

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Abstract

Saffron petal was dried from 85% to 10% moisture content with fixed layer bed (FLB), semi fluidized bed (SFB) and fully fluidized bed (FFB) at temperatures (t) of 35, 45 and 55 °C. The airflow (v) of FLB, SFB and FFB were 0.2, 0.7 and 1.7 ms^{-1}, respectively. When the t/v ratio increased in each method, the dehydration time decreased considerably. The dehydration times and drying rates of saffron petal for FLB (v = 0.2 ms^{-1}& t = 35 °C) and FFB (v = 1.7 ms^{-1}& t = 55 °C) were "570 & 30 min" and "0.13 & 2.50 gH_2O/min", respectively. When the airflow increased from 0.2 to 0.7 and then to 1.7 ms^{-1}, the phenolic, anthocyanin & antioxidant contents of dried saffron petal improved to about 6, 15 & 15% and then to 15, 20 & 42%, respectively. However, by increasing air temperature from 35 to 45°, their phenolic and anthocyanin contents did not change significantly. However, sharp reductions of 20, 23 and 41% respectively were noticed in phenolic and anthocyanin contents and antioxidant activities of saffron petal when the drying temperature exceeded 45 and reached to 55 °C. Overall, the fresh saffron petal dehydrated at 45 °C with FFB had the highest phenolic and anthocyanin contents and antioxidant activities.

Keywords: Saffron petals, Fluidized bed, Drying methods, Phenolic compounds, Anthocyanins

Introduction

The expensive saffron spice is obtained from a very small part of its flower (stigma) and the remaining petals are discarded as waste or animal feed [1]. Saffron petals contain considerable amounts of flavonoid (polyphenols), glycoside, and anthocyanin compounds [2]. There is a strong relationship between bioactive compounds (mainly anthocyanin and polyphenols) of plant materials with their antioxidant activity [3]. Since the stability of anthocyanin and polyphenols during dehydration are greatly affected by the drying temperature [4], the moisture removal of saffron petal should be done with high levels of care and caution to protect their valuable compounds.

Several factors, including relative humidity (RH), temperature, airflow, chemical composition, food configuration, and surface of the food influence moisture transmission during dehydration process [5]. Although shade drying of saffron takes place with very simple devices, it is not a controllable operation andit faces with different defects such as wrinkle, insects attack, microbial contamination, and loosing organoleptic properties due to long-time drying [6-8].

Recently the traditional drying methods have been replaced with industrial dryers. Although these dryers can dehydrate much faster and with higher amounts of saffron petal, most of the time, its final product is damaged due to high temperature difference (ΔT) between the drying air and center of food particles [9]. This is one of the reasons that fluidized bed system has been suggested for dehydration delicate materials without any side effect [9]. This drying method is more efficient because total surface of food particles is faced and fluidized with

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drying air. In fact, the rate of moisture evaporation rises due to an increase in rate of heat transfer and ΔT reduces between the food particles and drying air. This system dries materials uniformly and gently; therefore it is an efficient method comparing to other drying techniques [10]. It is easily possible to control flow rate, RH, air temperature as well as calculating the moisture-evaporation rate during quick-drying. Although fluidized driers may need more capital investment than industrial fixed bed dehydrators (at equal input capacity), they dry food particles with higher quality, shorter time and lower energy [11].

