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Determination of drying kinetics and quality parameters of grape pomace dried with a heat pump dryer

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ABSTRACT

Pomace of Hamburg Muscat was dried at temperature of drying air 45 °C and different air velocity (1.5, 2.0 and 2.5 m/s) in open-loop heat pump (HP) and laboratory-type closed-loop dryer (as a control). In the HP dryer, it was concluded that drying air velocity was slightly effective on drying time however there is no significant effect on the power consumption of the change in the drying air velocity at the same temperature. When comparing the energy consumption of the HP dryer and convective dryer, the energy consumption was reduced by up to 51%. In HP drying, the increase of air velocity from 1.5 m/s to 2.5 m/s caused a reduction in drying time by 69%. It was observed that part of the bioactive properties was lost in pomace samples but there were fewer losses in all bioactive properties than the others except the total anthocyanin at 2 m/s.

1. Introduction

Grape (*Vitis vinifera L*) is one of the well-known fruits in the world. Grape pomace is the one of the agro-industrial by-products that obtained end of processes of grape juice, molasses, wine etc. It consists of seed, fruit flesh part, stalk and skin therefore it has rather complex structure. Depending on the conditions of the harvested grapes and processing conditions, the residues may represent from 17% to 20% of the total volume of grapes (Russ and Meyer-Pittroff, 2004). In general, the percentage of seeds in grape pomace is assumed to be 25%. Due to the differences in grape cultivars, some studies have reported that the proportion of seeds in grape pomace varies widely, ranging from 7 to 20% (Jiang, Simonsen, & Zhao, 2010), 20–26% (Baydar and Akkurt, 2001) and 38–52% (Maier, Schiber, Kammerer, & Carle, 2009).

Grape pomace is composed of water, proteins, lipids, carbohydrates, vitamins, minerals, and compounds with important biological properties such as fiber, vitamin C, and high amount phenolic compounds that some of them have antioxidant effects (tannins, phenolic acids, anthocyanin, and resveratrol, catechin, epicatechin, gallic acid etc.), depending on the type of pomace components, the cultivar and climatic and cultivation conditions (Jayaprakasha, Singh, & Sakariah, 2001; Ahn et al., 2002; Jayaprakasha, Selvi, & Sakariah, 2003; Negro, Tommasi, & Miceli, 2003; Amico, Napoli, Renda, Spatafora, & Tringali, 2004; Guendez, Kallithraka, Makris, & Kefalas, 2005; Sousa, Chôa-thomaz, Carioca, Morais, & Lima, 2014). It was reported that grape pomace has high content phenolics with beneficial effects on human health due to its high antimicrobial and antioxidant properties (Frankel, Kanner, German, Parks, & Kinsella, 1993; Meyer, Yi, Person, Waterhouse, & Frankel, 1997; Ahn et al., 2002; Guendez et al., 2005). Grape pomace can be considered as interesting and valuable matter by grape processing plant owners in respect of legal, environmental and economic issues. Grape seeds are able to be used in very different areas such as edible oil, pharmaceutical ingredients, dietary fiber, valuable chemicals, areas related to its antibacterial effects, cosmetics and even for biofuel production (Akgün and Akgün, 2006). Generally, the skin of red grapes is used in making nutritional supplements. Grape skins possess a compound named resveratrol, which is not present in other parts of the grape. Resveratrol is a phytoestragen that takes preventive action against cardiovascular diseases (Gezer, 2011; Frémont, 2000).

Gezer (2011) reported that grape pomace is processed in order to obtain the previously mentioned health promoting products such as grape seed oil, grape seed extract, grape seed flour, grape skin extract, grape pomace extract, and grape skin powder. Except for the grape pomace extract, the seeds and skins should be separated. Generally, this

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Nomenclature

a_w	water activity
M_d	final dry weight (g)
M_i	initial wet weight (g)
p	the partial pressure of water over the samples
p_0	the vapor pressure of pure water
X_t	moisture content at time "t" (g water/g dry matter)
X_{t+dt}	moisture content at "t + dt" (g water/g dry matter)
t	time (min)
X	moisture content (g water/g dry matter)
X_{eq}	equilibrium moisture content (g water/g dry matter)

