Chapter 7

Grape Drying: Current Status and Future Trends

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Abstract

With high moisture and sugar content, fresh grapes respire and transpire actively after harvest, which contribute to quality loss. Drying can process grapes into raisins for longer shelf-life as well as dehydrated grapes, which can be used for wines or juice production. The pre-treatments, drying method and drying conditions, can significantly influence the quality of final products. In this chapter, firstly, different pre-treatments as a necessary operation previous to the drying of grapes into raisins is introduced. These pre-treatments include chemical pre-treatment, physical pre-treatment, and blanching. In addition, the quality and drying characteristics of different pre-treatments is summarized too. Secondly, the current status of different technologies for grape drying and their effects on drying kinetics and quality attributes of seedless grapes are described to highlight the advantages and disadvantages of each drying method. These drying methods include the traditional open sun drying, shade drying, hot-air drying, freezing drying, microwave drying, as well as the vacuum impulsed drying. Thirdly, influences of drying on bioactive substances (flavonoids, phenolics, anthocyanin, and resveratrol) and antioxidant capacity of grape by-products including seed, skin, stem, and stalk are also examined. Finally, the future research trends of grape and its by-product drying are indentified and discussed.

Keywords: grape drying, pre-trements, drying methods, quality attributes, by-products drying

1. Introduction

Grape is one of the most popular and largest fruit corps and is cultivated in more than 100 countries around the world. Grape production all over the world was about 7.7 × 10^9 tons according to Food and Agriculture Organization (FAO) data for 2013 [1]. The top five grape production countries are China (about 1.16 × 10^9 t), Italy (about 8.01 × 10^8 t), United States of America (about 7.74 × 10^8 t), Spain (about 7.48 × 10^8 t), and France (about 5.52 × 10^8 t).

As one of the most popular fruits, grape can be consumed directly or processed into various products, such as raisin, grape juice, and wine, as illustrated in **Figure 1**. Fresh grapes with relatively high moisture and sugar contents respire and transpire actively after harvest and are very sensitive to microbial spoilage during storage, even at refrigerated conditions [2, 3]. As one of the most frequently used methods for food and bioproducts preservation, drying can remove moisture content to a very low content and drastically reduce microbial, enzymatic degradation or any moisture-mediated deteriorative reactions [4–7]. In addition, drying can bring some benefits such as substantial reduction in weight and volume, minimizing packing, storage, and transportation costs [8–12]. Drying is one of the most frequently used methods for grape processing. It can process grapes into raisins for longer shelf-life as well as dehydrated grapes, which can be used for wines or juice production. Such as many world-renowned wines, e.g. Passito wines, Sauternes, Tokaj, Porto, Pedro Ximénez and Amarone are produced using dehydrated grapes [13, 14]. Additionally, the main by-products during juice and wine production are grape seed, skin, stem and stalks, which are usually treated as waste [15, 16]. Recently, how to improve the utilization value of grape by-products become more and more popular as they are good source of phytochemicals including flavonoids, phenolics, anthocyanin, and resveratrol [17]. However, raw grape by-products also with high moisture contents are very sensitive to microbial spoilage and component degradation, dehydration become an essential processing prior to effective constituent extracting from them. Additionally, the drying methods and drying conditions also have great effect on effective extraction of the constituent.

For raisin processing, pre-treatments including chemical pre-treatment, physical pre-treatment and blanching have been investigated and applied to remove the wax layer on grape surface and enhance drying rate. Drying has a great effect on the quality of the grape raisins product, such as its texture and nutrients [18]. However, presently the natural sun drying and shade drying are still the most common drying methods performed in many countries for grape drying [19]. Although the investments and operation of natural sun drying is small and simplicity, it has several drawbacks. Such as long drying time usually taking more than two or three weeks, the rewetting products caused by bad weather, contamination by dust and insects, tedious and laborious to make the product more uniform, nutrients deterioration caused by long exposure to solar radiation. Therefore, application of a suitable drying technology and selection of appropriate drying conditions are therefore of great important in the production of good raisins products.

For grape by-products drying, different drying methods and drying conditions have great influences on their antioxidant capacity [17]. Therefore, preservation of the constituent and the bioactive contents throughout the drying process is necessary.