So far, various researches have been done both on the factors affecting the quality characteristics of saffron petals and the effect of different drying methods of the physicochemical properties of saffron petals. Hemmati Kakhki (2001) optimized the factors affecting the production of food coloring from saffron petals. The results of his research showed that in terms of purity, the color extracted using citric acid had the lowest amount of impurities [12]. Mazloumi *et al* (2007) studied the methods of drying saffron using vacuum, freezing, microwave and solar. Also, they compared them with the traditional method and introduced the most appropriate drying method in terms of the stability of the color-generating agent (crocin) of solar methods, vacuum oven and microwave. There was no significant difference between the methods in terms of stability of perfume-producing agent (Safranal) and flavor-producing agent of dried samples (Picrocrocin) [13]. Azami *et al* (2012) examined the antibacterial effect of aqueous extract of saffron petals in laboratory environment using disk diffusion method on Staphylococcus aureus, Salmonella typhimurium, Escherichia coli O157 H7, Listeria monocytogenes and Bacillus cereus. Salmonella typhimurium was the most susceptible bacteria and Staphylococcus aureus and Escherichia coli O157 H7 were identified as the most resistant bacteria. Their study showed that the aqueous extract of saffron petals can be used as a natural preservative against the above bacteria [14]. Shariayei *et al* (2018) studied the effect of thin layer drying on quantity and quality characteristics of saffron petals and also determining optimum condition of its drying. After statistical analysis, the optimum temperature and air speed of drying saffron petals with maintaining the quantity characteristics was determined 50 and 1.4 degrees Celsius and m/s, respectively. The results showed that increasing the air temperature from 40 to 60 degrees Celsius can significantly reduce the drying time. While increasing the air speed from 0.7 to 1.4 m/s, results in an increase in the drying time of saffron petals and its further increase up to 2.1 m/s reduced the drying time. Also, the logarithmic model was found to be the best model to fit most experimental data [15].

Saffron petal is a gentle product and a good source of bioactive compounds including polyphenols and anthocyanins. It was our objective to use the drying effects of fully fluidized bed (FFB) and semi-fluidized bed (SFB) in comparison with commercial fixed layer bed (FLB). Also another goal of the study was to study the polyphenols, anthocyanins and antioxidant activities of resulting product in comparison with fresh saffron petal.

Material and Methods

Dehydration of Saffron Petals

Saffron petals were obtained from saffron cultivation farms near Sabzevar located in northeast of Iran. A laboratory fluidized bed dryer was designed and fabricated (Fig. 1). It has the ability to create a vertical airflow(with enough static pressure) and airflow velosity from 0 to 5 ms^{-1} for floating the relatively light materials. It also can increase the air temperature up to 80 °C and program to momentarily record weight of product during dehydration. This system has a horizontal duct, an air filter, an electric heat element and two blowers. The electrical heat elementplaced inside the channel after a blower and before a drying chamber to generate the required heat energy for drying air. The blower had a controllable device to adjust the speed of entering ambient air, which passed through a horizontal duct, filter and then drying chamber. To provide optimum conditions for three systems of FLB, SFB and FFB, the airflow rate was set to 0.2, 0.7 and 1.7 ms^{-1} (90% of critical fluidity rate), respectively. Three air temperature levels; 35, 45, and 55 °C were used for each drying method. Before starting the dehydration process, the heater of drier was turned on for a while until theair temperaturereached to a certain level andremained steady. Next, a sample of fresh saffron petal (collected from a growing farm in Northeast of Iran) was placed inside the weighing device of drier.

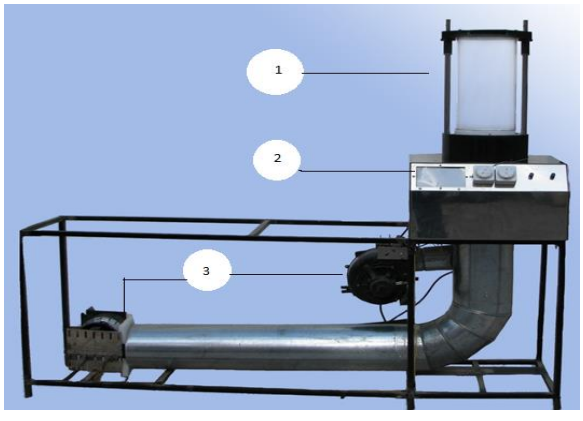

Fig. 1 Laboratory view of fluidized drier with three major sections of drying chamber (1), control panel (2), and airflowpump (3).

Then, its mass reduction was read and recorded at specified time intervals during drying process for each mentioned method.