Abbreviations

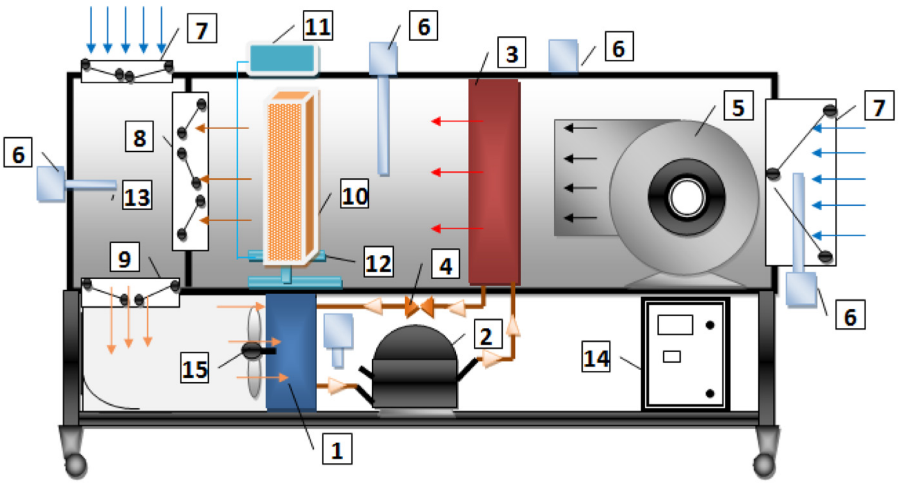
DR	drying rate (g water/g dry matter per minute)
ERH	equilibrium relative humidity
MR	moisture ratio (%)

separation is conducted via sieve machines in industry. Drying of pomace is important and necessary process for optimum separation of seed (Roberts, Kidd, & Padilla-Zakour, 2008).

Jordan (2002) emphasized that grape pomace should be dried immediately to prevent deterioration due to mold growth and to achieve fast and efficient separation. Effective drying is also required to obtain optimum storage especially for grape seeds. Grape seeds should be dried to 8% moisture content to keep the quality and safety of it during storage. For these reasons, a reliable pre-drying step of grape pomace is required to ensure free moisture is removed before drying in a commercial rotary drum seed dryer. An additional step is required to separate the fines or admixture from the seeds. Several studies have been carried out on grape pomace drying with different drying methods; Electrohydrodynamic drying (Martynenko and Kudra, 2016), infrared, convective and combined drying (Yinqiang, Yang, Qiuhong, Hua, & Wang, 2014), hot air and sun drying (Maskan, Kaya, & Maskan, 2002), air-circulating oven (Larrauri, Ruperez, & Saura-Calixto, 1997), open sun and solar drying (Taşeri, Gülcü, & Aktaş, 2016) and tray dryer (Goula, Thymiatis, & Kaderides, 2016). Martynenko and Kudra (2016) reported that available technologies for fruit pomace drying have extensively been reviewed by Jangam et al. (2010) and Shalini (2010). Solar drying is inexpensive, but could not guarantee the required product quality (Maskan et al., 2002) whereas the osmotic dehydration modifies usually the biochemical composition (Yadav and Singh, 2014). Freeze-drying is too expensive and justified only for high-value biomaterials (Ratti, 2001). Hot air convective drying is still a commonly used industrial method of fruit pomace drying, even though the heat negatively affects product quality (Man, Jaswir, Yusof, Selamat, & Sugisawa, 1997; Chen and Martynenko, 2013).

Kataria and Shaikh (2007) suggested a maximum permissible drying temperature for grape as 65 °C. The thermo physical properties in grape depend on the water content (Azzouz, Hermassi, Toujani, & Belghith, 2016). Drying of grape pomace at high temperatures may cause a significant reduction of extractable polyphenols and also affect antioxidant activity and free-radical scavenging activity (Larrauri et al., 1997). Goula et al. (2016) stated that the air temperature of 60–85 °C caused the loss of phenolic material by 87.0–95.4%. A heat-pump dryer is capable of lower drying temperature therefore, it is benefit for quality products drying at relatively low cost (Guochen, Arason, & Arnason, 2009; Aktaş, Khanlari, Amini, & Şevik, 2017).

In Thrace region in Turkey, a large part of grape pomace has been not evaluated and they cause to environmental pollution or it is used as mixing of it to soil as fertilizer and animal feed. Grape pomace is transformed to grape seed which is a valuable product by organizations that are sensitive to environmental problems. And then it is evaluated in the cosmetics, food and pharmaceutical industries. Drying is an ideal solution for optimum separation of seed. But, during drying period in this region (September), open sun drying is rather risky due to overmuch rainy and cloudy days namely high relative humidity climate that causes to microbial risks. For this reason, a HP dryer is built to reveal the change of phenolic content and other nutritional contents, to evaluate of pomace as antioxidant, to reduce the its negative effects on the environment. As a control, a laboratory-type dryer is used and, nutrient values and drying kinetics of dried products are compared



1) Evaporator 2) Compressor 3) Condenser 4) Expansion valve 5) Fan 6) Thermo-Hygrometer 7) Fresh air inlet damper 8) Drying chamber outlet air damper 9) Mixing unit output air damper 10) Drying chamber 11) Load-cell indicator 12) Load-cell 13) Mixing chamber (25% fresh air + 75% drying system exhaust air) 14) Main control unit 15) Evaporator fan

Fig. 1. Open cycle grape pomace drying system.

under the same conditions. In literature, despite the fact that grape drying has been studied with the HP dryer, there is no study investigating the quality values of dried pomace by testing the drying of the grape pomace by the HP dryer in different air velocities. The present investigation was focused on drying characteristics of the grape pomace and some physico-chemical and bioactive properties of dried samples with a heat pump dryer at temperature of drying air of 45 °C and different air velocities (1.5, 2.0 and 2.5 m/s).