In this chapter, the background of different pre-treatment methods to enhance grape drying were outlined since a thin-layer wax covers on grape surface and forms the main resistance hindering moisture transfer during dehydration process [20, 21]. Then, different drying technologies for grape drying were presented, such as natural open sun drying, shade drying, solar drying, hot air drying, microwave drying, vacuum pulsed drying etc. After that, the drying of grape by-products and their influences on bioactive and antioxidant capacity were also discussed. Finally, the future research trends of grape and its by-product drying are also identified and discussed. It is hoped that the information provided in the current review would not only contribute to a better understanding of the research status of grape and its by-products drying, but also trigger new research opportunities to develop innovative drying technologies for grape drying.

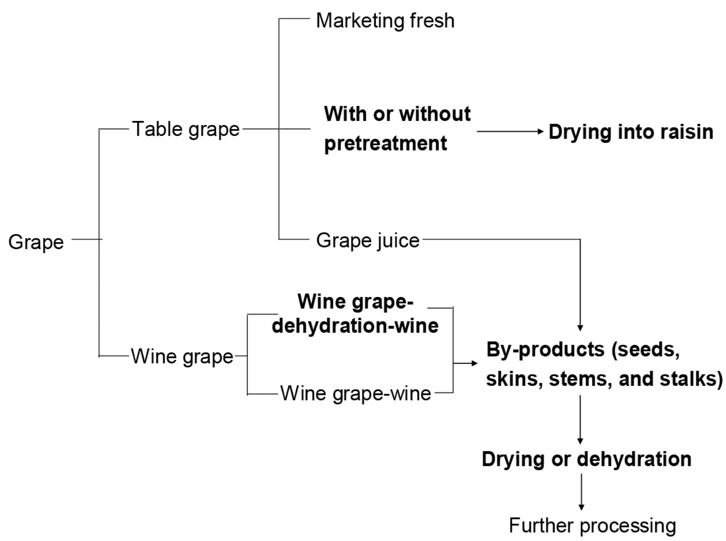

Figure 1. Flow diagram of grape processing.

2. Drying of grape into raisin

2.1. Pre-treatments of grapes pre-drying

Low moisture diffusion rate has become the basic problem during grape dehydration process. This can be attributed to the peculiar structure of a thin-layer of wax covered on grape surface which prevents the rate of moisture diffusion [21, 22]. The skin of the grape consists of an epidermis and six to ten layers of small thick-walled cells. The outer epidermis is covered by non-living layers, namely cuticle, lenticels, wax, and collenchymatous hypodermal cells [23]. Wax on grape skin serves as a protective barrier against fungal pathogens and protects the grape from UV light and physical injuries. However, the presence of waxes in the skin cuticle is an obstacle to drying. Therefore, it is necessary to remove the wax layer before drying [24]. Currently, various pre-treatments including chemical, physical, and blanching treatments have been carried out to remove the wax layer prior to the drying process. All the pre-treated results showed an increase in drying rate with reduction in drying time for the grapes to reach a safe moisture content required for storage. The different pre-treatments and main conclusions are summarized in **Table 1**.

The main constitutes of chemical pre-treatment usually contain two or three solution such as NaOH, K_2CO_3, $NaHCO_3$, olive oil, and ethyl oleate solution with a certain proportion. Chemical dipping pre-treatments could dissolve the grape skins and increase their permeability to water, by thus to improve the drying rate [31, 32]. The chemical dipping pre-treatment methods have been widely applied in commercial production [39]. However, there are some disadvantages of chemical pre-treatments, such as the residual chemical additives in the raisins, which are harmful for our health and may cause food safety problems; larger quantities of corrosive chemicals, which could pollute surroundings and their disposal is a high cost operation. As the food safety issues have attracted much more attention and the natural food consumption is becoming more and more popular, using of chemical additives in foods is being discouraged.

In order to avoid chemical residues during pre-treatment, some physical pre-treatments have been developed to remove the wax layer on grape surface. Di Matteo et al. [34] and Adiletta et al. [40] pre-treated the grape samples with some abrasion of the peel before drying. The results showed that the drying rate was significantly increased compared to untreated samples (**Table 1**). As the same treatment, Adiletta et al. [40] and Senadeera et al. [41] used a shaker with abrasive sheets created by Prof. Marisa Di Matteo, Department of Industrial Engineering, University of Salerno. The results also found that the pre-treatment affected the drying kinetics of grape samples, reduced drying times and rehydration time, and the surface structures of the pre-treated samples were detected by SEM. However, the physical pre-treated grape, which the final dried products occurred serious browning and the feasibility of this practice on larger scale has not been considered. Microwave-assisted pre-treatment [36] and ohmic pre-treatment [37] have also been explored. It was found both of them could enhance drying rate significantly.

