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ORIGINAL PAPER

Comparison of fatty acid profiles and contents of seed oils recovered from dessert and cider apples and further Rosaceous plants

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Abstract To get a more comprehensive knowledge of oil contents and fatty acid pattern, seed oils from various Rosaceous plants belonging to the subfamilies Maloideae and Rosoideae, respectively, were investigated. For this purpose, isolated seeds of 18 dessert and cider apple (*Malus domestica* BORKH.) cultivars of different provenances, pear (*Pyrus communis* L.), rose hip (*Rosa canina* L.), quince (*Cydonia oblonga* Mill.), and red chokeberry (*Aronia arbutifolia* L.) were analyzed for their oil content and fatty acid composition. Oil contents varied significantly, not only among the different genera, but also among cultivars of one species, ranging from 0.8 to 29.4 g/100 g dry matter. Qualitatively, the fatty acid profiles of the investigated seed oils showed good agreement in all representatives of the Rosaceae. Their triacylglycerols were uniformly composed of linoleic, oleic, palmitic, stearic, palmitoleic, α-linolenic, arachidic, gondoic, and behenic acids. Quantitation of individual fatty acids revealed the oils to be rich in mono- and diunsaturated oleic acid and linoleic acid, ranging from 15.1 to 33.3 g/100 g and from 32.5 to 49.7 g/100 g, respectively. As expected, contents of saturated fatty acids were 6–10 times lower. Moreover, apple cultivars showed pronounced differences in yields, numbers, and weights of their seeds. As demonstrated by the data obtained from this study, seeds resulting from the processing of apple, pear, quince, chokeberry (Maloideae), and rose hip (Rosoideae) into juices, jellies, and jams may serve as a promising source for the recovery of nutritionally valuable edible oils.

Keywords Maloideae · Rosoideae · Seed oil · Oil yield · Fatty acids · Quantitation · Seed weight

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Introduction

Epidemiological studies have revealed potential health benefits associated with a diet rich in fruits and vegetables. Consequently, the consumption of plant-based foods has been propagated by health authorities bringing about increased consumer awareness of food-related health aspects. In this context, fruit juices play a predominant role. With an annual per capita consumption of 9.25 L, apple juice is among the most popular juices in Germany [1]. Accordingly, yearly up to 300,000 tons of apple pomace arise from apple juice processing [2], which is currently mainly used as feed stock and for the extraction of apple pectin. Apple pomace also serves as a valuable source for the recovery of health-promoting polyphenols because they are insufficiently extracted during juice production [3–5].

A significant part (2–3 %) of apple pomace is made up of apple seeds [6]. In several studies of the past decades, apple seeds have been shown to be rich in proteins, carbohydrates, and minerals, making them useful as a potential food, feed, or fertilizer [7, 8]. Owing to their relatively high amount of lipids, apple seeds can also be utilized for the recovery of oils. These oils are rich in essential linoleic and oleic acids, and consequently, may be applied as ingredients of food and cosmetics [8, 9]. Moreover, according to recent in vitro investigations, apple seed oil may effectively inhibit the growth of bacteria, mildews, and yeasts [10].

Apart from economically important pomaceous fruits like apple and pear (*Pyrus communis* L.), other Rosaceous plants, such as rose hip (*Rosa canina* L.), quince (*Cydonia oblonga* Mill.), and black chokeberry (*Aronia melanocarpa* (Michx.) Elliot) are increasingly attracting interest due to their reported antioxidant, anti-carcinogenic, prophylactic and therapeutic properties, and as coloring additives for beverage and food products. Rose hip and quince extracts have been traditionally used as dietary supplements and for medical treatment for infections and inflammatory diseases. Furthermore, their fruits are commonly used for the production of jams and jellies [11–16]. Black chokeberry, however, has been shown to be one of the most promising sources of phenolic phytochemicals with potential health benefits [17–22]. Owing to their exceptionally high contents of phenolic antioxidants, in particular anthocyanins, fruit juice concentrates of black chokeberries are increasingly used as natural colorants in industrial juice and nectar production. By the application of black chokeberry concentrates to other fruit juices, color properties of the resulting beverage products may be improved and their antioxidant activities may be significantly increased, thus resulting in the production of functional foods [23, 24]. In the course of processing cyanogenic glycoside-containing seeds of Rosaceous fruits are usually removed, resulting in appreciable amounts of by-products hardly exploited so far. Hence, the recovery of seed oils appears to be a promising option for a more comprehensive utilization of by-products originating from fruit processing, thus contributing to sustainable food production as already discussed for seeds of pitaya fruits [25].

Despite the promising physiological properties of apple seed oil constituents, a systematic comparison of the seed oil contents and profiles of different cultivars and provenances is still lacking. Therefore, the aim of the present study was to determine the oil contents and the fatty acid profiles of seed oils originating from different cider and dessert apple cultivars commonly grown in Southern Germany. Investigations of the lipid contents and fatty acid profiles of the seeds of pear (*Pyrus communis* L.), quince (*Cydonia oblonga* Mill.), and red chokeberry (*Aronia arbutifolia* L. Elliot), also belonging to the Maloideae subfamily as well as rose hip (*Rosa canina* L.) as a representative of the Rosoideae were included, since such data considering different taxa within the Rosaceae are still lacking as well in the literature.