2. Material and methods

2.1. Material

Grapes were harvested when they became suitable for processing them into juice (September 2016). Harvested grapes were washed, separated from stalks, shredded. Obtained mash was heated and grape juice was taken using pneumatic membrane press in Grape Juice Processing Plant in the Institute. Remaining pulp residue namely pomace was obtained for drying experiments. In this research, grape pomace which was waste material of grape juice processing using Muscat of Hamburg grape variety was provided by Viticultural Research Institute, Tekirdag, Turkey.

2.2. Methods

Due to advantage of heat pump drying method in heating and low temperature drying applications (Şevik, 2014), this method is used and applied in the way that provided the precise and reliable measurements. Grape pomace is placed the tray to dry at temperature of drying air 45 °C and different air velocity (1.5, 2.0 and 2.5 m/s) in an open-loop laboratory pilot heat pump (HP) dryer. Drying system consists of a compressor (frequency controlled), condenser, evaporator, expansion valve, frequency inverter (to adjust the drying air velocity), fans, drying chamber (manufactured for the drying of grape pomace), mixing chamber, thermohygrometers, thermocouples and a main control unit. Heat pump dryer (HPD) is open cycle (Fig. 1). The fresh air is circulated over the condenser which was used as a heat source by a fan and then sent to the drying chamber. According to thermodynamic calculations which are done for R410A refrigerant, 75% of exhaust air which has high moisture and temperature, and 25% of fresh air were mixed in the mixing chamber to catch optimum evaporation temperature and then sent to the evaporator. The relative humidity and temperature measurements are done using the thermohygrometers where placed in fresh air inlet, condenser inlet and outlet and the inside of mixing chamber, and change in weight of the product is observed and recorded by a load cell which is mounted below the drying chamber. The total energy consumption of the drying system is measured by an electricity meter during the experiments. Equipment is placed at the measuring points. The specifications of parts of drying system and measurement equipment are shown in Table 1. In addition, laboratory type dryer with 10 trays in 45 * 45 cm size, weight-weighting feature, and temperature and air circulation control as a control in grape pomace drying is used.

Steps of obtaining of grape pomace, schematic of the system of the grape evaluation process and the position of this work in this scheme can be shown in Fig. 2.

The moisture content (X_{db}), moisture ratio (MR) and drying rate (DR) data of the samples can expressed as follows.

The moisture content (X_{db});

$$X_{db} = \left(\frac{M_i - M_d}{M_d}\right)100 \tag{1}$$

Moisture ratio (MR);

$$MR = \frac{X - X_{eq}}{X_0 - X_{eq}} \tag{2}$$

Drying rate (DR);

$$\frac{dX}{dt} = \frac{X_{t+dt} - X_t}{dt} \tag{3}$$

Wet grape pomace samples were packed and stored at −20 °C until analysis. Experiments were carried out by bringing the products to ambient temperature. Firstly, dried samples were prepared. Dried samples were packed and stored at +4 °C until analysis. After, some quality analyses for fresh and dried grape pomace were performed.

2.2.1. Water activity

Water activity (a_w) value is a critical factor uses in determining the drying, controlling spoilage and shelf life of products (Cemeroglu, 2004) and it can be measured using the water activity instrument (AquaLab 4 TE Series Decagon Device, Pullman WA, ABD). Nearly 2–3 g of the samples were weighed and placed in the instrument's chambers. When the temperatures of the samples were balanced by the instrument, the water activity value was read from the screen of the instrument. It can also be defined as follows:

$$a_W = \frac{p}{p_0} = \frac{ERH}{100} \tag{4}$$

2.2.2. Dry matter analysis

Dried grape pomace samples were weighed in the empty drying cap. They were dried at 70 °C in a laboratory-type vacuum oven (Nuve EV 018, Turkey) to until constant balance. Then they put to the desiccator for cooling to room temperature and weighed. The moisture contents of the samples were determined by dividing the difference between the initial weighing and the final weighing into the initial weight (AOAC, 1990).

2.2.3. Extraction of phenolic compounds

Extraction of grape pomace phenolics for analysis was performed according to solid-liquid extraction method. For this purpose, wet grape pomace samples by adding liquid nitrogen and dry pomace samples directly were ground at 60 s by a Waring blender with stainless steel container. Milled sample was weighed into a capped tube followed by addition of extraction solvent (80% aqueous methanol acidified with 0.1% HCl). Solid-liquid ratio for extraction was selected 1/10. The resulting mixture in tubes was shaken with rotary shaker (Rotator, Dragon Laboratory Instruments) at 70 rpm for 2 h at room temperature. After the extraction process, the extracts were centrifuged at 4500 rpm at 4 °C for 10 min and filtered through a qualitative filter to remove suspended materials. All extractions were conducted in triple.