Besides, pulsed electric fields (PEF) and ultrasounds are two other physical approaches to increase agricultural products drying rate by pre-treatment [42, 43]. Due to the advantages of short processing time, little heating of the medium, and low energy-consume, PEF is used for many material pre-treatments previous to drying and the drying rate was increased in various degrees [44]. For examples, compared to untreated samples, a 20, 34.7, and 12% drying rate increasing were obtained for PEF-pre-treated carrots [45], red pepper [46], and apple tissue [47], respectively. To get rid off the use of chemicals in raisin processing, Dev et al. [38] employed PEF pre-treatment to improve drying rate of grape, and a 20% decrease of drying time was obtained compared to untreated samples, and the highest drying rate was chemically treated samples (40% less). Ultrasound as one of pre-treatment methods also has been widely applied in extraction and prior to drying of grape and by-products [48].

Pre-treatment methods	Materials	Treatment	Control	Drying methods characteristics	Detecting indexes	Main conclusions	References
Chemical	Grapes (var. *sultanas*)	(1) 5% K_2CO_3 + 1.5% olive oil; (2) 4% K_2CO_3 + 2% ethyl oleate; (3) 5% K_2CO_3 + 2% ethyl oleate; (4) 6% K_2CO_3 + 2% ethyl oleate; (5) 7% K_2CO_3 + 2% ethyl oleate; All treatments with 20–25 s	Natural (untreated)	(1) Solar drying; (2) Sun drying on concrete ground; (3) Sun drying on wooden racks, or polypropylene canvas sheets	Drying rate, colour, and colour changes during storage	(1) Drying rate: solar drying> sun drying on concrete ground> sun drying on wooden racks, or polypropylene canvas sheets; (2) The drying rate increased with the increasing K_2CO_3 concentration from 4 to 7%; (3) The moisture content and colour intensities of the sun-dried grapes were found to be non-uniform	[25]
	Sultana (Thompson seedless) Initial moisture content 78% (w.b.)	2% $KHCO_3$ + 0.2% olive oil of 2 min	Natural (without treatment after collection from the farms)	Sun drying Temperature: 23–35°C Relative humidity: >72% Forced air drying Temperature: 60°C Air velocity: 0.5–1.5 m/s	Drying rate	(1) The drying time: sun drying took 179 h, forced air drying took 56 h (2)Different drying period with different temperature and air velocity would be reasonable	[26]
	Thompson seedless grapes Average diameter: 18± 1 mm Average brix: 23	D1: 0.5% NaOH solution of 5 s at 93°C±1.0°C; D2: 2.0% commercial dipping oil + 2.5% K_2CO_3 solution of 3 min at ambient temperature; D3: 2.0% ethyl oleate + 2.5% K_2CO_3 solution of 3 min at ambient temperature; D4: 0.4% olive oil + 7.0% K_2CO_3 solution of 3 min at temperature	D5: untreated grapes	The dryer was laboratory setup. Temperature: 60°C Air velocity: 0.5 m/s	Drying rate and organoleptic quality	(1) The drying time of different treatment of D1: 8 h, D2: 26 h, D3: 27 h, D4: 30 h, and D5: 46 h; (2) Hot dipping pre-treatment, though reduced the drying time, the quality of products found to be poor; (3) Page's model is accurate enough to predict the drying behaviour of pre-treated grapes.	[27]
	Sultana seedless grapes (*Vitis vinifera L.*) The initial moisture content: 77.3%-80.5% (w.b.)	*POTAS*: 0.5 kg K_2CO_3 + 10 L water + 0.05 kg olive oil; *AEEO*: ethyl oleate: 0.5 kg K_2CO_3 + 10 L water + 0.2 kg ethyl oleate Both *POTAS* and *AEEO* pre-treated 1 min at ambient temperature	NAT: untreated grapes	Cabinet drier: produced by APV&PASILAC firm (England) Temperature: 50, 55, 60, and 70°C; Air velocity: 1.2 m/s	Colour, drying rate	(1) Pre-treatment with the AEEO solution is effective in increasing the drying rate; (2) The use of ethyl oleate as pre-treatment solution for the drying of grapes leads to a better colour; (3) Exponential equations agree satisfactorily with the drying	[28]
	Grapes, initial moisture content of 80.20% (w.b.)	Immersed for 2 min in emulsion of 5% K_2CO_3 + 0.5% olive oil	Some other materials: apricots, peaches, figs, and plums	Open-air sun drying Temperature 31–43°C Solar radiation: 1.10–2.93 MJ/m²h	Drying rate, mathematical modelling of drying curves, and uncertainty analysis	(1) Water removal from the selected fruits in the drying process occurs in the falling rate period (2) The drying time of grape samples over 5 days (7000 min) (3) Verma et al. model could adequately describe grape open-air sun drying behaviour ($MR = a\exp(-kt) + (1-a)\exp(-gt)$)	[29]

