Review article

Fatty acid composition, bioactive phytochemicals, antioxidant properties and oxidative stability of edible fruit seed oil: effect of preharvest and processing factors

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ABSTRACT

Fruit seed is a by-product of fruit processing into juice and other products. Despite being treated as waste, fruit seed contains oil with health benefits comparable or even higher than the conventional seed oil from field crops. In addition to essential fatty acids, the fruit seed oil is a rich source of bioactive compounds such as tocopherols, carotenoids, flavonoids, phenolic acids and phytosterols, which have been implicated in the prevention of chronic and degenerative diseases such as cancer, diabetes and cardiovascular diseases. The emerging potential of fruit seed oil application in food and nutraceuticals has prompted researchers to study the effect of preharvest and processing factors on the seed oil quality with respect to nutritional qualities, antioxidant compounds and properties. Herein, the effect of cultivar, fruit-growing region, seeds pretreatment, seeds drying and seed oil extraction on tocopherols, polyphenols, phytosterols, carotenoids, fatty acids, antioxidant activity and oxidative stability of the fruit seed oil is critically discussed. Understanding the influence of these factors on seed oil bioactive phytochemicals, nutritional qualities and antioxidant properties is critical not only for genetically improving the oilseeds plants with desired characteristics, but also in seed oil processing and value addition. Therefore, preharvest and processing factors are essential considerations when determining the application of fruit seed oil.

1. Introduction

Fruit seed as a source of edible oil has not been given much attention compared with field crops seed oil (Raihana et al., 2015; Statista, 2019). With the increasing demand for edible oil, plant sources have become the target for researches to explore their quality and functional properties. Fruit seed is a cheaper alternative source of edible oil as it is commonly regarded as waste. In addition to providing energy to the human body, seed oil maintains normal body temperature, protects body tissues and carries liposoluble vitamins, among other functions (Xu et al., 2015). Adding seed oil to food improves texture, flavour and palatability. Nutritionally, consumption of seed oil has been associated with lowering the risks of different chronic and degenerative diseases such as cancer, diabetes and cardiovascular diseases. These health-promoting effects are attributed to fatty acids and bioactive compounds within the seed oil. Therefore, seed oil has gained recognition and found application in nutraceutical and medical products (Vermaak et al., 2011; Kong et al., 2018).

Seed oil is mainly composed of triacylglycerides and other minor components which include phytosterols, phenols, carotenoids, tocopherols and phospholipids (Hernandez, 2005; Przybylski and Eskin, 2011; Gunstone, 2013) Fatty acids, which occupy a greater percentage of seed oil, are categorized as saturated (SFA), monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA). PUFAs are further classified into essential and non-essential fatty acids. Due to the absence of appropriate enzymes, the human body cannot synthesize essential polyunsaturated

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fatty acids (Orsavova et al., 2015). Provision of these essential poly-unsaturated fatty acids from the diet is fundamental. Seed oil is a good source of the essential polyunsaturated fatty acids such as linoleic and α-linolenic acid with various health benefits (Arbex et al., 2015; Al Juhaimi et al., 2017; Xu et al., 2018).

Various factors have been reported to influence the quality, and potential application of fruit seed oil, and these include preharvest and processing factors. Preharvest factors such as cultivar and fruit growing region are recognized as crucial in determining oil quality and functionality (Górnaś et al., 2014, 2016b; He et al., 2016; Borges et al., 2017; Souayah et al., 2017). The processes involved in seed oil production, which include seeds drying, seeds pretreatment and oil extraction have been strongly implicated in altering the chemical composition and functional properties of the oil (Passos et al., 2009; Akbari et al., 2015; Jiang et al., 2015; Al Juhaimi et al., 2018; Gustinelli et al., 2018; Hassini et al., 2018). Therefore, there is considerable variation in fruit seed oil quality with respect to cultivar, fruit growing region and seed oil processing techniques.

On this basis, the objective of this review is to highlight current knowledge on preharvest and processing factors affecting bioactive phytochemicals, fatty acid composition, antioxidant properties and oxidative stability of fruit seed oil focussing on fruits, which generate seeds as waste during processing into other products.

2. Preharvest factors affecting quality attributes of edible fruit seed oil

Several preharvest factors may influence the quality attributes of seed oil before harvesting the oil-bearing fruit. Researches have predominantly focused on the effect of cultivar and fruit grown region on the quality attributes of the seed oil. This is arguably valid because these factors account for most of the other factors that have been highlighted to affect the bioactive phytochemicals, nutritional qualities and antioxidant properties of seed oil such as cultural practises, soil type and climatic conditions.

2.1. Cultivar

The effect of cultivar on fruit seed oil quality has been attributed to differences in genetic characteristics of the seed-bearing plants (Liu et al., 2016). Knowledge of cultivar effect on seed oil quality is essential in generating information that could be used to improve oilseed plants with desired characteristics genetically. Seed oils from different fruit cultivars have been shown to possess varied quality attributes and functional properties. For instance, fatty acids have been reported to vary in seed oil from different fruit significantly (Górnaś et al., 2014; He et al., 2016; Sicari et al., 2017) (Table 1).

2.1.1. Fatty acids

Variation of seed oil fatty acids among cultivars is crucial information in evaluating seed oil stability against oxidation and food fortification. In this sense, cultivars with seed oils high in essential fatty acids may be used to improve the availability of these fatty acids in other foods. This would improve access to essential fatty acids by people allergic to other sources of these valuable nutrients such as fish products. The fatty acids in the seed oil of several Spanish pomegranate cultivars ('Akko', 'Radisa', 'Hershkovitz', 'Valenciana', 'Ravenna', 'Veneti', 'Hijaz', 'Shiraz', 'Dent di Cavallo', 'Mollar (1)', 'Mollar (2)', 'Wonderful 1', 'Wonderful', 'G (1)', 'G (2)', 'Ecotipo (1)' and 'Ecotipo (2)') were studied (Fernandes et al., 2015) (Table 1). Punicic acid, linoleic acid, oleic acid, stearic acid and palmitic acid were the main fatty acids present in these seed oils and considerably varied among the cultivars. For instance, punicic acid a bioactive lipid that has been linked to the pomegranate seed oil health benefits (Aruna et al., 2016) was higher and lower in 'Valenciana' (3523 mg/100 g) and 'CG8' pomegranate (9570 mg/100 g), respectively. Saturated fatty acids (SFA) varied from 312 ('Valenciana') to 712 mg/100 g ('CG8')

pomegranate. Also, monounsaturated fatty acids (MUFA), which constituted the least fatty acids in the pomegranate seed oil varied from 198 to 503 mg/100g and were higher and lower in 'Valenciana' and 'CG8' pomegranate, accordingly. The highest concentration of polyunsaturated fatty acids (PUFA) was exhibited by seed oil from 'Katirbasi' pomegranate (11475 mg/100 g), while the lowest concentration was shown by oil from 'Valenciana' pomegranate (3846 mg/100 g). The authors also observed that lowest saturated to unsaturated fatty acids (SFA/UFA) ratio was shown by seed oil from 'CG8' pomegranate (0.065), suggesting that the oil might have better nutritional properties.

Fatty acids in the seed oil of eleven mango cultivar ('Tainong', 'Xiangya', 'Okrong', 'Keitt', 'Chiin Hwang', 'Guifei', 'Yuexi', 'Biantao', 'Zihua' and 'Guire') were investigated by Jing et al. (2012). The authors found out that oleic acid was the dominant fatty acid and ranged between 78.29 ('Biantao') and 84.37 % ('Chiin Hwang'). Oleic acid is more stable to oxidation than polyunsaturated fatty acids. In this line, the findings suggest that seed oil from mango cultivars might have better oxidative stability properties. Furthermore, fatty acids including palmitic acid (1.09–1.95 %), stearic acid (1.32–6.94 %), linoleic acid (8.27–14.78) and arachidic acid (1.13–1.74 %) significantly varied among the seed oils from the mango cultivars.

A study of the seed oil extracted from five grape cultivars ('Chardonnay', 'Merlot', 'Carbernet Sauvignon', 'Vitis amurensis' and 'Vitis davidii') showed that linoleic acid was the major fatty acid with levels ranging from 76.77 ('Vitis amurensis') to 63.53 % ('Vitis davidii'). Oleic acid and palmitic acid, some of the main fatty acids in grape seed oil varied from 13.63 to 22.03 % and 6.56 and 8.55 %, respectively and showed significant variation among the cultivars. One of the essential fatty acids, linolenic acid was higher in (0.46 %) in 'Carbernet sauvignon', while it manifested lower (0.35 %) in 'Chardonnay', Vitis amurensis' and 'Vitis davidii' grape. Slight variations were reported on minor fatty acids such as myristic, palmitoleic, margaric, arachidic, nanodecylic, paullinic, behenic and lignoceric acid (Wen et al., 2016).

Similar findings were reported with apple, passion, pear, mango and kiwi cultivars an indication that genotype has a significant influence the seed oil fatty acid composition and content (Fromm et al., 2012; De Santana et al., 2015; Górnaś et al., 2016c; Jin et al., 2016; Deng et al., 2018) (Table 1).