Measuring of Total Phenolics

The phenolic compounds of saffron petal could be measured by using methanol solvent extraction[10]. In this experiment, the standard gallic acid solutions in methanol were prepared and their absorptions read in 765-nanometer wavelength. The absorption degree curve depicted against the density of gallic acid (mg/ml) and the fitness curve relationship was obtained by using Equation 1 with (R^2=0.99):

$Y=1.0776\ X^2+ 0.2644X + 0.0099$ (1)

Where X is the absorption read in 765-nanometer wavelength and Y is the amount of phenolic compounds in mg/µL. Then Equation 2 used to calculate phenolic compounds of the sample in 100 µL of solvent [11].

$P =(Y/W) \times 1000$ (2)

Where P and W are the level of phenolic compounds of the sample (mg/g) and the sample weight (g), respectively.

Measuring the Total Anthocyanins

The dehydrated saffron petalwasinitially crushed with a coffee grinder and mixed with methanol solventin a ratio of 1:4 [18]. After dissolving 0.1 g of prepared essence solution in 0.5 mL methanol, it was mixed with 9.5 mL of chloride potassium buffer and then with 9.5 mL of acetate sodium buffer. Later, each prepared sample was diluted in 1:20 with methanol solvent and its absorption amount read in 520 to 523 and 700 nm wavelengths in spectrophotometer (uv/vis, PG Instruments Ltd, China). The anthocyanins content was measured based on differential pH of glycoside -3 cyanidin, which is the dominant anthocyanidin in anthocyanin of Saffron' petals [19]. It is necessary to note that the dominant anthocyanidin in anthocyanin of saffron petal depends on the kind of solvent used to extract anthocyanin. The dominant anthocyanidins of saffron petal are pelargonidine 3,5 glycosides; 3,5 cyanidin di-glycosides and pelargonidine 3,5 glycosides.While seperating solvents of acidified ethanol, sulfured water and aqueous enzyme solution of Pectinex (water mixed with cellulase, hemi-cellulase and pectinase) used for its anthocyanin extraction, respectively [14, 15]. Then Equations 4 and 5 used to calculate the anthocyanin content of each sample.

$A= (A_{\lambda vis\ max} - A_{\lambda 700})^{pH=1} \_ (A_{\lambda\ vis\ max} - A_{\lambda 700})^{pH=4.5}$(4)

Total anthocyanins (mg/L) $=A\times M_W\times DF\times 1000 /(\varepsilon\times L)$(5)

Where A is the absorption values between two pH=1 and pH=4.5; M_w expresses glycoside -3- cyanidin molecular mass (484.8 g); ε represents mole absorption of glycoside -3-cyadinin (34300); and DF stands for dilution factor.

DPPH Free Radical Scavenging Capacity Measurement

The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity (RSA) solution was used to determine the antioxidant activity of dried saffron petal[19]. The dehydrated petals were initially crushed with a coffee grinder and mixed with methanol solvent in a ratio of 1:5 to prepare primary sample solutions. Then, methanol solvent was used to mix three concentrations of 50, 100 and 150 µL of sample solutions with 3.95, 3.90 and 3.85 mL of methanol, respectively. After that, 1mL of 0.009% DPPH solvent was added to each sample solution. After transferring 1 mL of each concentration to a falcon tube, 1 mL of 0.009% of freshly prepared DPPH solvent was added to each sample solution and all of the test tubes were shaken for 30 seconds at room temperature. In the next stage, the resulting mixtures of test tubes were held in dark place for 30 minutes. Finally, the absorbance of each solution was read by spectrophotometer at 512 nm wavelength. The control sample was prepared in the same way, but 1 mL methanol was used instead of sample solution (i.e. 1 mL methanol+1 ml DPPH° indicator). Free radical scavenging capacity of prepared samples and control were computed according to the Equation 6.

$A (\%) = [(A_c-A_s) \times 100]/ (A_c)$ (6)

Where A (%) is DPPH free radical scavenging, A_c is the evidence absorption, and A_s is the sample absorption. Once the free radical scavenging diagram plotted against the antioxidant compound, the highest optical density was determined. At this optical density, the antioxidant compound could restrain the highest content of free radicals [19].