Materials

Chemicals

All reagents and solvents were purchased from Merck and were of analytical or HPLC grade. Boron trifluoride–methanol complex solution (13–15 % BF_3 in methanol) was from Riedel-de-Haën (Taufkirchen, Germany). Fatty acids (FAs) and standards of their respective methyl esters (FAMEs) of gas chromatographic purity were purchased from Sigma-Aldrich (Steinheim, Germany).

Plant material

Authenticated apple and pear varieties harvested in 2008 were provided by local growers and Hohenheim University research station for horticulture. Different quince (II and IV, both harvest 2009; III, harvest 2010), rose hip, and red chokeberry fruits (harvest 2010) originated from the same region and were from local growers. One batch of sun-dried quince seeds (quince I, harvest 2010) from North India (Himalaya) was kindly provided by WALA Heilmittel GmbH, Bad Boll, Germany. Red chokeberry was chosen instead of black chokeberry, because preliminary tests had shown the fruits of the latter to contain very small seeds with low weights, making their efficient isolation from the dark colored pomace quite challenging. In contrast, red chokeberries contained only one big seed per fruit, which could be easily isolated.

Apple, pear, quince, and red chokeberry seeds were separated from the cores by cutting the whole fruits into pieces. Additionally, for each of the apple and pear varieties, the average yield, number, and weight of the seeds were determined by weighing and counting both the fruits and the isolated seeds of each batch.

In the case of the much smaller rose hip seeds, the whole fruits were crushed and passed successively through sieves with decreasing mesh sizes (10 and 1.5 mm) using a finisher (type PAP 0533, Bertuzzi, Brugherio, Italy) to separate the seeds from skins and flesh. Complete isolation of the rose hip seeds was finally achieved by combining several washing, sieving, and decanting steps. Seeds isolated from the different Rosaceae fruits were lyophilized to constant weight and finely ground in a laboratory mill to yield the seed flours that were immediately used for the recovery of the lipid fraction.

Methods

Extraction of fatty oils from Rosaceous seeds

For the recovery of the lipids, seed flours were extracted in a Soxhlet apparatus for 2 h with boiling *n*-hexane after an additional acidic hydrolysis of matrix substances with hydrochloric acid for 1 h (‘Weibull-Stoldt’) [26]. The organic solvent was evaporated at 30 °C under vacuum to constant weight, and the oil content was gravimetrically determined. The extracted oils were stored in the dark at −80 °C under nitrogen atmosphere until further analyses.

Separation and quantitation of individual fatty acids by GC-FID

FAs were analyzed by gas chromatography after conversion into their corresponding methyl esters (FAMEs). FAMEs were prepared according to official standard procedures [27]. Briefly, 10–20 mg of seed oil was heated at 80 °C with 500 µL of methanolic KOH (0.5 M) for 5 min in a derivatization tube. After cooling, 1 mL of methanolic BF_3-reagent was added and heated for another 5 min at 80 °C. The samples were then cooled in an ice bath. The resulting FAMEs were extracted by adding 2 mL of saturated sodium chloride solution and 2 mL of *n*-hexane. Heptadecanoic acid and methyl heptadecanoate were used as internal standards for samples and calibration solutions of authentic reference compounds, respectively.

Aliquots of 1 µL of the organic phases were subjected to GC analysis. FAs were identified and quantitated using a Chrompack CP 9001 gas chromatograph (Chrompack, Middleburg, NL) equipped with an auto sampler CP 9010 and a FID detector. Separation was performed on a 30 m × 0.25 mm i.d., 0.15 µm fused silica capillary column (DB-225, J&W Scientific, Folsom, CA, USA) using helium (purity 5.0) as the carrier gas with a constant flow of 1.7 mL/min. A split ratio of approx. 1:60 was used. The oven was programmed as follows: starting from 35 °C and increasing to 195 °C at a rate of 25 K/min. Subsequently, temperature was raised from 195 to 205 °C at a rate of 3 K/min and from 205 °C to final temperature of 230 °C (rate of 8 K/min). Final temperature was held for 1 min. Temperature of both the injector and detector was set at 250 °C. Individual FAMEs were identified by the comparison of their retention times with those of authentic FAME standards. Data analysis was carried out using Maestro II 2.4 version software. Since the present study focused on the characterization of the entire lipid fraction, results are reported as g of individual fatty acids per 100 g of seed oil (%) unless otherwise stated. Apart from these fatty acids, the lipid fraction may contain further constituents, such as unsaponifiable material, which has not been covered in the present study. As a consequence, total fatty acid contents do not necessarily amount to 100 %.

Statistical analysis

All samples were prepared and analyzed in duplicate. Significant differences ($\alpha = 0.05$) between oil yields and FA contents of different samples were determined using the Tukey test. Data evaluation was performed with SAS software package (SAS Institute, Cary, NC, Software Version 9.1).