2.1.2. Tocopherols and polyphenols

Genetic factors and cultivars differences predominantly drive the expression of tocopherols and phenolic compounds in seed oil exist. The effect of cultivar on seed oil tocopherols and phenols is presented in Table 2. Xi et al. (2017) investigated the effect of cultivar on phenolic acids and flavonoids from lemon seed oil. 'Feiminailao' and 'Cuningmeng' lemon exhibited higher total phenols (3.36 μg gallic acid equivalent/g fresh weight) (GAE/g FW) and total flavonoids (24.97 μg rutin equivalents/g FW), respectively. The levels of total phenols and flavonoids in 'Beijingningmeng' and 'Pangdelusaningmeng' lemon were 1.5 and 1.3 fold lower than those from 'Feiminailao' and 'Cuningmeng, which showed the highest concentrations. Other phenolic compounds including chromogenic acid, caffeic acid, gallic acid and esperidin also varied among the lemon cultivars. Comparable findings were reported by Hssaini et al. (2020) from fig cultivars (Table 2).

Besides, Jing et al. (2012) reported significant variation of phenolics, flavonoids, tocopherols and proanthocyanidins from the seed oil of four pomegranate cultivars. 'Suanshiliu' pomegranate exhibited higher total phenolics (2.17 mg GAE/g), total flavonoids (0.62 mg catechin equivalence/g) (CE) and proanthocyanidins (181.98 μg cyanidin equivalence/g) (CyE), whilst 'Jingpitian' pomegranate showed lower total phenols (1.29 mg GAE/g), total flavonoids (0.42 mg CE/g) and proanthocyanidins (68.31 μg CyE/g). In the same study, total tocopherols were higher in 'Tianhongdan' pomegranate (11.97 μmol/g) and lower in 'Sabaitian' (5.31 μmol/g). The study also reported considerable variation in individual tocopherols such as δ-tocopherol, γ-tocopherol and α-tocopherol among the pomegranate seed oil cultivars. 'Sanbaitian'

Table 1. The effect of fruit type and cultivar on the fatty acid composition of seed oil.

Type of fruit seed oil	Cultivar	Key finding	Reference
Bergamot	'Castagnaro', 'Ferminello', 'Fantastico'	'Castagnaro' showed lower SFA but, higher UFA.	Sicari et al. (2017)
Pear	'Beurre d'Amanlis', 'Conference', 'Latgale', 'Mramornaja', 'Suvenirs', 'Muizas nr.4', 'Petrilas nr.49', 'Williams Bon Chretien'	'Conference' exhibited higher MUFA and lower PUFA. SFA was lower in 'Muizas nr.4'.	Gornas et al. (2016b)
Cactus pear	'Algerian', 'Gymno Carpo', 'Meyers', 'Morado', 'Nudosa', 'Roedtan', 'Sicilian Indian Fig', 'Skinners Court', 'Tormentosa', 'Turpin', 'Van As', 'Zastron'	'Van As' exhibited highest oleic acid and 'Skinners Court' showed the lowest.	De Wit et al. (2016)
Mango	'Tainong', 'Xiangya', 'Okrong', 'Keitt', 'Chiin Hwang', 'Guifei', 'Yuexi', 'Biantao', 'Zihua', 'Guire'	'Biantao' and 'Zihua' showed higher oleic acid and lower palmitic acid respectively.	Jin et al. (2016)
Sour cherry	'Tamaris', 'Zentenes' 'Haritonovskaya', 'Latvijas', 'Zemais', 'Shokoladnica', 'Bulatnikovskaya'	'Haritonovskaya' showed lower SFA. 'Latvijas' exhibited Lower PUFA and higher MUFA.	Górnaś et al. (2016c)
Avocado	'Fortuna', 'Collinson', 'Barker'	SFA was lower and higher in 'Collinson' and 'Fortuna' respectively. MUFA, PUFA and USA/SFA were higher in 'Collinson' and lower in 'Fortuna' and 'Barker'.	Galvão et al. (2014)
Grape	'Bolgar', 'Super ran Bolgar', 'Mavroud', 'Shiroka melnishka loza'	Linoleic acid, oleic acid and palmitic acid were higher in 'Super ran Bolgar', 'Mavroud' and 'Bolgar' respectively.	Ovcharova et al. (2016)
	'Kalecik karas 1', 'Narince', 'Emir', 'Hasandede'	'Hasandede' and 'Narince' exhibited higher unsaturated fatty acids.	Baydar et al. (2007)
	'Chardonnay', 'Merlot', 'Carbernet Sauvignon', 'Vitis amurensis', 'Vitis davidii'	PUFA was lower in 'Vitis davidii' and higher in 'Vitis amurensis'. 'Vitis davidii' and 'Vitis amurensis' exhibited higher and lower MUFA respectively.	Wen et al. (2016)
Apple	'Brettacher', 'Bohnapfel', 'Gewurzluiken', 'Idared', 'Boskoop', 'Bittenfelder', 'Trierer Weinapfel', 'Jonagold', 'Royal Gala', 'Roter Ziegler', 'Champagner Renette', 'Genereuse de Vire', 'Geheimrat Breuhahn', 'Koniginnenapfel', 'Hohe Wart', 'Kaiser Wilhelm', 'Transparent'	Lower SFA, higher MUFA, lower PUFA and higher UFA/SFA ratio were observed from 'Weinapfel', 'Jonagold', 'Champagner Renette' and 'Boskoop' respectively.	Fromm et al. (2012)
	'Kerr', 'Quaker Beauty', 'Kuku', 'Riku', 'Antej', 'Rikita', 'Ritu', 'Beforest', 'Kent', 'Sinap Orlovskij', 'Zarja Alatau'	Palmitic acid and linoleic acid were lower in Riku and 'Kerr' respectively. Oleic acid was greater in 'Kent'.	Gornas et al. (2014)
Sea buckthorn	'Aura', 'Serpenta', 'Tiberiu', 'Victoria', 'Ovidiu' 'Silvia'	'Silvia' exhibited lower SFA and higher MUFA. Lower and higher PUFA were shown by 'Tiberiu' and 'Serpenta' respectively	Dulf (2012)
Passion	'Passiflora alata BRS Doce Mel', 'Passiflora alata BRS Mel do Cerrado', 'Passiflora edulis BRS Gigante Amarelo', 'Passiflora edulis BRS Sol do Cerrado', 'Passiflora tenuifila VI', 'Passiflora setacea BRS Perola do Cerrado'	Palmitic and stearic acid were higher in 'Passiflora edulis BRS Gigante Amarelo' and Passiflora setacea BRS Perola do Cerrado' respectively. 'Passiflora tenuifila VI' and 'Passiflora alata BRS Mel do Cerrado' exhibited higher oleic and linoleic acid respectively.	De Santana et al. (2015)
Pomegranate	'Tianhongdan', 'Jingpitian', 'Sanbaitian', 'Suanshiliu'	'Jingpitian' exhibited higher punicic acid 'Suanshiliu' showed higher MUFA and lower PUFA.	Jing et al. (2012)
	'Akko', 'Radisa', 'Hershkovitz', 'Valenciana', 'Ravenna', 'Veneti', 'Hijaz', 'Shiraz', 'Dent di Cavallo', 'Mollar (1)', 'Mollar (2)', 'Wonderful 1', 'Wonderful', 'G (1)', 'G (2)', 'Ecotipo (1)', 'Ecotipo (2)'.	'Akko' exhibited higher MUFA and MUFA/PUFA ratio. 'Valenciana' exhibited higher PUFA and punicic acid.	Verardo et al. (2014)
	'Mollar de Elche', 'Valenciana', 'White', 'CG8', 'Cis 127', 'Katirbasi', 'Parfianka', 'Wonderful 1', 'Wonderful 2'.	'Katirbasi' exhibited higher MUFA.	Fernandes et al. (2015)
	'Valenciana 1',' Mollar de Elche 16,' Mollae de Albatera 2', 'Pinon Tiernode Ojos 8', 'Borde de Albatera 1'	SFA was lower in 'Borde de Albatera 1' and higher in 'Pinon Tiernode Ojos 8'. 'Mollar de Elche 16' and 'Mollae de Albatera 2' were lower and higher in UFA respectively. 'Borde de Albatera 1' exhibited higher punicic acid.	Hernández et al. (2011)
	'Mathura alandi pomegranate', 'Agra khandari pomegranate', 'Delhi muscat red pomegranate', 'Lucknow muscat white pomegranate', 'Jhansi bedara pomegranate', 'Kanpur dholka pomegranate'.	'Delhi muscat red pomegranate' and 'Jhansi bedara pomegranate' exhibited lower and higher SFA respectively. MUFA was higher in 'Lucknow muscat white pomegranate' and lower in 'Kanpur dholka pomegranate'. PUFA was lower in 'Mathura alandi pomegranate' and higher in 'Kanpur dholka pomegranate'. 'Delhi muscat red pomegranate' exhibited higher UFA.	Parashar (2010)
Kiwi	'Qinmei', 'Yate', 'Xuxiang', 'Haywai', 'Hort 16A', 'Huayon', 'Hongyang', 'Kuilv'	'Yate' exhibited higher UFA and linoleic acid Higher ratio of n-6/n-3 was shown by 'Haywai'.	Deng et al. (2018)
Sweet cherry	'Bryanskaya Rozovaya', 'Gårdebo', 'Iedzenu Dzeltenais', 'Krupnoplodnaya', 'Lapins', 'Tyutchevka', 'Vytenu Juodoji'	'Bryanskaya Rozovay' showed higher oleic acid and UFA/SFA ratio. 'Krupnoplodnaya' exhibited higher PUFA	Górnaś et al. (2016a)

UFA: Unsaturated fatty acids, SFA: Saturated fatty acids, PUFA: Polyunsaturated fatty acids, MUFA: Monounsaturated fatty acids, n-6/n-3 is the ratio of C18: 3n-6 to C18: 2n-3 fatty acids.