Statistical Analysis

Independent variables were three airflow rates of 0.2, 0.7 and 1.7 ms^{-1} related to three different drying methods, three drying temperatures (35, 45, and 55 °C) and three replicates applied for each dehydration system. The dependent variables including polyphenols, anthocyanins, and antioxidant activities were measured again in triplicate. This experiment was carried out on a completely randomized design and each replicate was considered as one block. Data were analyzed by SAS software and the means were compared by Duncan Test.

Results and Discussion

Dehydration Analysis

The operation time for dehydrating to remove the original moisture content of saffron petal from 85 ±2% to 10 ±1% was highly dependent on the air temperature and airflow rate of each method.

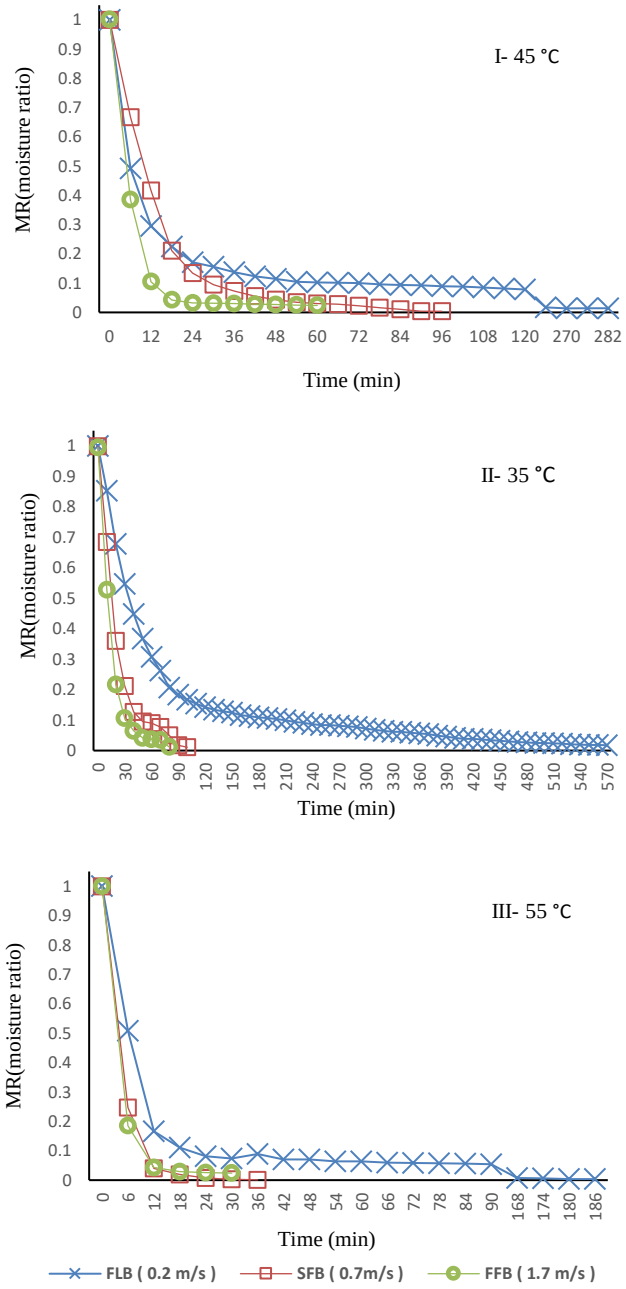

Fig. 2 Effects of time, three airflow rate and three air temperatures of 35 °C (I), 45 °C (II) and 55 °C (III) on MR (moisture ratio) of saffron petal.

Table 1 shows the longest (570 min) and shortest (30 min) drying times related to the lowest airflow of 0.2 ms^{-1}atair temperature of 35 °C and highest airflow of 1.7 ms^{-1}at air temperature of 55 °C, respectively. In other words, when the air temperature and airflow respectively increased from 35 to 55 °C and from 0.2 to 1.7 ms^{-1}, the averaged moisture-evaporation rate increased from 0.13 to 2.50 gH_2O/min, respectively (Table 1).