Table 1
Properties of drying system and measurement equipments.

Devices	Technical properties	Accuracy
Heat pump (frequency inverter)	3.5 kW, 50 Hz, compressor power 1 hp, R410A refrigerant	–
Radial fan (frequency inverter)	0.37 kW, 1000 m^3/h, 3000 d/d, 50 Hz	–
Electricity meter	Measuring the energy spent in 4 recipes, have the ability to store information, LCD display	± 1%
Thermo hygrometer	Temperature: −40 ~ +120 °C, Relative humidity: 0% ~ 100% RH	± 2 °C ± 4% RH
Load cell	Output (mV/V) 2.0, 5–12 V, 5 kg, −40 ~ +80 °C, 5–12 (DC)	± 0.02%
Load-cell indicator	3 W, 4–20 mA	–
Anemometer	Measurement range, 0–20 m/s	± 0.01 m/s
Water activity (a_w) measuring device	Value of water activity between 0 and 1	± 0.001
Digital weighing device	Maximum measurement capacity), 6100g	± 0.01 g
Thermocouple	−200 + 1300 °C	± 0.1 °C

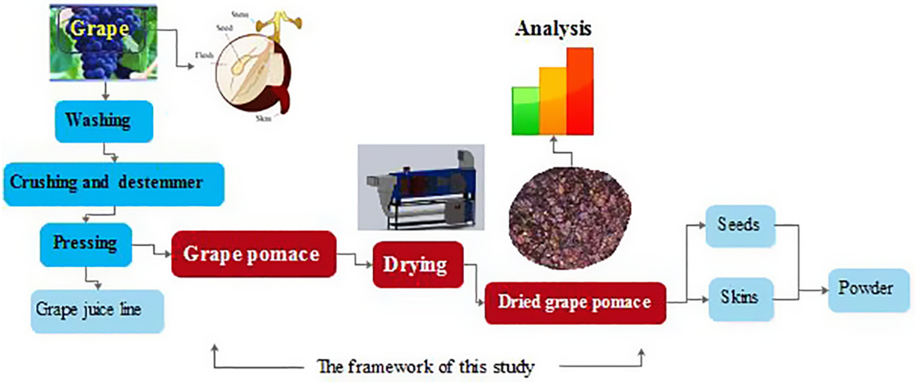


Fig. 2. Schematic of the system of the grape evaluation process and the position of this work.

2.2.4. *Determination of total phenolic content*

The total phenolic content was determined by using the Folin-Ciocalteu method with microscale protocol as described by Waterhouse (2002). Briefly, 40 µl methanolic solution of grape pomace extract or gallic acid standards (50–500 mg/L), 3.16 ml water and 200 µl of Folin–Ciocalteau reagent were added to a 4 ml plastic cuvette. After 1–8 min, 600 µl solution of Na_2CO_3 (20%) were added. The content was mixed and held for 2 h at room temperature and absorbance of the sample was measured at 765 nm against a blank by using spectrophotometer (Shimadzu UV–Vis Mini 1240, Tokyo, Japan). Total phenolics content was calculated as mg gallic acid equivalent per gram of dried grape pomace (mg GAE/g dw).

2.2.5. *DPPH free radical scavenging activity*

DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity assay was used based on the methods of Brand-Williams, Cuvelier, and Berset (1995), as modified by Xu and Chang (2002). The different volume of grape pomace extracts (25–50–75 µl) was mixed with 1.95 ml of 0.1 mM DPPH methanolic solution. The reaction mixture was left in the dark at room temperature for 30 min, and the absorbance was then measured at 517 nm against a blank. The percentage scavenging effect was calculated as Scavenging rate = (A0 − A1/A0) × 100, where A0 was the absorbance of the control (without extract) and A1 was the absorbance in the presence of the extract. The free radical scavenging activity of extracts was expressed as micromoles trolox equivalent per gram of dried grape pomace (µmol TE/g dw) from triplicate extracts using the calibration curve of Trolox. Linearity range of the calibration curve was 20–1000 µM.

2.2.6. *Total monomeric anthocyanin content*

Total Monomeric Anthocyanin Content was determined by the pH differential method as described by Giusti and Wrolstad (2001). Determinations were performed on a spectrophotometer (Shimadzu UV–Vis Mini 1240, Tokyo, Japan), measurements at 520 and 700 nm. Total monomeric anthocyanin concentration was expressed as mg malvidin 3-glukozid/g dw using a molar absorptivity of 28 000 and a molecular weight of 493.5.