Table 2. The effect of fruit type and cultivar on seed oil tocopherols and polyphenols.

Bioactive compound	Type of fruit seed oil	Cultivar	Key finding	Reference
Polyphenol	Lemon	'Feiminailao', 'Cuningmeng', 'Beijingningmeng', 'Pangdelusaningmeng', 'Limeng'	Feiminailao' and 'Cuningmeng' lemon exhibited higher total phenols than the rest of the cultivars. The individual phenolic compounds varied among the cultivars.	Xi et al. (2017)
	Fig	'White Adriatic', 'Bourjassote Noir',C7A14, C11A21	Total phenolic content was significantly higher and lower in 'White Adriatic' and 'Bourjassote Noir', respectively.	Hssaini et al. (2020)
	Pomegranate	'Suanshiliu', 'Jingpitian', 'Tianhongdan', 'Sabaitian'	'Suanshiliu' exhibited higher total phenolics, total flavonoids and proanthocyanidins	Jing et al. (2012)
	Grape	'Viognier', 'Sangiovese', 'Cabernet Sauvignon', 'French Colombard', 'Sauvignon blanc', 'Riesling', 'Chenin blanc', 'Pinot noir', 'Merlot', 'Petite Sirah Org' 'Merlot Org', 'Cabernet Sauvignon Org', 'Zinfandel', 'Chardonnay', Sirah'	'Merlot Org'was significantly higher in total phenolic content and individual phenolic compounds.	Cecchia et al. (2019)
		'Blatina', 'Cabernet', 'Merlot', 'Muscat Hamburg', 'Vranac'	'Blatina' (693.33 mg GAE/kg) and 'Merlot' (502.08 mg GAE/kg) showed the highest and lowest total phenolic content, respectively.	Banjanin et al. (2019)
	Apricot	'Early Orange', 'Goldrich Sungiant', 'Harcot', 'Hargrand', 'Somo'.	Totat phenolic content signifcantly varied among the cultivars	Stryjecka et al. (2019)
Tocopherol	Pomegranate	'Suanshiliu', 'Jingpitian', 'Tianhongdan', 'Sabaitian'	Considerable variation in individual tocopherols such as δ-tocopherol, γ-tocopherol and α-tocopherol was reported among the cultivars	Jing et al. (2012)
	Grape	'Alphonse', 'Lavallee', 'Early Cardinal', 'Muscat of Hamburg', 'Muscat of Alexandria', 'Razaki', 'Trakya ilkeren', 'Yalova incisi', 'Cabernet Sauvignon', 'Carignane', 'Chardonna'y, 'Kalecik karasi', 'Monte Puliciano', 'Semillon', 'Shiraz', 'Isabella'	Early Cardinal', 'Razaki', 'Trakya ilkeren', 'Yalova incisi', 'Muscat of Hamburg', 'Alphonse' and 'Monte Puliciano' exhibited higher α-tocopherols.	Tangolar et al. (2011)
		'Chardonnay', 'Merlot', 'Carbernet Sauvignon', 'V. davidii', 'V. amurensis'	Total tocotrienols were significantly higher in 'Vitis amurensis'	Wen et al. (2016)
		'Blatina', 'Cabernet', 'Merlot', 'Muscat Hamburg', 'Vranac'	'Merlot' and 'Blatina'were the best cultivars for γ and β-tocopherols, respectively	Banjanin et al. (2019)
	Orange	'Hamlin', 'Natal', 'Perario', 'Valencia'	'Pera-rio' exhibited the best total phenolic content.	Jorge et al. (2016)
	Avocado	'Merah bundar', 'Ijo bundar', 'Ijo panjang'	'Merah bundar' and 'Ijo bundar' showed higher γ and α-tocopherols, respectively	Manaf et al. (2018)

GAE = gallic acid equivalence.

Table 3. The effect of fruit type and cultivar on seed oil antioxidant activity.

Type of fruit seed oil	Cultivar	Key finding	Reference
Apple	'Gale Gala', 'Starking', 'Honeycrisp', 'Fuji', 'Qinguan', 'Golden Delicious', 'Qinyang'	'Honeycrisp' exhibited higher antioxidant capacity	Xu et al. (2016)
Date	'Boufgous', 'Bousthammi', 'Majhoul'	Higher FRAP (22.86 mmol TE/100 g DW) and ABTS radical scavenging capacity (8.02 (mmol TE/100 g DW) was manifested in oil from 'Bousthammi'. 'Boufgous'showed better DPPH radical scavenging capacity (0.17 g/L)	Bouhlali et al. (2015)
Apricot	'Early Orange', 'Goldrich Sungiant', 'Harcot', 'Hargrand', 'Somo'.	FRAP varied from 1.07 ('Early Orange') to 1.38 mM Fe^{2+}/L ('Somo')	Stryjecka et al. (2019)
Fig	'White Adriatic', 'Bourjassote Noir', C7A14, C11A21	'White Adriatic' and 'Bourjassote Noir' were reported the best in ABTS and DPPH radicals scavenging capacity	Hssaini et al. (2020)
Cactus pear	'Nepgen', 'Morado', 'Ofer', 'Gymno-Carpo', 'Meyers', 'Sicilian', 'Nudosa', 'Robusta'	DPPH radical scavenging capacity varied among the cultivars	De Wit et al. (2017)
Grape	'Merlot', 'Syrah', 'Sangiovese', 'Muscat d'Alexandrie', 'Razagui', 'Razaki', 'Khamri', 'Marsaoui', 'Cargnan'	'Carignan' and 'Muscat d'Alexandrie' and were higher in DPPH radical scavenging capacity (IC_{50}: 30.97 µg/g) and chelating ability (IC_{50}: 8.96 µg/g) and Reducing power (IC_{50}: 23.20 µg/g), respectively.	Harbeoui et al. (2017)
	'Blatina', 'Cabernet', 'Merlot', 'Muscat Hamburg', 'Vranac'	'Cabernet' and 'Muscat Hamburg' showed the best and least antioxidant activity, respectively	Banjanin et al. (2019)
	'Barbera', 'Chardonnay', 'Muller Thurgau', 'Muscat', 'Nebbiolo', 'Pinot Noir'	'Pinot Noir' had better hydrophilic antioxidant activity (1.73 mmol Trolox/g), whilst 'Barbera' showed greater lipophilic antioxidant activity (8.2 mmol Trolox/g)	Mohamed et al. (2016)
Pomegranate	'Tunisia soft', 'Taishanhong', 'Qingpiruanzi'	Greater DPPH radical scavenging capacity and FRAP were shown by Tunisia soft' and 'Qingpiruanzi', respectively	Peng (2019)
Lemon	'Feiminailao', 'Beijignningmeng', 'Pangdelusaningmeng', 'Limeng', 'Cuningmeng' (CN)	Greater antioxidant capacities (DPPH radical scavenging capacity: 4.01%), (ABTS radical scavenging capacity:11.97 mM) and (FRAP: 3.40 mM) were exhibited by 'Feiminailao'	Xi et al. (2017)
Orange	'Hamli', 'Natal', 'Pera-rio', 'Valencia'	Best DPPH radical scavenging capacity was exhibited by 'Pera-rio'.	Jorge et al. (2016)
Passion	'Passiflora alata BRS Doce Mel', 'Passiflora alata BRS Mel do Cerrado', 'Passiflora edulis BRS Gigante Amarelo', 'Passiflora edulis BRS Sol do Cerrado', 'Passiflora tenuifila VI', 'Passiflora setacea BRS P'erola do Cerrado'	'Passiflora setacea BRS P'erola do' Cerrado also showed higher antioxidant activity.	De Santana et al. (2015)

DPPH = 2, 2-diphenyl-1-picryl hydrazyl, FRAP = Ferric reducing antioxidant power, ABTS = 2, 2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid, TE = trolox equivalence.

Table 4. The effect of fruit type and seeds pretreatment technique on oil yield.