Pre-treatment methods	Materials	Treatment	Control	Drying methods characteristics	Detecting indexes	Main conclusions	References
	Seedless Sultanine grapes Initial moisture: 83.33–86.11% (w.b.)	1% NaOH solution at 90°C of 2–3 times for 2–3 s	(1) In the open air; (2) Under greenhouse; (3) In the drier.	Solar tunnel greenhouse drying Temperature: 18–60°C Relative humidity: 18–96% Solar radiation: 0–600 W/m^2	Drying rate	(1) The drying time of solar drier was 77 h (about 4 days), greenhouse was 119 h (about 5 days), open sun was 250 h (more than 11 days) (2) The solar greenhouse drying is advantageous in regard to solar dried, greenhouse have a big drying capacity and don't require a large initial investment or additional running cost.	[30]
	Black grapes (*var. Muscat*) Average radius, length and weight 1.83 cm, 2.78 cm and 5.85 g, respectively; The initial moisture content: 79.3% ± 0.2 (w/w)	POTAS: 5% K_2CO_3 + 0.5% olive oil; EO1: 2% ethyl oleate + 2.5% K_2CO_3; EO2: 2% ethyl oleate + 2.5% KOH; EO3: 2% ethyl oleate + 2.5% Na_2CO_3; All treatments immersed for 1 min	NAT: untreated samples	Cabinet dryer: installed in the Chemical Engineering Department of Yildiz Technical University, Istanbul, Turkey Temperature: 60°C Air velocity: 1.1 m/s	Drying rate	(1) EO1 (2% ethyl oleate + 2.5% K_2CO_3) obtained the shortest drying time (about 25 h) among all treated and untreated samples; (2) No constant-rate period was found of black grapes drying. (3) Page model showed a better fit to the experimental data; The effective moisture diffusivity: 3.82×10^{-10}~1.28×10^{-10} m^2/s	[31]
	Seedless grapes (*Vitis vinifera L.*) Dry matter 23.62%±1.38 Total sugar: 19.97% ±1.06	D1: 2% ethyl oleate + 5% K_2CO_3 solution of 60 s at ambient temperature; D2: 4% PAKSAN oil (contains free oleic acid and chiefly ethyl esters of fatty acids; C_{14}-C_{18}) + K_2CO_3 solution of 60 s at ambient temperature	Hot water (HW) of 15 s at 95°C	Laboratory -scale tray dryer Drying temperature: 40, 50, 60, 70°C; Humidity ranged from 10% to 15%; Air velocity: 1 m/s	Thermal diffusivity, moisture diffusivity, and heat and mass transfer coefficients	(1) Effective moisture diffusivity strongly depends on dipping as well as moisture content and the temperature of the product; (2) Thermal diffusivity of the grapes varies with the moisture content of the grapes (3) Pre-treatments affect thermal gradients in the early stage of the drying process, but had no significant effect on the thermal diffusivities.	[32]
	Thompson seedless grapes (*Vitis vinifera*) Average diameter: 17.5–18.5 mm The initial moisture content: 80.3–82.6% (w.b.)	5% (w/v) K_2CO_3 + 2% (v/v) ethyl oleate at 30, 40, 50, and 60°C for 1, 2, and 3 min	Not pre-treated with dipping solution	A tray dehydrator (Excalibur, Sacramento, CA) Temperature: 60°C Air velocity: 0.6 m/s	Effective diffusivity and colour	(1) Dipping time of 2- and 3-min played an important role at 30 and 40°C (2) Browning occurred at all dipping times and temperatures (3) Midilli model best described the drying kinetics of grapes pre-treated with dipping solutions ($MR = a\exp(-kt^n) + bt$)	[33]
Physical	Seedless white grapes (var. Nevado) The initial moisture content: 84.0% ± 1.6	The abrasion of the grape peel was carried out in a shaker the walls of which were covered by coating with abrasive sheets Shaker for 10 min (Abr) EtOl: 2% (v/v) ethyl oleate + 2.5% (v/v) K_2CO_3 at 40°C for 3 min	Untreated samples (UT)	Convection oven Temperature: 50°C Air speed: 0.5 m/s	Drying rate, colour parameters, and microstructure	(1) The physical treatment found to be as effective as the chemical dipping method, mass transport coefficient was about four times greater than untreated samples (drying time about 35 h) (2) Physical treated samples gives rise to a more coloured final product than the chemical one	[34]