2.2.7. *Total tannin content*

The total tannin content was estimated by a colorimetric assay based on procedures described by AOAC (1998), with slight modifications. Briefly, 40 µl methanolic solution of grape pomace extract or tannic acid standards (100–1000 mg/L), 3.36 ml water and 200 µl of Folin-Denis reagent were added to a 4 ml plastic cuvette. After 3–5 min, 400 µl saturated solution of Na_2CO_3 were added. The content was mixed and held for 30 min at room temperature and absorbance of the sample was measured at 760 nm against a blank by using spectrophotometer (Shimadzu UV–Vis Mini 1240, Tokyo, Japan). Total tannin content was calculated as mg tannic acid equivalent per gram of dried grape pomace (mg TAE/g dw).

2.2.8. *Analysis of catechin, epicatechin and trans-resveratrol with HLPC*

Catechin, epicatechin and trans-resveratrol levels (mg/g dw) in samples were measured by a high-performance liquid chromatography (HPLC) system (Shimadzu LC 20 A) based on procedures described by Gülcü (2016), with slight modifications. HPLC system was combined with a fluorescence detector in an Inertsil ODS-3 (C18) column (5 µm, 4.6 × 250 mm). Mobile phase A: 0.2% formic acid in water, mobile phase B: 0.2% formic acid in Acetonitrile. For separation to following gradient; B Conc. 23% (5 min), 26% (12 min), 40% (14 min), 100% (14.01–18 min), 23% (22 min); the flow rate was 1.5 ml/min. Column temperature was 30 °C. The fluorescence detector was set at λex 278 nm and λem 360 nm for catechin and epicatechin λex 300 nm and λem 386 nm for trans-resveratrol. 5 µl methanolic solution of grape pomace extract or standard were filtered by a 0.45 µm pore size PTFE syringe filter and directly injected.

2.3. *Statistical analysis*

The determinations were conducted in triplicate and results were expressed as mean ± standard error. Statistical analyses were done by one-way ANOVA followed by LSD (least significant difference) test with $P < 0.05$ as a limit of significance. The statistical software package JMP (version 5, SAS Institute, Cary, NC, USA) was used for the analysis.

3. Results and discussions

3.1. *Drying kinetics*

Grape pomace was dried from initial moisture content 2.57 g water/g dry matter (dry basis) to final moisture content 0.1 g water/g dry matter (dry basis) at 45 °C drying air temperature and different drying air velocities. The times required for HP drying of grape pomace samples were 1040, 840 and 720 min at air velocities of 1.5, 2.0 and 2.5 m/s, respectively. Variations of moisture ratio versus drying time are shown in Fig. 3. The variations of the *DR* with the X_{db} for different drying air velocities are shown in Fig. 4. According to the Figs. 3 and 4, drying rate in 2.5 m/s experiments has maximum values. Moreover, the drying period is the shortest in these experiments. The drying rates in the first stages of the drying process were quite high due to high moisture content. However, values were quite low in the first stages. When the drying air velocity is increased 33% and 66%, the drying period is decreased by 23.8% and 44.4%, respectively. In addition to this, energy consumption is decreased by 1% and 1.4%, respectively. It can be said that were showed the interaction of drying air temperature and air velocity during the drying of grape pomace and the drying air velocity were seemed to be a significant factor.

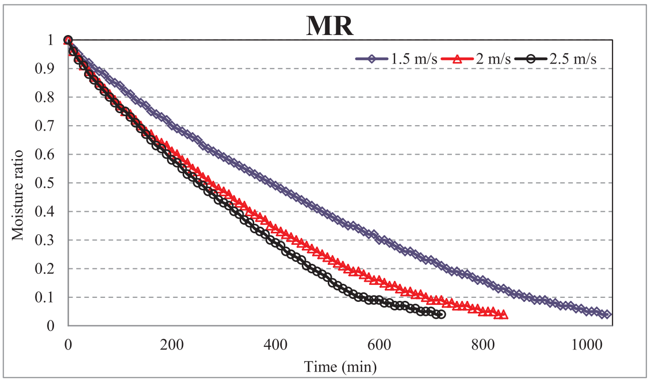


Fig. 3. Effect of drying air velocity on the moisture ratio.

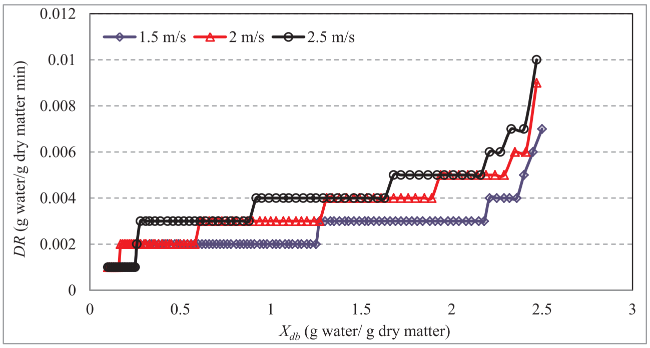


Fig. 4. Variation of the *DR* with the X_{db}.