Type of fruit seed oil	Pretreatment technique	Key finding	Reference
Grape	Enzymatic pretreatment C₁: (pectinase = 569, cellulase = 29, xylanase = 21, protease = 1191U/g sample) C₂: (pectinase = 1708, cellulase = 72, xylanase = 55, protease = 2977 U/g sample.	Enzymatic pretreatment at concentration: C_1, temperature: 40 °C, pH: 4 and extraction time of 120 h enhanced oil yield.	Passos et al. (2009)
Pomegranate	Microwave pretreatment at a frequency of 2450 MHz for 2 and 6 min, power (100, 250, 600 W) and temperature (63–136 °C)	Microwave pretreatment at 600 W for 6 min increased oil yield by 31 %.	Durdevic et al. (2017)
Palm	Microwave pretreatment (1000 W, 2450 MHz, 5, 10, 12, 13, 14, 15 min)	Microwave pretreatment at 120 °C for 15 min increased oil yield by 242 %.	Tan et al. (2016)
	Ohmic pretreatment (60–100 °C,0–150 V, 2–10 min)	Maximum oil yield (46 %) was obtained by ohmic heating with 150 V at 100 °C for 8 min.	Pootao and Kanjanapongkul (2016)
Orange	Microwave roasting (360 W, 30 min)	Microwave pretreatment increased oil yield by 19 %.	Guneser and Yilmaz (2017)
Apricot	Ultrasonic pretreatment (42 kHz, 2.5, 10, 15 min)	Oil yield increased by approx. 19–22 %.	Sharma and Gupta (2006)
Mango	Microwaving pretreatment (110 W, 150 s)	Microwave pretreatment improved oil yield from 5.20 to 9.35 %.	Kittiphoom and Sutasinee (2015)
Custard apple	Ultrasonic pretreatment (40 kHz, 30 W, 150 s)	Ultrasonic pretreatment improved oil yield by 2.53 %.	Panadare et al. (2020)

pomegranate exhibited higher δ-tocopherol (3513.19 μg/g) and α-tocopherol (1388.34 μg/g), whilst 'Tianghongdan' pomegranate was lower in the respective compounds (1414.42; 718.70 μg/g). The relatively minor γ-tocopherol was higher and lower in 'Sanbaitian' (54.91 μg/g) and 'Jingpitian' pomegranate (34.15 μg/g), respectively.

Tangolar et al. (2011) reported that among the fifteen grape cultivars studied, seed oil from 'Trakya ilkeren' (25.86 mg/kg) and 'Semillon' (6.05 mg/kg) exhibited higher and lower total tocopherols, respectively. 'Yalova incisi' grape exhibited higher γ-tocopherol (17.90 mg/kg) whereas 'Chardonnay' had lower γ-tocopherol (0.46 mg/kg). Significantly higher α-tocopherol was shown by 'Trakya ilkeren' grape (24.32 mg/kg) and lower α-tocopherol by 'Semillon' (4.69 mg/kg). The δ-tocopherol was higher in 'Yalova incisi' (8.51 mg/kg) and lower 'Alphonse Lavallee' (0.15 mg/kg), while β-tocopherol was only identified in 'Kalecik karası' grape (0.97 mg/kg) affirming the importance of cultivar consideration in seed oil processing.

Tocotrienols possess stronger neuroprotective, anticancer and cholesterol lowering properties than tocopherols (Sen et al., 2006). According to Wen et al. (2016), total tocotrienols (679.24 mg/kg), δ-tocotrienols (18.31 mg/kg), β-tocotrienols (7.66 mg/kg), and α-tocotrienols (521.11 mg/kg) were higher in 'Vitis amurensis' grape, while 'Chardonnay' grape exhibited lower total tocotrienols (320.08 mg/kg), γ-tocotrienols (128.87 mg/kg) and α-tocotrienols (177.77 mg/kg), despite containing a 2-fold total phenolic content than the other cultivars. Other examples, including differences in tocopherol and phenolic content in seed oil of avocado, fig and apricot cultivars are reported in Table 2.

2.1.3. Phytosterols

Apart from being valuable in the detection of seed oil adulteration, phytosterols have also been considered as cholesterol-reducing agents in the human body, and thus help reduce atherosclerotic risks (Kritchevsky and Chen, 2005). The impact of cultivar on seed oil phytosterols was demonstrated on five grape cultivars (Wen et al., 2016). 'Carbernet Sauvignon' grape exhibited higher (338.83 mg/100 g) total phytosterols, while 'Chardonnay' showed the lowest amount (277.99 mg/100 g). The two major phytosterols in grape seed oil, β-sitosterol (230.64 mg/100 g) and stigmasterol (47.92; 40.90 mg/100 g) were significantly higher in 'Carbernet Sauvignon' grape. The respective phytosterols were lower in 'Vitis amurensis' (146.77 mg/100 g) and Vitis davidii (30.14 mg/100 g). Campesterol varied from 20.23 to 30.40 mg/100 g with 'Chardonnay' and 'Carbernet Sauvignon' exhibiting the least and best concentrations, respectively.

Górnaś et al. (2016c) evaluated the effect of cultivar on phytosterols of seed oil from pears. It was found that seed oil from 'Beurre d' Amanlis' (600.10 mg/100 g) was the best with respect to total phytosterols. The individual phytosterols including campesterol (29.70 mg/100 g), β-sitosterol (500.70 mg/100 g), Δ5-avenasterol (20.60 mg/100 g), cholesterol (26.40 mg/100 g) and Δ7-stigmasterol (15.80 mg/100 g) were also higher in 'Beurre d' Amanlis'. Cultivars such as 'Petrilas nr.49', 'Survenirs', 'Conference' and Mramornaja' were more than 2 fold lower in the respective compounds. Gramisterol and Citrostadienol the minor sterols identified in pear cultivars were comparatively higher in 'Suvenirs' (7.80 mg/100 g) and 'Beurre d' Amanlis' (3.80 mg/100 g), respectively. The authors concluded that cultivar had a significant impact on the seed oil phytosterols.

'Tamaris' was the best in total phytosterols (1041.00 mg/100 g) campesterol (41.60 mg/100 g), β-sitosterol (852.80 mg/100 g), Δ5-avenasterol (78.20 mg/100 g), gramisterol (12.50 mg/100 g), Δ7-stigmasterol (11.20 mg/100 g), Δ7-avenasterol (6.40 mg/100 g) and citrostadienol (5.50 mg/100 g) amongst the six sour cherry cultivars studied (Górnaś et al., 2016a). Campesterol was 5.5 times lower, β-sitosterol (3.5 times), gramisterol (5.2 times), Δ7-stigmasterol (9.3 times) and Δ7-avenasterol (4 times) in 'Shokoladnica' (lowest) than 'Tamaris' sour cherry (highest). Other phytosterols identified in the sour cherry seed oils were cholesterol, 24-methylene-cycloartanol, and

Table 5. The effect of fruit type and seeds drying on the oil antioxidant activity.

Type of fruit seed oil	Drying technique	Key finding	Reference
Mango	Freeze drying (condenser temperature: -40 °C, vacuum pressure: 50 mPa), Oven drying (70 °C) with forced or static air	Higher DPPH and ABTS radicals scavenging capacity was exhibited by extracts from freeze drying and oven drying with static air	Dorta et al. (2012)
Avocado	Air drying with a tray drier (45–75 °C, 0.80–1.60 m/s, 1–3 kg/m²)	Optimum antioxidant activity was reported on extracts from seeds dried at 60 °C, 1.20 m/s and loading density of 2 kg/m²	Saavedra et al. (2017)
Papaya	Air drying (room temperature), freeze drying (72 h), oven drying (50 °C, 48 h), sun drying (3 days)	Oil extracts from freeze dried seeds showed higher TEAC (56.54 µMTE/g) and FRAP (150.01 µg GAE/g)	Irondi et al. (2013)
	Microwave vacuum drying (100 mbar, 100, 300, 450 and 600 W)	Microwave drying papaya seeds at 600 W produced oil with higher TEAC (0.15 mg TE/g DW)	Bualuang et al. (2018)
Kinnow mandarin, eureka lemon and orlendo orange	Oven drying (60, 70 and 80 °C for 24 h).	Best DPPH radical scavending capacity was exhibited by oil extracts from seeds dried at 60 °C	Al Juhaimi et al. (2018)
Grape	Air drying with tray drier (40 °C, 50 °C and 60 °C, 0.42 m/s and 1.5 cm thick)	Increasing the drying temperature reduced the oil extracts TEAC.	Teles et al. (2018)

DPPH = 2, 2-diphenyl-1-picryl hydrazyl, FRAP = Ferric reducing antioxidant power, ABTS = 2, 2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid, TEAC = Trolox equivalent antioxidant capacity, GAE = gallic acid equivalence, TE = trolox equivalence.

24-methylene-cycloartanol, which also varied among the cultivars. The findings were comparable to results from their previous study on seed oil from eleven apple cultivars (Górnaś et al., 2014). The study established that the most desirable cultivar with regards to phytosterols was 'Beforest' apple.