Pre-treatment methods	Materials	Treatment	Control	Drying methods characteristics	Detecting indexes	Main conclusions	References
	Red grapes (*Vitis Vinifera*) Initial moisture content: 6.43±0.02 kg/kg (d.b.) Average diameter: 24.4±1.95 mm	Abraded grape (TR-Abr): the abrasion of the grape peel was carried out in a motorized rotating drum (*D*=240 mm, *L*=250 mm) made of plexiglass, lined inside with sandpaper. Rotation speed of drum: 10 rpm; Pre-treatment time: 15 min; Mass of grapes: 4 kg.	Untreated grape (UTR) Chemical solution (TR-EtOl): 2% (v/v) ethyl oleate + 2.5% (v/v) Na_2CO_3 at 40°C for 3 min	Convective dryer (*Zanussi FCV/E6L3*) Temperature: 40, 50, 60, and 70°C Air velocity: 2.3 m/s	Drying rate, colour, total phenolic content, antioxidant activity, shrinkage, microstructure, rehydration.	(1) The highest drying rate was found for abraded grapes at 50 and 60°C, about 1/3 drying time of untreated grapes; (2)The colour of abraded grapes was darkest; (3) Based on total phenolic content, the best drying temperature was 50°C for both untreated and pre-treated samples (4) Abraded grape drying: The logarithmic model was the best fitting for all temperatures except at 70°C; Page model gave the highest correlation factor; Quadratic model showed an acceptable fit to experimental data for all the samples and temperatures investigated.	[35]
	Sultana seedless grape (with length 15–18 mm and diameter 12–14 mm). Average weight was 1.28 g.	Microwave pre-treatment: fresh, dipped (2.5% K_2CO_3 + 0.5% olive oil for 1 min) or blanched (boiling water for 0.5 min) for 0.5–2 min at 215 W, 325 W or 420W.	Untreated samples	Sun-drying: average daylight temperature was 22°C.	Colour and water activity	(1) Microwave pre-treated grapes dried nearly two times faster than the control; (2) The same drying rate be found of blanching and microwaves; (3) Colour and appearance of treated grapes were comparable to commercial products.	[36]
	Seedless red grape, the size and weight of each of the individual grape berries were relatively uniform to minimize their effects.	The treated bulk samples were ohmically heated in a solution containing 2% citric acid to a final medium temperature of 60°C using a field strength of 15 V/cm. The ohmic pre-treatment was conducted at 30 Hz, 60 Hz, and 7.5 kHz.	Untreated samples	Food dehydrator (Excalibur Products, Sacramento, CA), drying temperature was maintained 57°C.	Drying rate & adsorption isotherm	(1) Ohmically pre-treatment increased grape drying rate significantly; (2) The highest extent of the drying rate increased at the 30 Hz frequency of alternating; (3) Ohmic pre-treatment caused a shift in the sorption isotherm.	[37]
	Grapes (raisins variety)	pulsed electric fields (PEF), chemicals, microwave	No treatment	Convective drier at 65°C.	Colour (L, a, and b), total soluble solids (TSS), bulk density, appearance and market quality.	(1) Chemical treated grape obtained the highest drying rate; (2) PEF and microwave-treated samples had a significantly high TSS, appearance and market quality.	[38]
Blanching	Thompson seedless grapes Average length, width, and weight are 18.4 mm, 12.3 mm, and 3.34 g, respectively. The initial moisture content: 3.95 kg/kg (d.b.)	High-humidity hot air impingement blanching (HHAIB) Blanching time: 30, 60, 90, 120 s; Blanching temperature: 90, 100, 110, and 120°C Relative humidity: 40–45%	Fresh grapes	Air impingement dryer was installed in the College of Engineering of China Agricultural University, Beijing, China. Drying temperature: 55, 60, 65, 70°C.	Drying rate, polyphenol oxidase (PPO) activity, moisture diffusivity, and colour	(1) The PPO residual activity decreased with the increase of blanching time and temperature; (2) Fick's second law used to describe the drying kinetics of samples; (3) The colour analysis of the dried grape products showed that the Thompson seedless grapes pre-treated by HHAIB result in desirable green-yellow to green raisins.	[21]

Table 1. Comparison of different pre-treatments for grape drying.