As Figure 2 shows the moisture ratio reduction of saffron petal versus drying time (at different air temperature and airflow rate) had descending exponential curves. The moisture ratio was defined as the available moisture content of saffron petal in every moment of drying process to its dry matter (DM). While the periods of constant drying rates for SFB and FFB methods at different air temperature were less than those in FLB, the remaining moisture ratios (KgH2O/Kg DM) in the dried products of SFB and FFB were much lower than FLB. The results were similar to the drying moisture-reduction curves of various fruits and vegetables [22-28].

It previously discussed the higher rates of moisture removal in SFB and FFB were due to their higher heat transfer rates. Consequently, there was a lower temperature difference (ΔT) between the air temperature eat the surface and the center of each saffron petal particle than those in FLB products. As it was noted in Table 1, the drying time decreased when the ratio of Temperature/air speed increased with constant airflow. This factor reduced sharply when air speed increased.

Total Phenolic Content

Table 2 shows the effects of increasing airflow and temperature on phenolic, anthocyanin and antioxidant activities of saffron petal after dehydration. The table shows that when airflow increased from 0.2 to 0.7 ms^{-1} (FLB to SFB) and then from 0.7 to 1.7 ms-1 (SFB to FFB), the phenolic content of saffron petal dried with SFB and FFB methods had 6 and 15%higher phenolic content than those dehydrated with FLB. When the air temperature increased from 35 to 45 °C, the phenolic content of dried saffron petal showed an insignificant change in its value. However, when the air temperature raised from 45 to 55 °C, a sharp reduction of 20% observed in phenolic of dried Saffron. Increasing airflow from 0.2 to 0.7 and then 1.7 ms^{-1} had positive effects on phenolic contents of dehydrated saffron petal. While rising air temperature had a negative impact when temperature exceeded from 45 and reached to 55 °C. More clearly, when the air temperature changed from 35 and touched 45 °C, the phenolic content of fresh saffron petal was preserved and even improved up to 3% in comparison with FLB product. In fact, by increasing drying temperature from 35 to 45 °C, the drying time reduced and saved its original phenolic quantity of saffron petal (Table 2). When air temperature exceeded from 45 and reached 55 °C, almost 20% of the phenolic compounds were destroyed because of high temperature, regardless of its short drying time. This result is comparable with few researchers' findings who dried berries with different temperatures. Katsube, Tsurunaga [28] studied the influence of air temperature on the phenolic and antioxidant features of Mulberry (*Morus alba* L.). They observed higher contents of phenolic compounds at 60 °C than those berries dried at 40 °C. This happened because the drying time decreased from 45 to 7h, and the destructive effects of long-time dehydration on polyphenolic content reduced substantially.

However, when they raised the air temperature to 70 °C, considerable losses were observed on polyphenolic

compound and DPPH free radical capturing power. Similar results reported by [29-32] for different agricultural products.

Table 3 shows the phenolic content of saffron petal along with their standard deviations for dried products of FLB, SFB and FFB at different airflow rates and temperatures. The calculated LSD (least significant difference) for phenolic content shows that increasing airflow rate and air temperature in dehydration of saffron petal, respectively had positive and negative effects on the total phenolic content of product. In addition to LSD value in Table 3, the analysis of variance in Table 4 revealed that drying methods, air temperature and their interactions made significant ($P \leq 0.05$) effects on the amount of remaining phenolic compounds in dried saffron petal. The values of air temperature were much higher than drying airflows. Therefore, it was proved that this parameter had stronger effects on destruction of polyphenols than airflow when the drying temperature exceeded 45 °C and reached to 55 °C.

Total Anthocyanins

The analysis of variance showed that the drying method had a significant ($P \leq 0.05$) impact on the anthocyanin content of saffron petal. Consequently, the samples dehydrated with SFB and FFB methods contained higher amounts of anthocyanins than those in FLB (Table1). Most probably the long drying time of FLB (caused by low airflow) was the main reason that the dried product of this method had lower anthocyanin even at low air temperature of 35 °C. While SFB and FFB products respectively had 15 and 12 % more anthocyanins than FLB product (Table 2), there was not any difference in their anthocyanin content. Perhaps, the particles of saffron petal in FFB were exposed to higher volume of air in comparison with SFB during drying time.