Results and discussion

Yield, number, weight, and oil content of pomaceous seeds

The efficiency of the oil recovery process largely depends on yield, weight, and oil content of apple and pear seeds. In order to determine these technologically relevant parameters, we isolated the seeds from the fruits by manually cutting them into pieces. This labor-intensive method was chosen because their direct isolation from the pomace on laboratory scale was rather insufficient. Preliminary tests with wet apple pomace using water and several decanting steps, for example, failed due to insignificant differences in density. Moreover, separation of the seeds from dried pomace by sieving resulted in seed fractions with unsatisfactory purities (approx. 50 %). Similar observations were made in an Austrian study with apples originating from the "Mostviertel" [28]. On a larger scale, for complete removal of the core, a punching press and subsequent sieving of the cores on vibrating screens to isolate the seeds appears to be a promising process.

Our results summarized in Table 1 demonstrate that apart from differences in oil contents, also the investigated apple cultivars significantly differed as far as the average yields, numbers, and weights of their seeds were concerned. It is also worth mentioning that even within the same cultivar, these parameters varied considerably. Interestingly, the oil-rich cultivars "Geheimrat Breuhahn" and "Bittenfelder" exhibited the highest yields of seeds, ranging from approx. 5–7 g seeds/kg apples based on fresh weight. With approx. 6–17 seeds per apple, they also had the highest average seed number. In contrast, cultivars, exhibiting relatively low oil contents, e.g., "Boskoop," "Brettacher", or "Jonagold," contained only few and/or incompletely developed seeds with relatively low weights. Since the fruits of the latter cultivars were also bigger in size, the average yield of seeds was much lower (approx. 2 g seeds/kg fruit).

The same applied to the pear cultivar "Gelbmöstler," only yielding 1.4 g seeds/kg fruit. The fruits of this cultivar only contained few seeds (3.4 per fruit) most of which were also incompletely developed, resulting in low average seed weight (36.7 mg) and oil content. In a preliminary screening of other pear cultivars, seed yields have been even lower (data not shown). Therefore, a more extensive investigation of seeds from a broader selection of pear cultivars was not feasible. This is in agreement with previous findings of the aforementioned Austrian study, also indicating most pear varieties to exhibit only low yields of abortive seeds [28].

Oil yields within the investigated apple cultivars markedly differed as well (Table 1). The average seed oil

Table 1 Average yields, numbers, and oil contents of seeds of different dessert and cider apple varieties

Cultivar	n^a	Yield (g seeds FW/ kg apple FW)	Average seed number per apple	Average seed weight (mg FW)	Oil content (g/100 g seeds DM)
Brettacher[b]	5	1.3–1.8	4.9–6.2	35.3–58.1	**15.4 (13.0–19.3)**
Bohnapfel[b]	3	2.1–2.3	4.8–5.4	35.5–54.2	**19.4 (17.0–21.8)**
Idared[b]	3	2.0–3.0	4.4–6.5	55.1–59.9	**23.1 (19.8–25.1)**
Gewürzluiken[b]	3	1.5–5.2	5.5–8.1	12.8–54.1	23.7 (22.7–24.2)
Boskoop[b]	4	0.8–1.4	2.7–5.9	32.0–51.9	**17.0 (15.2–19.1)**
Bittenfelder[b]	2	5.1–7.1	6.1–11.4	65.6–71.0	21.2 (20.1–22.3)
Trierer Weinapfel[b]	2	5.4	3.3–7.9	55.0–67.2	**23.5 (21.4–29.9)**
Jonagold[b]	2	0.6–1.0	3.5–5.9	40.4–43.6	20.2 (19.0–21.4)
Royal Gala[b]	2	2.1–3.1	5.0–6.5	58.3–63.7	**25.1 (22.6–27.6)**
Roter Ziegler[b]	2	3.7–4.4	5.7–5.8	58.2–68.6	17.0 (16.7–17.3)
Champagner Renette[c]	1	5.3	9.3	64.4	23.3 ± 0.0
Genereuse de Vire[c]	1	3.4	7.4	75.4	26.4 ± 0.3
Geheimrat Breuhahn[c]	1	5.7	16.7	56.1	29.4 ± 1.2
Königinnenapfel[c]	1	1.3	8.5	49.5	23.4 ± 0.2
Hohe Wart[c]	1	3.2	5.9	57.6	27.3 ± 0.2
Kaiser Wilhelm[c]	1	2.4	8.7	53.0	14.3 ± 0.2
Transparent[c]	1	3.8	5.8	54.1	19.8 ± 0.0

FW fresh weight; *DM* dry matter

[a] number of samples from different origins

[b] means and range of variation, bold print indicates significant differences between samples of different origin ($\alpha = 0.05$)

[c] mean values ± SD

content of apple cultivars ranged from 14.3 to 29.4 g/100 g dry matter (DM). In our study, the maximum content was found in cv. "Geheimrat Breuhahn," whereas cv. "Kaiser Wilhelm" had the lowest amount of apple seed oil. With 15.4 and 17.0 g/100 g DM, respectively, the seeds of cvs. "Brettacher," "Boskoop", and "Roter Ziegler" only contained 50 % of those cultivars having the highest oil yields. The latter varieties are mainly used for cider production, while cvs. "Gala," "Topaz," "Jonagold", and "Idared" are typical dessert apples. Astonishingly, the seed oil contents of the latter ones were relatively high and varied within a smaller range from 23.1 to 25.1 g/100 g. This is in accordance with the oil content of 25.7 g/100 g DM in seeds from "McIntosh" apples as reported in a previous study [7]. Seeds from "Qingguan" apples were also shown to contain a comparable lipid content (27.7 g/100 g DM) [8]. Interestingly, an inverse correlation was observed in investigations on polyphenols of different apple cultivars demonstrating cider apple cultivars to exhibit generally higher polyphenol levels [29].