As an essential step before processing of agricultural products blanching has been widely applied to inactivate enzymes, preserve colour, improve drying rate, or even to soften tissue, etc. Hot water blanching is the most popular and commercially used blanching method due to the advantages of low-cost, simplicity and convenient, and the small capital investments. However, there are several disadvantages of hot water blanching, including excessive loss of nutritional substances and how to deal with the hot water after blanching which contented large quantity nutrients [49]. Based on the disadvantages of hot water blanching, Bai et al. [21] used high-humidity hot air impingement blanching (HHAIB) pre-treatment for seedless grapes drying, which combines the advantages of steam blanching and impingement technologies, and they found that the drying rate in this case remarkably enhanced and the dried grape products obtained desirable green-yellow to green raisins. Xiao et al. [49] reviewed the application of superheated steam impingement blanching (SSIB) in agricultural products processing especially the fruits with a thin-layer of wax on their surface.

2.2. Different drying methods and their effects on grape drying

Grape drying is one of the most important methods to prolong its shelf-life and reduce economic losses. Therefore, how to improve the drying rate as well as obtain desirable products are the main objectives of grape drying. A larger number of studies focused on different drying methods and quality change kinetics during drying process. Currently, there are three frequently used drying methods for grape drying: natural sun drying or solar drying, shade drying, and mechanical drying.

2.2.1. Natural sun drying

Natural drying of grapes includes the open sun drying (with or without cover) and shade drying [19]. As a traditional method (**Figures 2** and **3**), natural drying of grape can be dated to 1490 BC in Greece and even today it is still widely applied, especially in developing countries due to its low initial and running costs [22, 24].

As the oldest drying method, natural open sun-drying is widely used method for thousands of years by human beings even nowadays. When open sun drying is performed the grapes are spread over the grape bunches either the ground or on a platform in a thin layer directly exposed to the sun or on a plastic sheet. During sun drying process, part of the solar radiation may penetrate the material and be absorbed within the grape itself, thus generating heat in the interior of the material as well as at its surface, therefore, increasing the heat transfer and enhancing moisture evaporation. This method is cheapest and is successfully employed in grapes producing countries [25]. Practically, no capital outlay for equipment is required, although considerable labour may be involved, which is seldom costly. However, the drying time is nearly 8–10 days, even much longer if the weather is sunny-less. Insect attacks, dust and potential rain resulting in a risk of grape deterioration. In addition, direct exposure to intense sun radiation and various temperature ranges would cause colour, appearance, and aroma deterioration and difference [19, 50]. The sensory quality of dehydrated grape especially colour and aroma is closely related to its' acceptability and wine-making. Ruiz et al. [50] found that different temperatures have a significant effect on aroma profile of musts from the dried grapes, a less loss of raisiny aroma for a lower temperature was found.

Figure 2. The open sun drying of grape into raisin.

Figure 3. Shade drying of grape into raisin and the structure of shade-room.

Above all, a series of disadvantages limited the application of natural sun drying, such as lack of ability to control the drying operation properly, the length of the drying time, weather uncertainties, high labour costs, large area requirement, insect infestation, mixing with dust and other foreign materials and so on [29].

2.2.2. Solar drying

With rich solar energy radiation and available free of cost in many countries, solar energy has been widely used for heat production or power generation. Solar drying is the most commonly used for drying agricultural products. There are several types for grape solar drying, such as direct type [51], indirect type [52], and mixed type [53, 54]. For each type the solar energy is used as either the sole source of the required or as a supplement source. For grape drying, direct solar radiation causing poor quality formed due to light-sensitive of ascorbic acid and polyphenol, especially undesirable discolouration and aroma loss. Therefore, the indirect and mixed type solar dryer are more suitable for raisin [55].