Table 1 The effects of air temperature and air speed (related to different methods) on drying time and averaged drying (water evaporation) rate of 100 g fresh saffron petal.

Drying Method	Airflow (v, ms^{-1})	Temperature (t, °C)	Drying time, min	Average of drying rate, gH_2O/min	(t/v) °C /ms^{-1}*
FLB	0.2	35	570	0.13	175
	0.2	45	282	0.91	225
	0.2	55	186	0.40	275
SFB	0.7	35	100	0.75	50
	0.7	45	96	0.78	64.3
	0.7	55	36	2.08	78.5
FFB	1.7	35	80	0.94	20.6
	1.7	45	60	1.25	26.5
	1.7	55	30	2.50	32.4

*The drying time decreased when the ratio of (Temperature/Airflow) increased with constant airflow. This factor reduced sharply when airflow increased from 0.2 to 1.7 ms^{-1}.

Table 2 The effect of dehydration methods and temperatures on the mean values of phenolic compounds, anthocyanin and antioxidants (free radicals scavenging) of saffron petal.

	Phenolic (mg/g)	Anthocyanin (mg/L)	Free radicals scavenging (%)	Changes in (SFB/FLB) % and (FFB/FLB) % Phenolic-Anthocyanin-DPPH
Drying methods*				
FLB (at 0.2 ms-1)	42.1±5.6 c	1158.6±123.3 c	42.9±11.0 c	- - -
SFB (at 0.7 ms-1)	44.7±4.9 b	1336.3±145.0 a	49.2±11.2 b	+ 6 - +15 - +15
FFB (at 1.7 ms-1)	48.6±5.6 a	1293.5±208.0 b	61. 0±18.5 a	+15 - + 12 - +42
LSD	0.7206	10.192	2.3658	
Temperatures**				
35 °C	47.8±4.4 b	1369.0±111.1 a	57.1±12.5 b	- - -
45 °C	49.3±1.6 a	1367.1±83.1 a	62.3±9.0a	+3 - (<-1) - +9
55 °C	38.3±2.8 c	1052.3±69.2 b	33.7±4.2 b	(-20) - (-23) - (-41)
LSD	0.7206	10.196	2.3658	

*Averaged bioactive compound (phenolic content, anthocyanins and antioxidant contents) of saffron petal dried at three different temperatures of 35, 45 and 55 °C.

**Average of bioactive compound (phenolic content, or anthocyanins) or antioxidant power of saffron petal dried at three different airflows of 0.2, 0.7 and 1.7 ms^{-1} related to FLB, SFB and FFB, respectively.

Table 3 Interaction of dehydration method and dehydration temperature on phenolic compounds, anthocyanin compounds and free radicals scavenging capacity

Dehydration method	Dehydration temperature(°C)	phenolic compounds (mg/g)	anthocyanin compounds (mg/L)	Free radicals scavenging capacity (%)
FLB	35	43.5±0.57 e	1221±3.77 e	47.4±0.61 d
	45	47.6±0.50 d	1258±9.76 d	52.8±0.38 c
	55	35.1±0.14 h	996±14.91 h	28.6±1.88 f
SFB	35	46.5±0.46 d	1432±10.21 b	50.5±0.73 cd
	45	49.2±0.86 c	1433±5.14 b	61.3±0.85 b
	55	38.5±1.46 g	1143±2.99 f	35.6±2.12 e
FFB	35	53.3±0.61 a	1453±14.11 a	73.4±4.41 a
	45	51.2±0.76 b	1409±15.68 c	72.8±4.17 a
	55	41.3±0.35 f	1018±6.12 g	36.7±2.14 e
LSD		1.24	17.6	4.09

Table 4 Analysis of variance for the effects of three drying methods of FLB (0.2 ms^{-1}), SFB (0.7 ms^{-1}) and FFB (1.7 ms^{-1}) and three air temperatures (35, 45 and 55 °C) on polyphenol, anthocyanin and antioxidant content of saffron petal after dehydration.