Differences in the average seed oil content of different cultivars, but also within the same cultivar, originating from different localities, were significant (see Table 1). As exemplified by "Trierer Weinapfel" and "Idared," the oil contents of different provenances ranged from 21.4 to 29.9 g/100 g and from 19.8 to 25.1 g/100 g, respectively. Consequently, besides varietal also abiotic factors like temperature, water availability, exposure to sunlight, and horticultural measures may strongly influence the biosynthesis of lipids in apple seeds. To the best of our knowledge, there are no studies dealing with climatic or geographical influences on the yield and composition of apple seed oils. In general, temperature has been shown to be the most important factor influencing the biosynthesis and accordingly the content of oil and proportion of unsaturated fatty acids in plants. As demonstrated for sunflower seeds, lower temperatures result in decreased lipid contents [30, 31]. Additionally, water supply of sunflowers may also influence the yields of seeds and oil. In irrigation experiments, a deficit of water resulted in a significant drop of both the number and the oil content of the seeds [32]. This may also be assumed for the differences observed within identical apple cultivars.

Fatty acid composition of seed oils recovered from Rosaceous plants

Qualitatively, fatty acid profiles of the Maloideae and Rosoideae seed oils did not differ in our study. Our GC experiments established the presence of the following FAs in the oil from isolated seeds: palmitic acid (C16:0), palmitoleic acid (C16:1), stearic acid (C18:0), oleic acid

(C18:1), linoleic acid (C18:2), α-linolenic acid (α-C18:3), arachidic acid (C20:0), gondoic acid (C20:1, Δ11), and behenic acid (C22:0).

Proportions of individual FAs in apple seed oils

Tables 2 and 3 give an overview of the contents of individual FAs and their proportions in 18 representatives of the genus Malus under study. As can be seen, FA contents were comparable. Furthermore, differences between FA patterns of cider and dessert apples appear marginal. However, as observed for the oil content, statistical analysis revealed non-varietal influences to be of great importance because fatty acid contents significantly ($\alpha = 0.05$) differed even among different samples of the same cultivar, thus aggravating a comparison of various cultivars. This may be mainly attributed to differing abiotic conditions in the plantations. In this context, temperature may play a decisive role regarding the ratio of unsaturated and saturated fatty acids in the apple seeds, since lower temperatures are known to induce the accumulation of unsaturated fatty acids. Such correlations have also been confirmed for sunflowers [30].

Total fatty acid contents in the seed oils of apple varied from 73.0 to 88.4 g/100 g in the cvs. "Trierer Weinapfel" and "Brettacher," respectively. This is in good accordance with the findings of a previous study [33], where *n*-hexane extracts of apple seeds ("Royal Gala") were analyzed by GC–MS resulting in the detection of 46 compounds with FAs totaling to 80.9 %.

Unsaturated linoleic and oleic acids were the predominant fatty acids in apple seed oils. Ranging from 36.1 g/100 g oil for cv. "Champagner Renette" to 49.9 g/100 g for cv. "Transparent," essential linoleic acid was the most abundant fatty acid accounting for 44–59 % of total FAs. Linoleic acid also represented the most important part of the polyunsaturated FAs (PUFAs). PUFA levels ranged from 37.1 % (cv. "Champagner Renette") to 50.9 % (cv. "Royal Gala"). The amounts of monounsaturated oleic acid varied between 19.4 % for cv. "Jonagold" and 33.3 % for cv. "Champagner Renette." Interestingly, oleic and linoleic acid contents were almost equal for "Champagner Renette," whereas for the remaining cultivars, linoleic acid was predominant, approximately two times exceeding the amount of its monounsaturated counterpart. Total contents of monounsaturated FAs (MUFAs) with prevailing oleic acid were in a range between 20.7 and 34.8 %.

As far as saturated palmitic acid was concerned, the seed oil of cv. "Brettacher" exhibited the highest content (7.1 %), while the lowest value was observed for "Champagner Renette" (5.1 %). With amounts ranging from 1.5 % (cv. "Jonagold") to 2.4 % (cv. "Brettacher"), stearic acid yields were relatively low. Palmitic and stearic acid were the most important components among SFAs in apple seed oils, ranging from 8.8 to 11.6 %.