Verardo et al. (2014) reported a 120 % difference in total phytosterols between the lowest and highest cultivars among the seventeen pomegranate cultivars studied. 'Wonderful 1' pomegranate was the best cultivar as it was consistently high in total phytosterols (16.42 mg/g) and the individual phytosterols such as 'campesterol' (1.20 mg/g) 'stigmasterol' (0.57 mg/g) 'sitosterol' (11.42 mg/g) 'Δ5-avenasterol' (2.42 mg/g) and 'citrostadienol' (0.80 mg/g). Significant effect of cultivar on seed oil phytosterols was also reported by De Santana et al. (2015) and Jorge et al. (2016) from passion and orange fruits, respectively.

2.1.4. Carotenoids

Carotenoids are important compounds, which determines seed oil colour due to numerous conjugated double bonds. Nutritionally, carotenoids act as precursors for vitamin A synthesis (Aruna et al., 2016). The variation of seed oil colour with cultivar suggests that cultivar is an invaluable factor in the seed oil processing industry. Overall, fruit seed oils have a low concentration of carotenoids. Therefore these valuable compounds can be improved by selecting and producing cultivars with a higher content of seed oil carotenoids. Total carotenoids concentration in seed oil from fifteen apricot cultivars ranged between 0.15 mg/100 g ('Rasa') and 0.53 mg/100 g oil ('Veselka') (Górnaś et al., 2017). In a research conducted by De Santana et al. (2015) on seed oil from seven passion cultivars, total carotenoids significantly varied from 50.87 mg β-carotene equivalence/100 g ('Passiflora alata BRS Doce Mel') (βCE) to 115.44 mg βCE/100 g ('Passiflora setacea BRS P'erola do Cerrado'). Similarly, Górnaś et al. (2016a) confirmed that cultivar significantly affects the seed oil carotenoids. In their study, total carotenoids were higher in seed oil from 'Tamaris' (1.75 mg βCE/100 g) and lower in seed oil from 'Haritonovskaya' (0.51 mg βCE/100 g) of the seven sour cherry cultivars studied. These findings were supported by the results reported in the study of Górnaś et al. (2016b) from the seed oil of seven sweet cherry cultivars.

2.1.5. Antioxidant activity

Antioxidant activity is a good example of a functional benefit that plant extracts can provide. Cultivars with higher antioxidant properties are desirable to seed oil processors and consumers. The effect of cultivar on seed oil antioxidant activity has been studied (Table 3). For example, Xu et al. (2016) reported that seed oil from 'Honeycrisp' exhibited higher antioxidant activity among the five different apple cultivars studied. Differences in seed oil antioxidant activity was also reported among pomegranate cultivars (Peng, 2019). The authors observed that greater DPPH (8.61 µmol TE/g) and ABTS (2.53 µmol TE/g) radical scavenging capacity were shown by seed oil from 'Tunisia soft' and 'Qingpiruanzi', respectively. On the contrary, the oil from 'Qingpiruanzi' exhibited lower ferric, reducing antioxidant power (FRAP) (2.21 µmol TE/g) indicating that the antioxidant assay might also influence the experiment result. Hssaini et al. (2020) established that antioxidant activity varied among the seed oil from fig cultivars with 'White Adriatic' and 'Bourjassote Noir' showing the best ABTS and DPPH radicals scavenging capacity. Moreover, Bouhlali et al. (2015), Harbeoui et al. (2017) and Stryjecka et al. (2019) reported similar findings from seed oil extracted from different grape, date and apricot cultivars, respectively (Table 3). In this respect, it is evident that cultivar significantly affected the seed oil antioxidant activity mainly due to variation in genetic characteristics.

2.1.6. Oxidative stability

The stability against oxidation is one of the major factors to be considered in the industrial application of edible fruit seed oil. Seed oil oxidative stability, defined as the resistance to oxidation during processing and storage may be assessed using several oxidation indices,

Table 6. The effect of fruit type and oil extraction technique on fatty acids.

Type of fruit seed oil	Oil extraction technique	Key finding	Reference
Pomegranate	Aqueous extraction (AE), cold pressing (CP), hot pressing (HP), solvent extraction (hexane) (SHE)	Higher punicic acid was exhibited by AE oil. SE and AE exhibited higher MUFA and UFA/SFA ratio. Lower SFA and PUFA were shown by AE and CP oil respectively.	Ghorbanzadeh and Rezaei (2017)
	Cold pressing (CP), solvent (hexane) (SHE) extraction	CP oil exhibited higher MUFA, punicic acid and SFA. SE oil exhibited lower PUFA.	Akbari et al. (2015)
	Subcritical propane: SC-P) extraction, supercritical CO_2 extraction (SC–CO_2)	Higher oleic acid was obtained with SC-CO_2 extraction (pressure: 20 MPa, temperature: 39.9 °C). Higher punicic acid was shown by SC-P extraction (pressure: 12 MPa, temp: 59.9 °C).	Ahangari and Sargolzaei (2012)
	Solvent extraction (hexane) (SHE), super critical fluid extraction (SFE), ultrasonic-assisted extraction (UAE)	UAE oil exhibited higher palmitic acid and punicic acid. SHE oil showed higher stearic acid, oleic acid and linoleic acid.	Tian et al. (2013)
Kiwi	Solvent extraction (SHE), compressed propane	SHE exhibited higher linolenic acid. Oleic acid and linoleic acid were higher in compressed propane extracted oil.	Coelho et al. (2016)
	Solvent extraction (hexane) (SHE), microwave (MW), super critical carbon dioxide (SC–CO_2), ultrasonic (US), microwave integrated solvent extraction (MIS)	MUFA, SFA and MUFA/PUFA ratio were higher in SE oil. US oil exhibited higher PUFA.	Cravotto et al. (2011)
Bilberry	Super critical CO_2 extraction (SC–CO_2)	No significant variation in fatty acids.	Gustinelli et al. (2018)
Bayberry	Super critical CO_2 (SC–CO_2), solvent (hexane) extraction (SE)	The fatty acids were not considerably different.	Xia et al. (2013)
Raspberry	Ultrasonic-assisted extraction (UAE), solvent extraction (SE)	Higher stearic acid and SFA were shown by SE oil. Higher linolenic acid, linoleic acid and PUFA were exhibited by UAE oil.	Teng et al. (2016)
Sea buckthorn seed	Solvent (hexane) extraction (SHE), Ultrasonic-assisted extraction (UAE), Microwave assisted extraction (MAE)	Extraction technique did not significantly affect the oil fatty acid content.	Isopencu et al. (2019)
Apricot	Cold pressing (CP), hot pressing (HP)	No considerable variation in fatty acid was reported	Zhou et al. (2016)

UFA: Unsaturated fatty acids, SFA: Saturated fatty acids, MUFA: Monounsaturated fatty acids, PUFA: Polyunsaturated fatty acids, SC-CO_2: Super critical carbon dioxide.

which include peroxide value, free fatty acids, acid value, anisidine value and induction period. Fruit seed oils vary greatly in their stability to oxidation due to dissimilarities in chemical composition, which differs with cultivar. Galvão et al. (2014) reported that peroxide value (PV) and acid value (AV) significantly varied among three avocado cultivars ('Fortuna', 'Collinson' and 'Barker'). The authors observed that lower AV (1.19 g/100 g) and PV (1.22 meqO$_2$/kg) were exhibited by 'Barker', while the same oxidation indices were higher in 'Collison' (2.23 g/100 g) and 'Fortuna' (1.41 meqO$_2$/kg), respectively. In a related study, Sicari et al. (2017) reported similar findings from the seed oil of bergamot cultivars ('Castagnaro', 'Ferminello' and 'Fantastico'). The highest variations in PV and AV among the cultivars were 44 and 23 %, respectively. The presence of stronger antioxidant compounds in seed oil may delay or prevent the oxidation of fatty acids. Deng et al. (2018) found out that seed oil from 'Hongyang' and 'Haywa' kiwi (14.15 and 10.77 meqO$_2$/kg, respectively) were more susceptible to oxidative degradation, whilst 'Huayou' (7.23 meqO$_2$/kg) kiwi showed the most stable oil for PV. The finding that 'Huayou' exhibited lower PV could be attributed to the higher antioxidant activity reported from the same cultivar. The variation of seed oil oxidation indices with cultivar is also reported in the studies of Jin et al. (2016), Nehdi et al. (2018) and De Wit et al. (2017) from mango, date palm and cactus pear seeds. However, Bouhlali et al. (2015) established no significant differences in the PV and AV of seed oil from three Moroccan date cultivars ('Boufgous', 'Bousthammi' and 'Majhoul').

2.2. Fruit growing region

Soil type, cultural practices and climatic conditions are important factors in plant growth, and as such, variation in seed oil quality attributes can result from plant growing region. The seed oil-bearing plant genetic characteristics may differ as the plant adapts to the existing environmental conditions. Influence of fruit growing region on the seed oil nutritional qualities and functional properties can be utilized to establish a differentiation of seed oil according to their origin and strategically market the oil.