2.2.3. Shade drying

Shade drying is also a kind of natural method and extensively used for grape drying in China (**Figure 3**), Australia, and India. Shade drying is also known as natural rack dryer, the ambient air is the principal source of heat required for drying [19]. Raisin of shade drying obtained better colour than sun drying, avoid the directly contact with sundries. However, there are some disadvantages of shade drying, such as long drying time, high labour require, and poor sanitary conditions.

2.2.4. Mechanical drying

With the rapid development of mechanization in agricultural production, mechanical drying has been widely used in raisin production due to its rapid, controllable, low labour, and high quality of products. Using solar energy as the heating generator, combined with some thermal-energy supplied dryer have been widely developed. Besides, microwave drying [56–58], vacuum pulsed drying, as well as combination of different drying methods also used for grape drying [59]. Heat pump dryer is also been developed due to its' improved efficiency, accurate control of drying conditions, wide range of drying conditions, better product quality, and increased throughput [60–62]. However, there are some limitations for the use of heat pump dryer, such as high maintenance cost, refrigerant leak causing environment pollution, and the initial capital cost [63, 64].

3. Drying of grape by-products from wine production and effects of their quality

Grape by-products from wine and juice production include grape seeds, skins, stems and stalks. Many researches have demonstrated that those sub-products are source of phenolic compounds, flavonoids, and anthocyanin pigments, which are natural antioxidants and of interest for food, cosmetic and pharmaceutical industries [65–67]. Wet grape residues with an approximate moisture content of 70% (wet basis) are generated as final residues, which are very sensitive to microbial spoilage and degradation of its effective components [68]. Traditionally, grape by-products are mainly used to obtain rectified alcohol, livestock feed production, and usually they are regarded as fertilizer, and even as waste into the environment [69]. Furthermore, the grape seed can be used extraction of oil, which is an alternative option for industrial application. For all grape residues from wine-making, about 15% is seed, and the extraction of oil from grape seed would be an excellent case [70]. However, such process is quite limited nowadays, and grape seed oil is only available at specialised dietetic shops. More and more researchers focus on the high valuable functional components extraction and their contribution for human beings [71–76].

Drying is a necessary step before antioxidants extraction, which may affect not only drying kinetics and energy efficiency but also product quality. However, drying could provoke a change in the physical, chemical and biological properties of the treated biomaterials [77]. The phenolic content degradation has been linked to the drying temperature-time combination [48, 78]. Different drying methods have been studied to obtain high effective ingredients reservations, and their influences and main results are summarized in **Table 2**.

Drying methods	Type of by-products	Drying condition	Main results	References
Freeze-drying & oven-drying	Skin from Carmenere and Cabernet Sauvignon, respectively.	Freeze-drying: samples were frozen at −78°C for 12 h and then freeze-dried in a vacuum (2.4×10^{-2} mB) for 24 h; Oven-drying: 60°C for 24 h.	(1) many volatile compounds decreased significantly with the oven-drying method, in contrast to the freeze-drying method; [2] Both phenolic compounds, anthocyanins and flavonols, were identified in fresh and dehydrated samples, thus resulting in the freeze-drying method being less aggressive than oven-drying methods.	[79]
Air-circulating oven	Red grape pomace (*Vitis vinifera* var. Cencidel)	Flow rate of 2.3 m^3/min; Temperature of 60, 100, and 140°C	(1) The total extractable polyphenols, condensed tannins, and antioxidant activity decreased significantly of 18.6.	[65]
Convective hot air drying	Seeds of Riesling, Concord, and Cab Franc.	Temperatures: 40, 50, 60°C; Air velocity: 1.5 m/s.	(1) Effective moisture diffusivity: Riesling seeds of 1.57–3.96 × 10^{-10} m^2/s, Concord seeds of 2.93–5.91×10^{-10} m^2/s, and Cab Franc seeds of 3.89–8.03× 10^{-10} m^2/s; (2) The activation energies of Riesling seeds was 40.14 kJ/mol, Concord seeds was	[80]