Palmitoleic, α-linolenic, gondoic, behenic, and arachidic acids were found to be minor FAs in apple seed oils. Palmitoleic acid and behenic acid contents were in the same range, varying from 0.5 to 0.7 % and from 0.5 to 0.6 %, respectively. Yields of α-linolenic (0.9–1.1 %) and gondoic acids (0.7–0.9 %) were slightly higher for the different apple cultivars under investigation. The most important minor fatty acid, however, was arachidic acid, exhibiting contents between 1.3 and 1.7 %. Highest arachidic acid content was determined in one of the samples of the cv. "Gewürzluiken," accounting for 1.9 % of total FAs. Data on FAs of apple seed oils reported elsewhere [8, 10, 34] fall within the ranges determined in the present work. In a previous study [10], the same FAs were identified in cv. "Fuji" with linoleic and oleic acids being the most abundant FAs, accounting for 51.40 and 37.49 %, respectively. Palmitic (6.51 %), stearic (1.75 %), and arachidic acids (1.54 %) were also present in appreciable amounts, whereas α-linolenic (0.30 %), gondoic (0.56 %), and behenic acids (0.40 %) were minor constituents as well.

Oil contents and FA patterns of further representatives of Maloideae and Rosoideae

Oil contents of pomaceous species other than apple showed considerable variability (Table 4). The oil content of seeds from cv. "Gelbmöstler," the only pear variety included in this study, was low (14.6 g/100 g DM) coming close to that of apple cultivars preferably used for cider production, such as "Brettacher," "Kaiser Wilhelm," and "Roter Ziegler." Analogously, "Gelbmöstler" pears are exclusively used for the production of cider or hard liquor. There are only few studies dealing with the oil content of pear seeds. However, in a recent Chinese study [34], comparable oil contents of 17.9 g/100 g were reported for cv. "Dangshau Suli," whereas apple seeds from cv. "Red Fuji" yielded significantly higher amounts of fatty oil (29.1 g/100 g).

In our study, oil contents of the quince seeds ranged from 14.7 to 20.6 g/100 g. Thus, they came close to the values of some cider apple cultivars such as "Brettacher" and "Boskoop" and to the cider pear cv. "Gelbmöstler." This is in good agreement with data (18.73 %) presented for quince seeds from Turkey [35]. A slightly higher oil content of 25.27 % was reported for quince seeds originating from Poland [36].

Seeds of rose hip and red chokeberry contained 10.0 and 0.8 g oil/100 g, respectively. Thus, oil contents of both representatives of the Rosoideae and Maloideae, respectively, were significantly ($\alpha = 0.05$) lower compared to the remaining pomaceous seeds ranging between 13.0 and

Table 2 Individual fatty acid contents (%, g/100 g oil) and their variation in seed oils of different dessert and cider apple cultivars

Cultivar	*n*[a]	C16:0	C16:1	C18:0	C18:1	C18:2	α-C18:3	C20:0	C20:1	C22:0
Brettacher[b]	5	**5.8–7.1**	0.6–0.7	**1.8–2.4**	**22.8–27.4**	**39.2–48.7**	1.0–1.1	1.4–1.6	0.8	0.6
Bohnapfel[b]	3	6.0–6.2	0.5–0.6	**1.9–2.1**	**20.9–26.0**	44.7–46.9	0.9–1.0	1.3	0.7–0.8	0.5–0.6
Idared[b]	2	**5.5–6.0**	0.6–0.7	**1.7–1.9**	**22.9–25.5**	45.1–46.8	0.9–1.0	1.4–1.5	0.8–0.9	0.6
Gewürzluiken[b]	3	**5.2–5.7**	0.6	**2.2–2.3**	**27.4–31.1**	**39.6–44.1**	0.9–1.0	1.7	0.8–0.9	0.6
Boskoop[b]	4	6.2–6.7	0.6	1.9–2.1	25.9–27.9	39.1–42.2	1.0–1.1	1.5–1.6	0.8–0.9	0.6–0.7
Bittenfelder[b]	2	**6.0–6.7**	0.6	**2.1–2.3**	**25.4–27.7**	**42.6–45.6**	0.9–1.0	**1.5–1.6**	0.8–0.9	0.6
Weinapfel[b]	2	5.2–5.7	0.6	1.7–1.8	20.2–21.1	41.7–45.5	**0.9–1.1**	1.3–1.4	0.8	**0.6**
Jonagold[b]	2	**5.5–6.4**	0.6	**1.5–1.6**	**19.4–22.7**	**43.8–49.7**	0.9–1.1	**1.3–1.4**	**0.8–0.9**	0.5–0.6
Topaz[b]	2	5.9–6.0	0.6	**1.8–2.1**	23.6–24.2	48.4–49.4	1.0	1.5	0.8	0.6
Royal Gala[b]	2	**5.6–5.9**	0.6	**1.8–2.1**	23.6–24.7	46.4–49.9	1.0	1.5–1.6	0.8	0.6
Roter Ziegler[b]	2	6.2–6.4	0.6	2.0–2.1	27.5–27.8	42.1–42.9	0.9	1.5	0.8	0.6
Champagner Renette[c]	1	5.1 ± 0.2	0.6 ± 0.1	2.2 ± 0.1	33.3 ± 0.6	36.1 ± 0.8	1.0 ± 0.1	1.7 ± 0.1	0.9 ± 0.0	0.6 ± 0.0
Genereuse de Vire[c]	1	5.4 ± 0.0	0.5 ± 0.0	2.2 ± 0.0	25.2 ± 0.0	43.8 ± 0.2	0.9 ± 0.0	1.5 ± 0.0	0.8 ± 0.0	0.6 ± 0.0
Geheimrat Breuhahn[c]	1	5.5 ± 0.0	0.6 ± 0.0	1.9 ± 0.0	25.0 ± 0.3	46.0 ± 0.6	1.0 ± 0.0	1.5 ± 0.0	0.9 ± 0.0	0.6 ± 0.0
Königinnenapfel[c]	1	6.7 ± 0.1	0.7 ± 0.0	1.9 ± 0.0	23.1 ± 0.3	47.8 ± 1.1	1.1 ± 0.0	1.4 ± 0.0	0.8 ± 0.0	0.6 ± 0.0
Hohe Wart[c]	1	5.9 ± 0.0	0.6 ± 0.1	2.1 ± 0.0	25.4 ± 0.1	44.7 ± 0.2	0.9 ± 0.0	1.5 ± 0.0	0.8 ± 0.0	0.6 ± 0.0
Kaiser Wilhelm[c]	1	6.3 ± 0.0	0.6 ± 0.1	1.9 ± 0.0	23.7 ± 0.0	45.3 ± 0.0	1.0 ± 0.1	1.5 ± 0.1	0.8 ± 0.0	0.6 ± 0.0
Transparent[c]	1	6.2 ± 0.0	0.6 ± 0.0	1.8 ± 0.0	22.6 ± 0.4	49.9 ± 0.7	0.9 ± 0.0	1.4 ± 0.0	0.8 ± 0.0	0.6 ± 0.0