2.2.1. Fatty acids

Based on the growing region, the fruit-bearing plants are subjected to varied horticultural practices, climatic and soil conditions, which could affect the fatty acids biosynthesis (Deng and Scarth, 1998). De Wit et al. (2016) study on cactus pear seed oil from South Africa suggested that fruit growing region had minimal effect on the fatty acid composition. Cactus pear seed oil from Cradock was higher in palmitic acid (14.24 %), while oil from Oudtshoorn (14.07 %) was lower in the respective fatty acid. Oleic acid, the main monounsaturated fatty acid in cactus seed oil varied from 19.55 % (Cradock) to 19.90 % (Bloemfontein). Also, Oudtshoorn and Cradock cactus seed oil had higher and lower stearic acid content, respectively. Minor fatty acids including eicosenoic acid, heptadecanoic acid, behenic acid, eicosanoic acid and eicosatrienoic acid were not affected by the fruit growing region.

Bada et al. (2015) assessed the fatty acid composition of grape seed oil from different geographical locations in Spain and reported varied results among the various locations. Oil from Mencia was significantly lower in palmitic acid (5.48 %) than the oil from the rest of the regions. Valencia (5.61 %) and Cangas (4.64 %) oil contained higher stearic acid. Linoleic acid, the major fatty acid in grape seed oil was significantly lower in oil from Valencia (68.67 %), while oil from the other regions showed relatively similar amounts of linoleic acid (71.40–75.70 %). On the other hand, the oils from the different regions showed no significant variation for oleic, palmitoleic and gadoleic acid. The effect fruit growing region on seed oil fatty acid composition was also evaluated on prickly pear grown in different locations in Turkey (Belviranli et al., 2018). It was

observed that the oils from Fethiye, Anamur and Iskenderun had the highest content of linoleic acid (63.38 %), oleic acid (15.46 %) and palmitic acid (11.777 %), respectively. Other fatty acids, including stearic, myristic, arachidic, linolenic and behenic acid did not significantly differ among the studied locations.

2.2.2. Tocopherols, phytosterols and polyphenols

Bada et al. (2015) observed significant variation in tocopherols of seed oil from grapes grown in five different areas in Spain. Seed oil from grapes grown in Cangas exhibited higher β-tocopherol (0.10 mg/100g), while seed oil from Ribera grapes (0.03 mg/100g) was lower in the same type of tocopherol. According to the study, seed oil from grapes grown in Toro and Cangas had higher α-tocopherol the most potent antioxidant (3.69–3.82 mg/100 g), suggesting that the oils might have better antioxidant properties.

It was also observed that campesterol, β-sitosterol and stigmasterol were the major phytosterols and significantly higher in grape seed oil from Valencia (11.01; 74.15 mg/100g) and Ribera (17.65 mg/100g). The β-sitosterol has been associated with lowering the low density lipoprotein (LDL) cholesterol levels and therefore oil from Valencia might be valuable in food fortification. The oil from Ribera was also consistently higher in minor phytosterols such as sitostanol (0.72 mg/100g), Δ5-avenasterol (1.77 mg/100g) and Δ5, 24 stigmastadienol (0.48 mg/100g). On the contrary, Valencia oil was lower in Δ5-avenasterol (0.56 mg/100g), Δ5, 24 stigmastadienol (0.48 mg/100g) and Δ7-stigmastenol (1.53 mg/100g). Cholesterol varied from 0.15 mg/100g (Cangas) to 0.34 mg/100g (Ribera). The significant variation in tocopherols and phytosterols among the oils from the five different regions in Spain could be attributed to differences in cultural practises climatic and soil conditions of the grapefruit grown areas. In their Cossignani et al. (2017) established that goji berry seed oil from Mongolia was higher in β-sitosterol, cholesterol, stigmasterol, ergosterol and Δ5-avenasterol than oil from China and Italy, confirming the value of geographical origin in determining seed oil bioactive compounds.

Inan et al. (2017) studied the phenolic compounds of seed oil from mandarins, oranges and lemons grown in different regions of Turkey. The authors observed that seed oil of oranges and mandarins from Adana (88.66 and 91.36 mg GAE/kg seed, respectively) exhibited the highest total phenolic content, while the seed oil of oranges and mandarins from Mersin (75.37 and 46.63 mg GAE/kg seed, respectively) showed the least amount of total phenolic content. At the same time, the total phenolic content of lemon seed oil did not significantly differ among the locations. The authors concluded that fruit growing region considerably influenced the tocopherols, phytosterols and polyphenols, which are implicated in the antioxidant activity of the oils.

2.2.3. Antioxidant activity

The effect of fruit growing region on seed oil antioxidant activity was studied on mandarins, oranges and lemons grown in different regions of Turkey (Inan et al., 2017). It was established that the seed oil of mandarins and oranges from Antalya (IC$_{50}$: 0.65) and Adana (IC$_{50}$:0.61) exhibited significantly higher DPPH radical scavenging capacity. The DPPH radical scavenging capacity of lemon seed oil did not significantly vary among the growing regions. Altitude is one of the important factors that can influence the growth of the seed bearing plants and the seed oil antioxidant activity. In the study of Coklar (2017), the seed oil from grapes grown in higher altitude area of Hadim, Konya in Turkey showed higher ABTS radical scavenging capacity (293.88 mmol TE/kg DW) and ferric reducing capacity (1.272.50 μmol Fe^{2+}/g DW) as compared to the oil extracts of grape seeds from lower altitude (235.76 mmol TE/kg DW and 888.19 μmol Fe^{2+}/g DW, respectively). The findings affirm that fruit growing region is one of the major factors to be considered in value addition of fruit processing waste such as seeds.

3. Processing factors affecting quality attributes of edible fruit seed oil

3.1. Effect of seeds pretreatment on oil yield

Seed oil extraction techniques are faced with a number of limitations. Besides health, environmental and economic related issues, seed oil extraction techniques are associated with low oil and bioactive compounds recovery. Treatment of the oil-bearing seed prior to oil extraction has been reported to increase oil yield and bioactive compounds recovery and even the formation of new functional compounds (Passos et al., 2009; Zhang and Jin, 2011; Da Porto et al., 2016). Efficiency is a key element to ensure profitability in the production of seed oils (Mcdowell et al., 2017). Literature showing the effect of seeds pretreatment on oil yield has been summarised in Table 4.

Enzymatic pretreatment of grape seeds at concentration (pectinase = 569, cellulase = 29, xylanase = 21, protease = 1191 U/g sample), temperature (40 °C), pH (4) and extraction time of 24 hours increased oil yield by 3 fold (Passos et al., 2009). By virtue of enzymatic hydrolysis being a slow process, the authors emphasized on increasing time of hydrolysis. The enzymatic hydrolysis of the oil-bearing seeds decreases the integrity of plant tissues and increase their permeability to oil (Grasso et al., 2012).

Sharma and Gupta (2006) demonstrated that seeds ultrasound treatment can be valuable in improving oil yield. In their study, ultrasonic pretreatment (42 kHz, 2.5, 10, 15 min) of apricot seeds enhanced oil yield by approximately 19–22 % with enzymatic aqueous extraction. Ultrasonic irradiation increased the seed cell walls porosity, which improved the enzymes accessibility to the oil bodies. Kittiphoom and Sutasinee (2015) concluded that microwave pretreatment of mango seeds had a significant effect on yield. Furthermore, Durdevic et al. (2017) observed that microwave irradiation of pomegranate seeds at 600 W for 6 min before solvent extraction increased oil yield by 31 %. The improvement in oil yield was attributed to the rapture of the oilseeds cell walls due to intense intracellular pressure created by the conversion of electromagnetic energy to heat energy (Gaber et al., 2018). Improvement in oil yield after pretreatment of orange, palm, custard apple and mango seeds has also been reported (Table 4).

3.2. Effect of seeds drying

Drying involves heat and mass transfer and therefore may lead to alterations in the chemical properties of the product. Seeds drying is an indispensable step in seed oil processing and therefore the choice of seeds drying technique should minimize nutritional quality and antioxidant compounds losses in the oil.

3.2.1. Fatty acids

The imbalance between dietary cholesterol and fats has been identified as the primary cause of atherosclerosis and cardiovascular disease (Orsavova et al., 2015). Consumption of polyunsaturated fatty acids, particularly the omega 3 and 6 is strongly recommended because they reduce the absorption of cholesterol by the body (Xu et al., 2018). In line with this, seeds drying techniques, which minimize the degradation of these essential fatty acids are important to preserve the nutritional quality of the oil.

Radocaj et al. (2014) evaluated the effect of room temperature (22 °C for 72 h) and oven drying (63 °C for 20 h and 103 °C for 2 h) on blackberry and raspberry seeds. While drying decreased the concentration of unsaturated fatty acids such oleic acid, linoleic acid and linolenic acid, it did not significantly affect the level of myristic acid, palmitic acid and heptadecanoic acid in both blackberry and raspberry oil extracts. Comparing the two drying methods, oven dried seeds produced oil extracts higher in oleic acid, linoleic acid and linolenic acid, but lower omega 6 to omega 3 fatty acids ratio than room temperature dried seeds indicating that the oil extracts from oven dried seeds possessed better

nutritional qualities. A lower ratio of omega-6/omega-3 fatty acids is more desirable in reducing the risk of chronic diseases such as heart disease, cancer and diabetes.