Drying methods	Type of by-products	Drying condition	Main results	References
			30.45 kJ/mol, and Cab Franc seeds was 31.47 kJ/mol; (3) Lewis model was shown to be an excellent model for predicting all three grape seed varieties.	
Convective drying with air-borne	Skins	Temperature: 40, 50, 60, and 70°C with (21.7 kHz, 45 W) and without power ultrasound application.	(1) Drying kinetics, total phenolic content and antioxidant capacity are influenced by both temperature and ultrasound; (2) Ultrasound application reduced the antioxidant potential, and increased as a consequence activation temperature drying.	[78]
Freeze-drying & oven drying	Muscat skin	Freeze-drying: -49±2°C under vacuum (2.4×10^{-2} mB) for 24 h; Oven drying: 30 and 45°C	(1) Freeze-drying is a good technique to preserve characteristic volatiles loss and phenolic compounds decrease of grape skins; (2) Freeze-dried grape skin could apply to enhance the flavour of white wines and other fields.	[79]
Hot air drying	Grape seed	Temperature: 40, 50, 60, 70°C; Velocity: 1.0, 1.5, 2.0, 3.0 m/s; With or without ultrasound application.	(1) Peleg's model could well describe grape seed drying; (2) Air velocity no significant influence on the dehydration process according to experimental result; (3) Ultrasound application had no influence on the dehydration kinetics of grape seeds.	[48]
Freeze-drying & hot-air drying	Grape stalk (*Vitis vinifera* var Bobal)	Hot-air drying: temperatures of 40, 55, 70, 85, 100 and 115°C; Freeze-drying: initial temperature -48±2 C, pressure 10^{-3} mbar	(1) The drying method have an significant effect on antioxidant of grape stalk, and hot air drying has a lower antioxidant and a slower extraction process; (2) The minimum antioxidant diffusivity and concentration was found for grape stalks dried at temperature ranging between 60 and 80°C; (3) Reduction of the mass transfer coefficient in hot air samples suggested the formation of a crust or shell during drying caused by the higher drying rate.	[81]

Drying methods	Type of by-products	Drying condition	Main results	References
Convective drying + ultrasound	Grape stalk from *Vitis vinifera* var. Bobal	Temperature of 40 and 60°C with or without ultrasound (45 and 90 W), velocity of 1 m/s.	(1) Ultrasound power enhance the diffusion and heat transfer coefficient during grape stalk drying; (2) The use of ultrasound increased the energy efficiency during the drying of grape stalk.	[82]
Infrared drying	Wet grape residues	Temperature: 100, 120, 140, 160°C	(1) Midilli model can well decrease the change of moisture ratio with drying time in the temperature range from 100 to 160°C; (2) The values of effective diffusivity and activation energy for moisture diffusion were determined.	[69]
Infrared, Convective, and Sequential infrared + convective	Wine grape pomace	Convective Drying (CD): 60, 70, 80, and 90°C; Infrared Drying (IR): the distance from the infrared emitter to the pomace was about 20 cm, far infrared range of 12,250 W; Sequential infrared and convective drying (SIRCD): IR7 min-CD, IR14 min-CD, IR21 min-CD, IR28 min-CD	(1) IR drying had the highest drying rate, which reduced the drying time by more than 47.3% compared with other methods; (2) SIRCD had a faster drying rate than CD; (3) Midilli et al. model had the highest R^2 and lowest *RMSE* and χ^2 for experimental data.	[83]

Table 2. Effects of different drying methods on grape by-products.

4. Summary and future research opportunities

1. For raisin production, pre-treatment is an important step to enhance drying rate. Chemical dipping pre-treatment is the most commonly used method in practical production. However, chemical residues in products has become a serious problem as the residual chemicals are bad for human being's health and can trigger food safety problems. While, different pre-treatments have a quite influence on grape quality, especially colour, bioactive component, and texture. Therefore, novel pre-treatment method should be developed to improve the permeability of the grape skin without damaging the product attributes. Microscopic analysis as the tool of evaluating pre-treatments should been taken into consideration in the future research.

2. Different varieties have different requirements for quality of raisin, proper drying method, drying condition, and processing should be classified. High quality products are the target of grape drying, therefore, except texture, aroma, colour, and rehydration, the change of bioactive components should accounted during drying processing. To explore the mechanism of quality changes, the form of moisture in grape and diffusion mechanism should be studied.

3. Grape by-products during juice or wine-making, has attracted more and more attention because of their rich content of bioactive component and high natural antioxidant capacity. Dehydration is the necessary processing prior to further operation, such as extract of phenolic compounds, flavonoids, and anthocyanin pigments. Temperature is the key influence parameter for maintaining bioactive components. So, lyophilisation has been widely studied and indicated ideal drying conditions. However, large-scale commercial production and high cost of lyophilisation should be considered.

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