3.2. Quality parameters of grape pomace

Physico-chemical and bioactive properties (total phenolic matter, total tannin, antiradical activity and total anthocyanin) and some phenolic components of raw pomace and dry pomace (dried at 45°C in a HP dryer) were determined. Results were given as mean values of analyses for raw pomace and dry weight samples in the Table 2.

The amount of total dry matter was determined as 43.5% and the water activity (a_w) value as 0.96 in the raw (wet) pomace samples of Muscat of Hamburg grape varieties. As a result of these features, considering the high humidity, water activity value and possible sugar content, raw grape pomace show an ideal working environment for many microorganism species, especially yeast-mold. Total phenolic content, total tannin content, total anthocyanin content and antiradical activity of raw pomace are respectively; 64.2 mg GAE/g dw, 84.0 mg TA/g dw, 0.41 mg ME/g dw and 173.6 µmol TE/g dw. These values were much lower than previously reported values by several researcher that total phenolics and total anthocyanin content of unprocessed grape pomace were about 165 mg GAE/g dw and 1.076 mg/g dw, respectively (Goula et al., 2016; Khanal, Howard, & Prior, 2010).

A combination of unit operations involving heat such as blanching, pasteurization, and duration can also markedly affect the anthocyanin content of fruits and vegetables (Patras, Brunton, O'Donnell, & Tiwari, 2010). Also, catechins are highly unstable against change in temperature, light and pH, and resulting in loss of activity and easily undergo epimerization (Gadkari and Balaraman, 2015). Catechin, epicatechin, trans-resveratrol content of raw pomace are respectively; 1.763 mg/g dw, 1.254 mg/g dw and 0.029 mg/g dw. In a previous study was on muscadine grape reported that catechin, epicatechin contents of pomace extract were 1.46 mg/g and 1.28 mg/g respectively, but resveratrol was not detected (Wang, Tong, Chen, & Gangemi, 2010). These results are quite close with our study.

It is known that a significant portion (about 90%) of the phenolic compounds present in grapes is found in the skin and the seed tissues. In this respect, we have also confirmed our study of the bioactive properties of raw grape pomace, which are composed of skin and seed, the phenolic material is rich. The results of processing in the food industry wastes/residues age emerged as the material/raw grape pomace and the extraction of bioactive compounds of high value-added processed food supplement, the production of new products such as natural food dye is common. In this context, it is important to quickly dry the wet/raw pomace which is the result of the processing of grape in the food industry, and identified the changes that occur in the bioactive properties during drying. The drying pretreatment of the raw material affected significantly the yields and the bioactive properties of the resulting compounds (Rajha et al., 2014).

As expected, drying process affected bioactive properties of dried grape pomace negatively and the bioactive properties of dried product were lower than raw one. According to Table 2, while the highest amount of total phenolic matter is detected 38.1 mg GAE/g dw in the pomace samples dried with 2 m/s application at dried pomace samples with HP technique, 1.5 m/s and 2.5 m/s were found to be very close to one another with 30.6 and 28.3 mg GAE/g dw, respectively. Also the amount of total tannin in the pomace samples, the highest value was determined 45.1 mg TAE/g dw at the application of 2 m/s, 1.5 m/s and 2.5 m/s were found to be very close to one another with 36.1 ve 39.2 mg TAE/g dw, respectively. The effect of drying conditions on total phenolic substances and total tannins in pomace samples was statistically significant ($p < 0.05$). 1.5 m/s and 2.5 m/s applications were found to be included in the same group ($p > 0.05$) in terms of both parameters.

The lowest values for the total amount of anthocyanin were determined in the application of 0.26 mg ME/g dw at 2.5 m/s, whereas applied with 2 m/s and 1.5 m/s were found to be close to each other 0.37 and 0.39 mg ME/g dw, respectively. The lowest DPPH antiradical activity value (78.3 µmol TE/g dw) was detected at 2.5 m/s and the results of DPPH antiradical activity were found to be close to those of 2 m/s (98.6 µmol TE/g dw) and 1.5 m/s (93.4 µmol TE/g dw). In pomace samples, the effect of drying on total anthocyanin and DPPH

Table 2
Physico-chemical and bioactive properties of raw pomace and dry pomace samples.