In another research conducted by Al Juhaimi et al. (2018), increasing the kinnow marandin seeds drying temperature from 60 to 80 °C enhanced palmitic acid and stearic acid between 18 and 49 %. At the same time, it decreased oleic acid, linoleic acid and arachidic acid between 0.2 to 13 % confirming that polyunsaturated fatty acids are more susceptible to thermal degradation than saturated fatty acids. The same phenomenon was observed with oil extracts from orlendo orange and eureka lemon seeds, which showed an increase and decrease in saturated and unsaturated fatty acids, respectively, with an increase in the seeds drying temperature.

3.2.2. Tocopherols, phytosterols and polyphenols

By virtue of tocopherols being thermolabile bioactive compounds, varied results on the effect of seeds drying techniques on these antioxidant compounds have been reported. For instance, Hassini et al. (2018) studied the effect of convective vertical downward flow drying of cactus pear seeds and found out that increasing drying temperature, relative humidity and air velocity significantly reduced α-tocopherol concentration. A higher concentration of α-tocopherol was obtained by drying cactus pear seeds at 45 °C, 15 % RH and 1 m/s air velocity. Increasing the drying temperature to 70 °C, RH to 30 % and air velocity to 2 m/s reduced the α-tocopherol concentration by 3 fold. Radocaj et al. (2014) reported that oven drying blackberry seeds significantly increased α-tocopherol, δ-tocopherol and total tocopherols by 4, 10 and 6 %, respectively when compared with room temperature drying.

Al Juhaimi et al. (2018) concluded that drying temperature had a significant effect on the concentration of tocopherols in kinnow marandin, orlendo orange and eureka lemon seed oil. However, minimum losses on α-tocopherol in kinnow marandin oil (5 %), eureka lemon oil (13 %) and orlendo orange oil (2 %) were observed from seeds oven dried at 60 °C. In contrast, lowest losses of γ-tocopherol (2 %) in eureka lemon oil were reported from seeds oven dried at 70 °C. Unlike eureka lemon, oven drying kinnow marandin at 60 °C slightly increased γ-tocopherol from by 4 %. Likewise, increasing drying temperature significantly reduced the concentration of tocopherols in kinnow marandin, orlendo orange and eureka lemon. Oomah et al. (1998) compared the effect of air drying (50 °C for 2 h) and microwave heating (950 W, 60 Hz for 9 and 24 min) on grape seeds tocopherols and reported a significant effect of drying method on the oil tocopherols and tocotrienols. More so, higher tocopherols and tocotrienols were exhibited by oil from 9 min microwave dried grape seed.

The effect of room temperature (22 °C for 72 h) and oven drying (63 °C for 20 h and 103 °C for 2 h) on the oil phytosterols was investigated on blackberry and raspberry seeds (Radocaj et al., 2014). Campesterol, stigmasterol and β-sitosterol were identified in both blackberry and raspberry seed oil and significantly varied among the seeds drying techniques. The β-sitosterol, which was the main phytosterol varied from 4331.9 to 4337.9 mg/kg and 6867.9–6989.7 mg/kg for seed oil from blackberry and raspberry, respectively. For both blackberry and raspberry seeds, oven drying produced oil higher β-sitosterol. A similar trend was observed with campesterol and stigmasterol, suggesting that oven drying maximized the extractability of phytosterols from the seeds matrices relative to room temperature drying of the berries seeds.

Phenolic compounds have been associated with a variety of pharmacological properties including anti-inflammatory, anticancer and antioxidant activity. Preservation and maximization of these bioactive phytochemicals during seeds drying should be prioritized. Bualuang et al. (2018) evaluated the effect of microwave vacuum drying (100 mbar, 100, 300, 450 and 600 W) papaya seeds and found out that total phenolic content significantly improved by 11 %, but decreased by 16 and 20 % when the microwave power was increased from 100 to 300, 450 and 600 W, respectively. In a related study, Al Juhaimi et al. (2018) reported a significant effect of oven drying (60, 70 and 80 °C for 24 h) kinnow

extracted using SC-CO$_2$, microwave and ultrasonic-assisted and microwave integrated solvent extraction. SC-CO$_2$ extraction of kiwi seed oil favoured the extraction of palmitic acid (8.46 %), while stearic acid (4.55 %), oleic acid (18.79 %) and vaccenic acid (1.10 %) manifested higher in solvent extracted seed oil. Linoleic acid (18.43 %) was higher in SC-CO$_2$ extracted kiwi seed oil. Essential fatty acid, linolenic acid (61.41%) manifested higher in ultrasonic-assisted solvent extraction. SFA (12.57 %) and UFA (19.89 %) were higher in solvent extracted kiwi seed oil. Ultrasonic-assisted solvent extraction favoured the extraction of total polyunsaturated fatty acids (76.27 %). Solvent extracted kiwi seed oil exhibited higher MUFA/PUFA ratio (0.29). However, ultrasonic, microwave-assisted, and microwave integrated solvent extraction had a negative effect on palmitic, stearic, oleic and vaccenic acid. On the other hand, these processes enhanced linoleic and linolenic acids significantly, suggesting an improvement in the oil nutritive value.

In addition to the varied effect of oil extraction techniques on fatty acids composition, it is worth to mention that, integration of extraction techniques and processes enhances variation in the seed oil fatty acid concentration. In this sense, depending on the oil extraction technique, management of temperature and pressure is critical to preserve the bioactive phytochemicals.

3.3.3. Tocopherols, polyphenols and phytosterols

The effect of oil extraction technique on bioactive compounds such as tocopherols, polyphenols and phytosterols has been studied. Liu et al. (2009) evaluated the influence of varying SC-CO$_2$ extraction temperature, pressure and time on tocopherols and antioxidant activity of pomegranate seed oil. The authors observed that SC-CO$_2$ extraction of pomegranate seed oil at 30 MPa, 50 °C for 10 min produced higher total tocopherols (609.29 mg/100 g), α-tocopherol (15.39 mg/100 g), γ-tocopherol (570.77 mg/100 g) and δ-tocopherol (23.30 mg/100 g). Further increasing extraction time considerably reduced tocopherols, for instance, increasing the extraction time to 40 min significantly decreased total tocopherols, α-tocopherol, γ-tocopherol and δ-tocopherol by 0.5–5 fold. The variation of seed oil tocopherols with oil extraction technique has also been confirmed by Pereira et al. (2019). It was observed that higher α-tocopherol, γ-tocopherol, δ-tocopherol and total tocopherol was exhibited by passion seed oil extracted by solvent extraction with hexane followed by subcritical fluid extraction with propane at 60 °C and 2 MPa.

Ultrasonic-assisted extraction of raspberry seed oil revealed that optimum conditions for vitamin E (15.10 mg α-tocopherol/g dry weight) (dw) recovery were sonication time of 30 min and extraction temperature of 50 °C (Teng et al., 2016). Similarly, comparison of SC-CO$_2$ and solvent extraction with hexane on tocopherols and tocotrienols from grape seed oil ('Pinot Noir') revealed that α-tocopherol was 74 %, γ-tocopherol (105 %), α-tocotrienols (31 %0, β-tocotrienols (38 %), γ-tocotrienols (22 %) and total tocols (37 %) higher than those from grape seed oil extracted with solvent extraction, a fact that be explained by increased solubility, low surface tension and viscosity of carbon dioxide at supercritical conditions (Mohamed et al., 2016).

Contrarily, Ramadan et al. (2008) reported insignificant variation in tocopherols from solvent (SE), enzyme-aided aqueous (EAE) and enzyme-aided solvent extracted (ESE) golden berry seed oil. Tocopherols, which are the major lipid-soluble compounds, are also predominant membrane-localized antioxidants in humans. In solvent extracted and enzyme-aided solvent extracted golden berry seed oil α-tocopherol inconsiderably varied from 0.34-0.36 g/kg, β-tocopherol (2.10 g/kg), γ-tocopherol (1.08–1.10 g/kg) and δ-tocopherol (0.85-0.88 g/kg). The α-tocopherol (0.21 g/kg), β-tocopherol (2.05 g/kg) and δ-tocopherol (0.77 g/kg) manifested lower in enzyme-aided aqueous extracted seed oil. In the same study total phenolics were higher in seed oil from enzyme aided solvent extraction (101 mg/L) followed by solvent extraction (97 mg/L) and lastly enzyme aided aqueous extraction (89 mg/L).

Cold pressed and solvent extracted lemon seed oil exhibited significant variation in flavonoids and phenolic acids content (Guneser and Yilmaz, 2017). The predominant flavonoids, eriocitrin (1052.60 vs.

1007.00 mg/kg), hesperidin (907.39 vs. 868.64 mg/kg), naringin (389.79 vs. 202.60 mg/kg) and rutin (76.80 vs. 52.31 mg/kg) were higher in cold pressed than solvent extracted lemon seed oil. Likewise, the main phenolic acids, gallic acid (93.42 vs. 43.96 mg/kg) and tr-ferulic acid (85.13 vs. 63.39 mg/kg) manifested higher in cold pressed lemon seed oil and lower in solvent extracted oil. However, solvent extraction maximized the extraction of phenolic compounds such as catechin, kaempherol, rosmaniric acid, tr-2-hydrocinnamic acid and syringic acid.