[a] number of samples from different origins

[b] range of variation, bold print indicates significant differences between samples of different origin ($\alpha = 0.05$)

[c] mean values ± SD

Table 3 Contents (%, g/100 g oil) and proportions of saturated and unsaturated fatty acids in seed oils of different dessert and cider apple varieties

Cultivar	*n*[a]	Σ SFA	Σ MUFA	Σ PUFA	Σ Total	UFA/SFA
Brettacher[b]	5	**9.8–11.6**	**24.3–28.8**	**40.2–49.7**	**76.2–88.4**	**6.6–7.4**
Bohnapfel[b]	3	9.7–10.0	**22.2–27.3**	45.6–47.8	**77.7–82.8**	7.0–7.3
Idared[b]	3	9.2–9.7	**24.3–27.1**	46.1–47.8	81.6–82.7	7.4–7.9
Gewürzluiken[b]	3	**9.7–10.2**	**28.8–32.5**	**40.6–45.1**	82.6–85.1	7.3–7.5
Boskoop[b]	4	10.4–11.1	27.4–29.4	40.2–43.2	79.0–83.6	6.5–6.8
Bittenfelder[b]	2	**10.3–11.2**	**26.8–29.1**	**43.5–46.6**	**80.6–86.9**	6.7–6.8
Weinapfel[b]	2	8.8–9.5	21.6–22.5	42.7–46.6	73.0–78.5	7.3
Jonagold[b]	2	**8.8–10.0**	**20.7–24.2**	**44.8–50.7**	**74.3–84.9**	7.5
Topaz[b]	2	9.8–10.2	25.0–25.6	49.4–50.4	84.2–86.2	7.4–7.6
Royal Gala[b]	2	**9.6–10.2**	25.1–26.1	47.4–50.9	82.0–87.1	7.6
Roter Ziegler[b]	2	10.2–10.5	28.8–29.1	43.0–43.8	82.1–83.4	6.9–7.0
Champagner Renette[c]	1	9.6 ± 0.2	34.8 ± 0.6	37.1 ± 0.8	81.5 ± 1.0	7.5
Genereuse de Vire[c]	1	9.6 ± 0.0	26.5 ± 0.0	44.7 ± 0.2	80.8 ± 0.2	7.4
Geheimrat Breuhahn[c]	1	9.6 ± 0.0	26.5 ± 0.3	47.0 ± 0.6	83.1 ± 0.6	7.7
Königinnenapfel[c]	1	10.6 ± 0.1	24.6 ± 0.3	48.9 ± 1.1	84.1 ± 1.1	6.9
Hohe Wart[c]	1	10.1 ± 0.1	26.8 ± 0.1	45.6 ± 0.2	82.4 ± 0.3	7.2
Kaiser Wilhelm[c]	1	10.3 ± 0.1	25.0 ± 0.1	46.3 ± 0.1	81.6 ± 0.2	6.9
Transparent[c]	1	9.9 ± 0.0	24.0 ± 0.4	50.9 ± 0.7	84.8 ± 0.8	7.6

[a] number of samples from different origins

[b] range of variation, bold print indicates significant differences between samples of different origin ($\alpha = 0.05$)

[c] mean values ± SD

Table 4 Oil (g/100 g DM) and fatty acid contents (%, g/100 g oil) of seeds from quince, rose hip, red chokeberry, and pear in comparison with the investigated apple cultivars