Sample	Water activity (aw)	Total phenolic mg (GAE/g dw)	Total tannin mg (TAE/g dw)	Total anthocyanin (mg ME/g dw)	Antiradical activity TEACDPPH (µmol TE/g dw)	Catechin (mg/g dw)	Epicatechin (mg/g dw)	Trans-resveratrol (mg/g dw)
1.5 m/s	0.57	30.6 ± 0.8b	39.2 ± 0.8b	0.39 ± 0.01	93.4 ± 6.3	0.543 ± 0.025b	0.444 ± 0.025b	0.003 ± 0
2 m/s	0.57	38.1 ± 2.9 a	45.1 ± 1.3 a	0.37 ± 0.06	98.6 ± 2.0	0.677 ± 0.042 a	0.573 ± 0.047 a	0.005 ± 0.001
2.5 m/s	0.56	28.3 ± 0.9b	36.1 ± 0.3b	0.26 ± 0.02	78.3 ± 12.7	0.507 ± 0.006b	0.402 ± 0.006b	0.003 ± 0
LSD* $\gamma = 0.05$		5.22	3.77	N.S.	N.S.	0.11	0.12	N.S.
% CV		7.1	4.2	16.3	15.5	8.2	10.9	16.3
Raw pomace	0.96 ± 0	64.2 ± 3.5	84 ± 3	0.41 ± 0.04	173.6 ± 9.8	1.763 ± 0.145	1.254 ± 0.07	0.029 ± 0.004

(Mean ± SD); GAE: Gallic acid equivalent; TAE: Tannic acid equivalent; ME: malvidin-3-glucoside equivalent; TE: Trolox equivalent; dw: Dry weight; N.S.: Not significant; % CV: Variation coefficient.

* Different letters in the same column are significantly different from each other ($p < 0.05$).

antiradical activity values was not significant ($p > 0.05$). Vega-Gálvez et al. (2012) found that during the air drying at 40 °C treatment in a convective dryer (hot-air drying), the greatest loss of DPPH antioxidant capacity occurred, also both the total phenolic and DPPH results showed statistical differences in different air velocities.

HPLC method is a common tool used to the determination of phenolic compounds in foods. It has been identified and quantified the catechin, epicatechin and trans-resveratrol in the grape pomace dried at three different air velocities based on an HPLC method.

When the amounts of catechin, epicatechin and trans-resveratrol, which are important phenolic compounds in grape, different drying parameters with heat pump technique were examined changes in dried pomace samples, the highest catechin, epicatechin and trans-resveratrol values were determined in dried pomace samples with 2 m/s application, 0.677, 0.573 and 0.005 mg/g dw, respectively. 1.5 m/s and 2.5 m/s values were found to be close in terms of catechin, epicatechin and trans-resveratrol values in pomace samples. The effect of drying applications on catechin and epicatechin values was statistically significant ($p < 0.05$). Decreased loss rates (%) of dried grape pomace compared to raw pomace in terms of bioactive properties for both HP and Control are given in Table 3.

Open-loop HP drying processes affected bioactive properties of dried grape pomace negatively and losses in the bioactive properties of the dried product were lower than raw one and closed-loop convective dryer. According to Table 3, while the highest loss of total phenolic matter is detected 55.919 % in the dried pomace samples with 2.5 m/s application at pomace samples dried with HP dryer, the highest loss of total phenolic matter in Control was found as 39.408% at same air velocity. The lowest value being obtained at a drying air velocity of 1.5 m/s in Control however, it was obtained at a drying air velocity of 2.0 m/s due to the fact that many reasons such as design of HP system, the optimum conditions and pomace has a very complex structure. The highest loss in total tannin value in HP drying was 57.024% at the application of 2.5 m/s and it was found to be very close to one another with 49.286% at same air velocity. In this study, the losses of total phenolic, tannin and antioxidant activity were showed similarity in different air velocity treatments. A high and significant correlation between antioxidant activity and total phenolic content was reported in grape pomace samples, and also increasing correlation between antioxidant activity and total phenolic content was reported during food dehydration (Spigno, Tramelli, & De Faveri, 2007; Jara-Palacios, Hernanz, Escudero-Gilete, & Heredia, 2014; Vega-Gálvez et al. 2012). Vashisth, Singh, and Pegg (2011) reported that during drying process significant degradation of the polyphenolics and also affect antioxidant and free-radical scavenging capacities of grape pomace. Several researcher reported that, especially long thermal treatments at low temperature polyphenol oxidase gets longer time to oxidize the polyphenolics present and causes reduction in total phenolic content and antioxidant capacity (Garau, Simal, Rossello, & Femenia, 2007; Vashisth et al. 2011; Goula et al., 2016). Pascariu, Pop, and Albu (2014) reported that total polyphenols, tannins and anthocyanin content of grape pomace significantly decreases when the drying temperature is increased from 20 °C to 38 °C and 50 °C.

The total anthocyanin content that is least affected properties by the drying applications. Khanal et al. (2010) reported that anthocyanin contents in both grape and blueberry pomace were slightly reduced by drying at 40 °C, but a significant overall drop in total anthocyanin content occurred with increasing drying temperature from 40 °C to 125 °C but without a significant drop from 40 °C to 60 °C in both types of pomace. Previously other workers reported that catechin and epicatechin are the desirable substrates for polyphenol oxidase and exposure of oxygen caused significant loss of catechin and epicatechin during air-drying (Joshi, Rupasinghe, Pitts, & Khanizadeh, 2007; Joshi, Rupasinghe, & Khanizadeh, 2011).