	DF	Mean square		
Sources		Phenols	Anthocyanin	Antioxidant Activities (DPPH)
Drying Methods	2	95.07**	77393**	759**
Air Temperatures	2	320**	299134**	2097**
Methods*Temperatures	4	8.93**	8919**	104**
Error	18	0.529	106	5.71
CV		1.61	0.82	4.68

** Significant at 0.01

Therefore, the FFB method provided better conditions to oxidize and deteriorate anthocyanin of saffron petal. Anyhow, more investigation is needed to show the oxygen effects of high and low airflow rates on anthocyanin content of the Saffron' petals. The comparison results of anthocyanin in dried saffron petal revealed that increasing air temperature from 35 to 45 °C did not reduce the anthocyanin contents of saffron petal more than 5%. However, when the air temperature elevated from 45 to 55 °C, a sharp reduction (more than 20%) was found in anthocyanin content (Table 2 and Table 3). A higher reduction (~40%) was noticed when the anthocyanin content of saffron petal dried at 35 and 55 °C, are compared with each other. While the anthocyanin content of Saffron petal was susceptible to degradation and destruction when air temperature of drying exceeded 45 °C, it was protected when its drying air temperature held between 35 to 45 °C. On the other hand, when airflow increased from 0.2 to 0.7 ms^{-1} and air temperature< 45 °C, the anthocyanin content of dried product increased more than 15% (Table 2 and Table 3). However, anthocyanin content of saffron petal dried at 55 °C had 25-35% less anthocyanin than those dried between 35 to 45 °C.Overall, the Saffron petal dried at 35 °C with FFB method (airflow of 1.2 m/s) had the highest content of anthocyanin (Table 3). Conversely, the lowest amount of anthocyanin was observed in the saffron petal dried at 55 °C with FLB method (airflow of 0.2 m/s).The highest drying rate (0.94 gH_2O/min) and lowest drying time (80 min) of FFB protected the anthocyanin content of fresh Saffron petal among three methods, and its dehydration rate and dehydration time were 7 times and 50% of FFB, respectively. Since the original thickness and surface area of fresh saffron petal in the three drying methods were similar to each other, the ratio of drying temperature (t) to airflow (v) was the main criteria for the remaining bioactive compounds in the final product. When the ratio of t/vdecreased from the maximum of 275 to minimum value of 20.6 ($°C/ms^{-1}$), the anthocyanin content reduced from maximum of 1460 to 980 mg/L (see Table 1 and Table 3). The application of higher temperature will destroy anthocyanins and polyphenolic compounds[28-33].Although limited information is available on effects of temperature on anthocyanin,present result shows that high drying temperature more than 50 °C can reducethe levels of anthocyanins in plant-food products [34]. Anthocyanins are belonging to a group of phenolics[35] which have similar performance against drying conditions. The effects of drying airflow and temperature on anthocyanin are similar to the acts of these two parameters on phenolic compounds during dehydration. The color of monomeric anthocyanins altered due to the change in its pH, heating and increasing temperature polymerize and turn them into brown polymeric pigments[36].

While this study showed that increasing drying airflow of Saffron petal improve its sturdy relations with phenolic and anthocyanin contents, researchers showed these compounds have a strong relationship with the antioxidant activity of different plant materials during dehydration [33,37,38].

Table 3 shows the anthocyanin content of saffron petal along with their standard deviations for dried products of FLB, SFB and FFB at different airflow rates and temperatures. The calculated LSD for anthocyanin content proved that increasing airflow rate and temperature in dehydration of saffron petal respectively had insignificant and negatively significant effects on its final anthocyanin. Additionally, the analysis of variance in Table 4confirmed that the increased airflow, air temperature (>45°C) and their interactions made significant (P≤0.05) effects on the amount of remaining anthocyanin content in dried saffron petal. The F values of air temperature were much higher than drying airflows; therefore, it proved that this parameter again had stronger effects on destruction of polyphenols than airflow when the drying temperature is more than 45 °C.