	Quince I	Quince II	Quince III	Quince IV	Rose hip	Red chokeberry	Pear cv. "Gelbmöstler"	Apple, range
n^a	1	1	1	1	1	1	1	–
Oil content	20.6 ± 0.5a	15.9 ± 0.3bc	14.7 ± 0.2c	17.3 ± 0.2b	10.0 ± 0.4d	0.8 ± 0.0e	14.6 ± 0.1c	13.0–29.9
C16:0	4.7 ± 0.0c	5.7 ± 0.1b	4.9 ± 0.1c	5.6 ± 0.0b	3.1 ± 0.2d	5.1 ± 0.1c	7.1 ± 0.2a	5.1–7.1
C16:1	0.5 ± 0.1b	0.6 ± 0.1b	0.5 ± 0.1b	0.5 ± 0.0b	0.6 ± 0.0b	1.0 ± 0.1a	0.4 ± 0.0b	0.5–0.7
C18:0	1.5 ± 0.0bc	1.6 ± 0.1bc	1.4 ± 0.0c	1.6 ± 0.0b	2.2 ± 0.1a	1.4 ± 0.0c	1.6 ± 0.0bc	1.5–2.4
C18:1	31.1 ± 0.5a	28.6 ± 1.7a	21.3 ± 0.0bc	30.0 ± 0.4a	18.8 ± 1.3c	15.1 ± 0.4d	23.7 ± 0.6b	19.4–33.3
C18:2	36.0 ± 0.6bc	42.2 ± 0.7a	36.1 ± 0.1bc	42.8 ± 0.2a	36.7 ± 2.2b	32.5 ± 0.7c	43.9 ± 1.2a	36.1–49.9
α-C18:3	0.7 ± 0.1c	0.9 ± 0.1c	0.9 ± 0.1c	0.9 ± 0.0c	14.3 ± 0.8a	2.5 ± 0.0b	0.8 ± 0.0c	0.9–1.1
C20:0	1.1 ± 0.0c	0.8 ± 0.0d	0.8 ± 0.0d	0.8 ± 0.0d	1.3 ± 0.0b	1.3 ± 0.0b	1.4 ± 0.0a	1.3–1.7
C20:1	0.7 ± 0.0b	0.7 ± 0.1bc	0.6 ± 0.0c	0.7 ± 0.0bc	0.8 ± 0.0b	0.9 ± 0.0a	0.7 ± 0.0b	0.7–0.9
C22:0	0.5 ± 0.0b	0.5 ± 0.0b	0.5 ± 0.0b	0.5 ± 0.0b	0.5 ± 0.0b	0.8 ± 0.0a	0.5 ± 0.0b	0.5–0.7
Σ SFA	7.8 ± 0.1cd	8.6 ± 0.1b	7.5 ± 0.1d	8.5 ± 0.0bc	7.1 ± 0.2d	8.5 ± 0.1bc	10.6 ± 0.2a	8.8–11.6
Σ MUFA	32.3 ± 0.5a	29.9 ± 1.7a	22.4 ± 0.1bc	31.1 ± 0.4a	20.1 ± 1.3cd	17.0 ± 0.4d	24.9 ± 0.6b	20.7–34.8
Σ PUFA	36.6 ± 0.6c	43.0 ± 0.7b	37.0 ± 0.1c	43.7 ± 0.2b	51.0 ± 2.3a	35.0 ± 0.7c	44.7 ± 1.2b	37.1–50.9
Σ Total	76.7 ± 0.8a	81.5 ± 1.8a	66.9 ± 0.2b	83.3 ± 0.4a	78.2 ± 2.7a	60.5 ± 0.9b	80.2 ± 1.3a	73.0–88.4
UFA/SFA	8.9	8.5	7.9	8.8	10.1	6.1	6.6	6.5–7.9

SFA saturated fatty acids; *MUFA* monounsaturated fatty acids; *PUFA* polyunsaturated fatty acids; *UFA* unsaturated fatty acids; *DM* dry matter. Mean ± SD. Different letters within the same line indicate significant differences among Rosaceae species other than apple ($\alpha = 0.05$)

[a] number of samples

29.9 g/100 g. In particular, the recovery of fatty oils from red chokeberry seeds appears to be less profitable. The problem of low oil yield of red chokeberry is also aggravated, since its fruits only contain one single seed. Whereas no data on oil yield of *Aronia arbutifolia* L. seeds could be found in the literature, yields of 4.97 % [37] and 4.85 % [38] were reported for rose hip (*Rosa canina* L.) seed oils. Thus, seed oil yield in the present study was found to be twice as high. Besides climatic and genotypic variations, this might be attributed to the additional acidic digestion in our study, resulting in a more exhaustive extraction of bound lipid components.

Table 4 summarizes the proportions and contents of individual fatty acids in seed oils of quince, rose hip, red chokeberry, and pear fruits. Like for apple seed oils, linoleic acid and oleic acid were the major FAs.