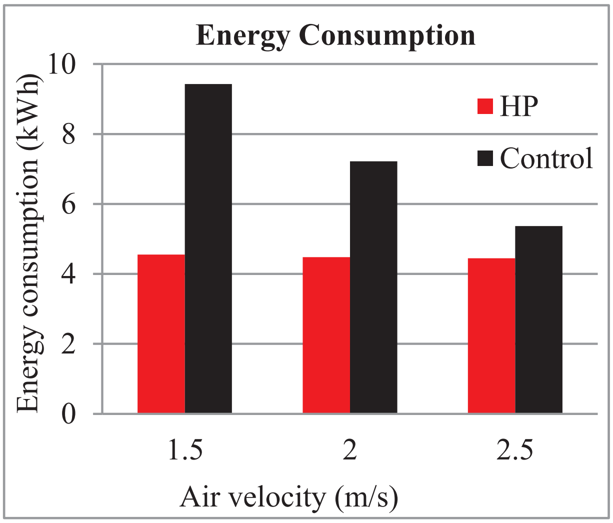


Fig. 5. A comparison in terms of energy consumption (kWh).

Compared to open-loop heat pump dryers and closed-loop convective dryers, both dryers seem to have strong or weak sides. An open-loop heat pump can be used to dry of grape pomace but in terms of food quality products with lower values than the closed-loop convective dryer can be obtained. However, especially at low speeds, the HP dryer offers considerable advantages in terms of energy consumption. When the energy consumptions of HP dryer compared with Control at 1.5 m/s, the energy consumption reduced up to 51% (Fig. 5). Thus, it was clearly observed that compared to Control, heat pump drying considerably reduced the energy consumption of grape pomace. It could be said that this reduction mainly comes from the efficient use of energy. In HP drying, the increase of air velocity from 1.5 m/s to 2.5 m/s caused a reduction in drying time by 69%. However, the increase of air velocity from 1.5 m/s to 2.5 m/s caused a reduction in energy consumption by 3%. Despite the fact that drying time varies at HP drying process, energy consumption is almost constant. As a result; an open-loop HP dryer can be recommended to dry of grape pomace. When both dryers are compared for food quality, open-loop HP dryer has relatively lower values than the closed-loop convective dryer. However, it seems that HP dryer has a considerable advantage in terms of energy consumption, especially at low speeds. On the other hand, closed-loop HP drying may be a good solution in terms of product quality.

Table 3
Decrease-loss ratios (%) occurring in the bioactive properties of drying applications according to raw pomace.

Method	Sample (for 45 °C)	Total phenolic	Total tannin	Total anthocyanin	Antiradical activity	Catechin	Epicatechin	Trans-resveratrol
HP	1.5 m/s	52.336	53.333	4.878	46.198	69.200	64.593	89.655
	2 m/s	40.654	46.310	9.756	43.203	61.600	54.306	82.759
	2.5 m/s	55.919	57.024	36.585	54.896	71.242	67.943	89.655
Control	1.5 m/s	24.143	29.524	2.439	39.977	56.948	44.976	75.862
	2 m/s	27.882	34.405	4.878	43.894	59.331	48.804	82.759
	2.5 m/s	39.408	49.286	19.512	52.131	63.471	55.582	86.207
Raw pomace	–	0.0	0.0	0.0	0.0	0.0	0.0	0.0

4. Conclusions

Grape pomace was dried using HP technology at different drying air velocities. When comparing the energy consumption of the HP dryer and convective dryer, the energy consumption was reduced by up to 51%. In HP drying, the increase of air velocity from 1.5 m/s to 2.5 m/s caused a reduction in drying time by 69%. However, the increase of air velocity from 1.5 m/s to 2.5 m/s caused a reduction in energy consumption by 3%. Some of the bioactive properties of the samples were lost during the drying process. It was observed that the losses in all bioactive properties were less than the total anthocyanin. The properties that are most affected by the drying applications applied to the grape pomace and the highest loss are trans-resveratrol, catechin, epicatechin compounds, respectively. The most noticeable difference between the applications was the amount of total anthocyanin (red color compounds of the grape). In this study, it was observed that application of 2 m/s in pomace drying process with heat pump method gave better results than other applications in terms of bioactive properties of samples. Heat pump drying is a promising method for grape pomace drying, pre-drying and the preparation of highly quality seeds and skins. Although the heat pump drying technology is applied in different food industries, it is not used in grape pomace. From these results, it can be concluded that drying air velocity was slightly effective on drying time however there is no significant effect on the energy consumption of the change in the drying air velocity at the same temperature. It could be applied to valorize byproducts of grape juice as cost-effective process and an environmentally friendly solution.

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