Evaluating of Free Radical Scavenging

Table 3 denotes that more antioxidant compounds preserved in the samples as the flow rate increases at each specific drying air temperature. The highest and the lowest amounts of antioxidants were obtained for the saffron petal when it was dried with FFB (air flow rate 1.7 ms^{-1}) at 35 °C and FLB (air flow rate 0.2 ms^{-1}) at 55 °C, respectively. While increasing airflow improved the antioxidant activity of dried Saffron petal, the effects of raisingair temperature on antioxidant activity of final product could not be predicted. The highest radical capturing power of saffron petal (> 62%) belonged to the fresh samples dried at 45 °C (Table 2). When drying temperature exceeded 45 °C, the DDPH capacity reduced becausesome of the available antioxidant (mainly anthocyanins and phenolic) compounds weredestroyed during high temperature drying. This happens because thesmaller capacity of free radical scavenging power remained in the saffron petal dried at 55 °C. Two reasons could be mentioned for the higher free radicals scavenging capacity in saffron petal dehydrated at 45 °C against 35 °C. Firstly, it had shorter drying time and consequently less side-effects of higher temperature and long dehydration time on its antioxidant content. Secondly, the saffron petal dried at 45 °C had relatively more resistance antioxidants (mainly phenolic compounds) than those dried at higher temperature. In addition, some new antioxidant compounds may be generated through dissolving cell materials such as pigments when air temperature of plant materials rises to 45 °C [39]. Cheigh, Um [39] believed that the antioxidant features of phenolic compounds were more stable for active oxidation at 45 °C than those in lower temperatures. Additionally, the drying temperature (closely to 45 °C) is active formelanoidin (resultants of non–enzymatic browning or Millard reaction) production and; therefore, it could increase antioxidant power of drying products in plant materials [33-37-40-42]. On the other hand, the thermal degradation of anthocyanin may produce phenolic compounds at this drying temperature, which elevate antioxidant properties of final product [34]. However, applying higher temperatures will deteriorate not only anthocyanins, but also polyphenolic compounds [28-33]. Owing to the fact that least number of phenolic compounds remained in final product of FLB method, smaller radical capturing power in these samples can be ascribed to the less amount of phenolic. Consequently, less antioxidant compounds available in the final sample dried at 35 °C for long dehydration time or dried at high drying temperature of 55 °C. Table 3 shows the free radical scavenging power of saffron petal along with their standard deviations for dried products of FLB, SFB and FFB at different airflow rates and temperatures. The calculated LSD for free radical scavenging power anthocyanin of dried saffron petal proved that increasing airflow rate and air temperature in its dehydration, respectively had insignificant and negatively significant effects on the anthocyanin content of product. Additionally, the analysis of variance in Table 4 confirmed that the increasing airflow (>45 °C for different drying methods) and their interactions made significant (P≤0.05) effects on the amount of remaining antioxidnt power of dried saffron petal. The F values of drying temperature were much higher than drying airflows. Therefore, it proved that this parameter again had stronger impact on the destruction of free radical scavenging power of dried saffron petal than airflow when the drying temperature was more than 45 °C.

Conclusion

The fixed bed drying (FLB) of saffron petal had the lowest drying rate in comparison with SFB and FFB methods. Additionally, its dried product had the lowest polyphenols, anthocyanin content and antioxidant power in comparison with other methods. Most probably case hardening happened in the fixed situation for fresh saffron petal dried with FLB (airflow of 0.2 ms^{-1}). The fluidized drying (by increasing airflow up to 1.7 ms^{-1}) improved the moisture-evaporation rate of the saffron petal product (from 0.13 to 2.50) and reduced dehydration time considerably. Also, the best conditions for protecting polyphenols, anthocyanin and antioxidant activities in saffron petal were provided when the ratio of t/v kept maintained to a minimum. As a result, the fully fluidized bed (FFB) drying of fresh saffron petal with air flow of 1.7 ms^{-1} and temperature drying of 35 ºC had the

dehydration time of 80 minutes, dehydration rate of 0.94 gH_2O/min and best conditions for protecting its bioactive compounds along with antioxidant power.

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