In oils from quince seeds of different origins and harvest seasons, linoleic acid and oleic acid contents ranged from 36.0 to 42.8 % and from 21.3 to 31.1 %, respectively. Linoleic acid and its monounsaturated counterpart accounted for 46.9–53.9 % and for 31.8–40.6 % of total FAs, respectively, in contrast to a Turkish study, where far lower proportions of linoleic and oleic acids ranging from 22.6 to 39.5 % were reported [35]. These discrepancies may most probably arise from markedly different climatic conditions in the growing areas. Compared to Mediterranean conditions, colder climate in Germany may have favored the accumulation of the polyunsaturated fatty acid at the expense of its monounsaturated precursor. Significant differences were also observed in the contents of linoleic and oleic acids of different quince provenances (II and III), illustrating the influence of annually changing climatic conditions on the biosynthesis and consequently on total contents of FAs. The fruits and seeds of the aforementioned samples originated from the same tree but from different harvests (2009 and 2010).

FA contents of the seed oil derived from the pear "Gelbmöstler" were in accordance with those of a Chinese pear cultivar [34], indicating pear seed oil also to be rich in unsaturated fatty acids (77.8 %). Major FAs reported in this study were linoleic acid (56.8 %) and oleic acid (20.3 %). Altogether, comparison of their FA contents and their distribution revealed quince, pear, and apple seed oils to be very similar.

More distinctive differences, however, could be found with regard to the FA proportions of rose hip and red chokeberry seeds, showing significantly ($\alpha = 0.05$) higher levels of polyunsaturated α-linolenic acid than apple, pear, and quince seed oils. The content of α-linolenic acid was found to be 2.5 and 14.3 % for red chokeberry and rose hip, respectively. For Turkish rose hip seed oils, comparable proportions of 19.66 % [37] and 18.13 % [39] have already been reported.

In general, the contents of unsaturated fatty acids (UFA) were 6–10-fold higher in seed oils than those of saturated

Table 5 Representative fatty acid distributions (%) of various Prunoideae kernel oils

	Peach[a]	Apricot, average[b]	Almond, late harvest[c]
C16:0	6.0	4.92	4.97–7.28
C18:0	2.25	1.21	1.10–2.03
C18:1	71.9	70.83	74.12–81.07
C18:2	19.5	21.96	11.01–16.77
C18:3	0	0.08	0.02–0.06
C20:0	0.05	0.10	0.04–0.12

[a] Ref. [42]

[b] Ref. [44]

[c] Ref. [46]

ones (SFA) for all Rosaceae fruits under investigation. High levels of unsaturated fatty acids make these oils very nutritional, because particularly PUFAs have been shown to increase the ratio of HDL to LDL cholesterol [40, 41], thus helping to prevent cardiovascular diseases.

In contrast to the Rosaceae representatives included in this study, recovery of fatty oils from kernel by-products of peach (*Prunus persica* L.), apricot (*Prunus armeniaca* L.), and almond (*Prunus dulcis* (Mill.) D.A. Webb), all belonging to the Prunoideae subfamily, is more common [42–47]. In Table 5, representative data on the FA distributions of peach, apricot, and almond kernel oils found in the literature are given.

A comparison of their FA proportions with those of the seed oils under investigation shows that fatty oils from the representatives of the Prunoideae subfamily contained significantly lower amounts of PUFAs, in particular linoleic acid. Whereas linoleic acid accounted only for 11–22 %, monounsaturated oleic acid was shown to be the most abundant FA, exhibiting contents between 70 and 80 % in Prunoideae seed oils [42, 44, 46]. Therefore, from a nutritional point of view, the higher contents of PUFAs, namely essential linoleic acid, makes seed oils of the Maloideae and Rosoideae also worth being recovered from by-products of fruit processing. However, like almonds, apple seeds are also known to contain cyanogenic glycosides [28]. Consequently, as in the case of bitter almond oil, removal of hydrocyanic acid by distillation of the seed oil is required to rule out any potential health hazards of such products recovered for dietary or cosmetic purposes.

Altogether, seed oils of the Rosaceae family were shown to significantly differ in their FA composition, thus offering a wide range of nutritional, technical, and cosmetic applications. Due to their high levels of unsaturated fatty acids, investigations into other constituents, in particular antioxidants, are currently under way to get a better insight into Rosaceae seed oils and their potential utilization in food and cosmetics.

Conclusions

The present study demonstrated seeds originating from processing of rose hips and various representatives of pomaceous fruits to be promising sources for the recovery of vegetable oils possessing high amounts of unsaturated FAs, particularly essential linoleic acid. FA profiles of seed oils produced from apples, pear ("Gelbmöstler") and quince did not differ significantly, whereas red chokeberry and rose hip seeds exhibited significantly higher amounts of polyunsaturated α-linolenic acid. While differences in FA patterns were only slight, oil contents markedly differed not only within the investigated genera of the Rosaceae subfamilies, but also within the same cultivar of one species. Contrary to polyphenol contents, oil contents of cider apples were generally much lower than in dessert apples. Besides cultivar, non-varietal effects, such as cultivation conditions, climatic factors, and horticultural measures may mainly be responsible for the significant differences among identical cultivars of different origins. Such influences need to be considered when different cultivars are compared. Moreover, apple cultivars showed pronounced differences as far as yields, numbers, and weights of their seeds were concerned. Consequently, apart from oil content, seed yields may decisively determine the profitability of the oil recovery process.

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