Briones-Labarca et al. (2015) studied the effect of high hydrostatic pressure (500 MPa for 5, 10 and 15 min with pulses of 1 min each) and ultrasound assisted solvent extraction (130 W, for 5, 10 and 15 min) with methanol on papaya seed oil and reported that higher total phenolic content (TPC) was exhibited by high hydrostatic pressure extracted oil. Rombaut et al. (2014) also observed that oil extraction technique significantly affect the extracted oil TPC. Furthermore, Araujoa et al. (2014) assessed the effect of microwave assisted solvent extraction of bioactive compounds from avocado seeds and found out that a temperature of 50 °C, extraction time of 30 min and 50 % ethanol were the optimum conditions for higher TPC (70 mg GAE/g dry seed). In the same study, acetone avocado oil extracts (307.09 mg GAE/g) showed higher TPC than ethanol oil extracts (254.40 mg GAE/g) at optimum extraction conditions, indicating that acetone had greater power to the extract phenolic compounds than ethanol.

Gornas et al. (2019) reported the effect of oil extraction technique on Japanese quince seed oil phytosterol content. Highest total phytosterols was shown by oil extracted by ultrasonication (6239.3 mg/100 g), while SC-CO$_2$ (5910.7 mg/100 g), soxhlet extraction (5784.5 mg/100 g) and cold-pressing (5679.7 mg/100 g) showed no significant differences. A similar trend was observed with the individual phytosterols such as campesterol, β-sitosterol, Δ5-avenasterol and Δ7-stigmasterol, which were 13–16 % higher than the other oil extraction techniques. In addition, Regalado-Rentería et al. (2020) observed that cold pressing prickly pear seeds produced oil that was significantly higher in β-sitosterol than maceration using hexane. According to Sicari and Poiana (2017) campesterol and 2,4-metylencolesterol were significantly higher in bergamot seed oil extracted using SC-CO$_2$ at 30 °C, 250 bar and CO$_2$ density of 919 kg/m^3 than petroleum ether oil extracts. In respect of other phytosterols, including β-sitosterol, stigmasterol and cholesterol, no significant differences were reported among the oil extraction techniques.

3.3.4. Antioxidant activity

The functionality of seed oil as a source of antioxidants can be determined by its ability to scavenge free radicals or reduce Fe^{3+} to Fe^{2+} in the presence of 2,4,6-trypyridyl-s-triazine. Ramadan et al. (2008) studied the effect of solvent extraction (SE), enzyme aided solvent extraction (ESE) and enzyme aided aqueous extraction (EAE) on gol-denberry seed oil antioxidant activity. Using 2, 2-diphenyl-1-picrylhydrazyl (DPPH) assay as a source of free radicals, after 1 h 55 % of the DPPH assay had been scavenged by ESE, while SE and EAE scavenged only 53.5 and 48.9 %, respectively. In the study of Liu et al. (2009), SC-CO$_2$ extraction of pomegranate seed oil at 30 MPa, 50 °C for 40 min produced oil higher in antioxidant activity (DPPH assay). Increasing extraction time to 90 min and reducing the pressure to 15 MPa significantly decreased the IC$_{50}$ value of pomegranate seed oil by 50 %. In the study of Perreira et al. (2019) on subcritical propane extraction of oil from sweet passion seeds, increasing pressure from 2 to 8 MPa at 30 °C significantly increased EC$_{50}$ by 33 %, but significantly reduced ABTS radical scavenging capacity and FRAP by 12 and 34 %, respectively. Increasing temperature to 60 °C and reducing pressure to 2 MPa negatively affected the oil EC$_{50}$ and FRAP. Therefore the authors concluded that temperature, pressure and extraction time are critical factors in determining the antioxidant capacity of seed oil from subcritical and supercritical fluid extractions. Cissé et al. (2018) compared the antioxidant activity of baobab seed oil extracted by mechanical pressing and solvent extraction using acetone, chloroform and hexane. The DPPH radical scavenging

capacity of baobab oil extracts from mechanical pressing was 1.2–3.4 fold higher than the DPPH radical scavenging capacity of acetone, hexane and chloroform oil extracts. With respect to solvent extraction of baobab seed oil, the DPPH radical scavenging capacity was higher and lower in acetone and chloroform oil extracts, respectively. The polarity dependent increase in DPPH radical scavenging capacity indicates the extraction of strong antioxidant compounds in polar solvents. The variation in seed oil antioxidant capacity due to solvent polarity was also reported by Araujoa et al. (2014). In their study, acetone avocado oil extracts exhibited better DPPH (266.56 v. 221.69 mg TE/g) and ABTS radical scavenging capacity (607.28 v. 516.34 mg TE/g) than ethanol oil extracts.

The authors pointed out that the extractability of antioxidant compounds from the seeds matrices is dependent on the oil extraction technique. Further to that, varying the extraction conditions such as extraction solvent, temperature, pressure and time significantly altered the seed oil bioactive compounds and antioxidant activities.

3.3.5. Oxidative stability

Among other factors, the oxidative stability of seed oil may be influenced by processing. In this sense, depending on the processing conditions such as temperature, pressure and solvent type, oxidative stability may vary with seed oil processing technique. Pereira et al. (2019) reported that ethanol passion seed oil extract was 37 % higher in free fatty acids (FFA) and AV than hexane oil extract. In the same study, varying temperature and pressure in subcritical propane extraction of passion seed oil did not significantly affect FFA and AV of the extracted oil. On the contrary, decreasing temperature from 40 to 30 °C and increasing pressure and carbon dioxide flow rate from 150 to 250 bar and 731–919 kg/m^3, respectively in supercritical fluid extraction of bergamot seed oil doubled the PV (Sicari et al., 2017). Rui et al. (2009) evaluated the PV and AV of pitaya seed oil extracted with soxhlet extraction, microwave assisted solvent extraction, aqueous enzyme assisted extraction, microwave aqueous enzyme assisted extraction and supercritical fluid extraction and found that PV and AV varied from 0.8 to 1.93 meqO$_2$/kg and 2.34–4.13 mg KOH/g, respectively. The variation in the respective oxidation indices was attributed to the differences in the extraction conditions among the oil extraction techniques. Herchi et al. (2014) compared the oxidative stability of date seed oil extracted using hexane, soxhlet (petroleum ether) and modified Bligh–Dyer method for PV, AV, FFA, anisidine value, induction period, conjugated dienes and trienes. The authors observed that date seed oil extracted using the modified Bligh–Dyer method was more stable to oxidation than hexane and petroleum ether oil extracts. According to Mariod et al. (2010) soxhlet (petroleum ether) extracted sugar apple (Annona squamosal) seed oil was 1.8 fold higher in AV than cold extracted (petroleum ether) oil, a phenomenon that can be related to the differences in extraction temperature. Variation in seed oil oxidative stability with extraction technique was also reported in the studies of Cavdar et al. (2017), Cissé et al. (2018) and He et al. (2016) on pomegranate, date and cherry seeds, respectively.

4. Conclusions

The quality of fruit seed oil is highly dependent on preharvest and processing factors. Fruit cultivar, growing region, seeds drying, seeds pretreatment and oil extraction technique significantly affected the oil yield, tocopherols, polyphenols, phytosterols, antioxidant activity and oxidative stability of the extracted oil. Furthermore, factors, including extraction time, pressure, temperature, solvent type, enzyme concentration, have been implicated. Fruit growing region and seeds processing has a limited influence on the fatty acid composition of seed oil. However, processing factors including extraction time, pressure, temperature and solvent type may be manipulated to maximize the retention of health-promoting compounds, including fatty acids such as the omega-3 and omega-6 fatty acids. Therefore, consideration of cultivar, fruit growing region, selection of the right processing techniques and

conditions that minimizes nutritional qualities and bioactive compounds losses during seed oil processing is fundamental.

5. Future prospects

Currently, little has been researched about the relationship between ripening index of the seed bearing fruit and oil fatty acids, bioactive compounds and antioxidant activity. This should be considered in order to have a clearer understanding of the preharvest effect on seed oil nutritional qualities and antioxidant properties. There were no studies found on the effects of seeds pretreatment to enhance drying efficiency on seed oil quality. For instance, the drying time of seeds would have a considerable effect on extracted oil quality. In view of the thermolabile nature of bioactive compounds such as tocopherols and polyphenols, the effect of seed drying and pretreatments for seed drying on oil antioxidant compounds and capacity deserves more research. This would assist in quantifying losses of bioactive compounds losses and instituting preventive measures at this stage of seed oil processing. More studies are also needed to determine the effect of fruit growing region and processing factors on carotenoids, one of the antioxidant compounds in seed oils.

Also, limited researches are available on the effect of fruit growing region on fatty acids, bioactive compounds and antioxidant activity of the extracted oil. Despite the current advances, expanding the knowledge in this field should be incited and further exploited, particularly with a broader spectrum of fruit seeds.

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