applied sciences

Perspective

Perspective of Using Apple Processing Waste for the Production of Edible Oil with Health-Promoting Properties

Wojciech Kolanowski

Faculty of Health Sciences, Medical University of Lublin, Staszica Str. 4, 20-081 Lublin, Poland; wojciech.kolanowski@umlub.pl; Tel.: +48-603842005

Featured Application: The technology outlined here allows for the production of apple seed oil on an industrial scale. It solves the problem of separating seeds from dried apple pomace for oil pressing. The line combines a series of devices used in the processing of cereals, fruit, and vegetables, but its innovation lies in the combination of these devices into one technological line that is adapted to the specificity of the raw material. This is the first technological line for the separation of seeds from apple pomace on an industrial scale. The technology outlined here is in the conceptual phase and requires further research.

Abstract: (1) Background: The effective management of waste and by-products generated in the food industry helps development and implementation of ranges of health-promoting products. The manufacturing of apple juice and cider results in the generation of large quantities of apple pomace. (2) Methods: This paper outlines the concept of a technological process for industrial-scale production of edible oil with a health-promoting fatty acids profile using dried apple pomace as a raw material. (3) Results: Described approach allows for innovative and profitable industrial-scale utilization of the pomace generated from apple juice production. This paper presents a new technological line for apple seed separation intended for oil pressing. (4) Conclusions: The new technological approach could increase the production of apple seed oil. Because of the growing needs in managing post-production waste and by-products, apple seed oil produced from apple pomace on an industrial scale may become a new, attractive product in the functional food market. The fatty acids profile of apple seed oil is high in polyunsaturated fatty acids and can beneficially influence health. The technology outlined here is in the conceptual phase and requires further research.

Keywords: apple pomace; apple juice; apple seed oil; by-products; edible oils; functional food

Citation: Kolanowski, W. Perspective of Using Apple Processing Waste for the Production of Edible Oil with Health-Promoting Properties. *Appl. Sci.* **2024**, *14*, 2932. https://doi.org/10.3390/app14072932

Academic Editor: Anna Lante

Received: 12 March 2024
Revised: 28 March 2024
Accepted: 29 March 2024
Published: 30 March 2024

1. Introduction

Currently, new assortments of edible oils are being introduced to the food market, such as avocado oil, blackcurrant seed oil, herbs, and various nut oils [1]. These oils usually have health-promoting properties or specific sensory and technological properties. Oils with health-promoting properties include blackcurrant or evening primrose seed oil because of the significant content of polyunsaturated fatty acids (PUFA) from the omega-6 and omega-3 groups, which are essential for human health, and monounsaturated omega-9 fatty acids [2,3]. These acids have a beneficial effect on the functioning of the circulatory system, the structure of cell membranes, and the modulation of inflammatory reactions [4]. Oils with special technological properties include, for example, coconut oil, avocado oil, or grapeseed oil with high stability at high cooking temperatures. Oils with special sensory properties include, for example, black cumin seed oil, rose hip oil, or pepper seed oil, which are used to flavor food [5]. Although some of them are produced from waste and by-products of the food industry, such as grapeseed oil or pepper seed oil [1,2,5], these new oils on the market are usually more expensive than commonly used cooking oils.

A special example of market success is grapeseed oil [5–7]. Grape pomace is waste from the production of grape juice and wine. Grape seeds contain large amounts of oil (up to 20% dry matter, depending on the variety) and are used for the production of edible oil [6,8]. Grapeseed oil, the raw material for which is large amounts of grape pomace, is produced on an industrial scale mainly in Italy and Spain [6,9]. This oil has gained success in the market and is now used for frying, baking, and cooking not only in Italy and Spain but also in other EU countries. Similarly, it has been found that the annual production of significant quantities of apple pomace can be utilized as a raw material in the production of a novel edible oil from apple seeds [10]. Apple seeds contain anywhere from 15% to 22% fat in dry matter, which is characterized by a nutritionally beneficial composition of fatty acids: a high content of PUFA, mainly omega-6 linoleic acid, and monounsaturated acids, mainly omega-9 oleic acid [10–14].

There is a noticeable trend in the useful management of waste and by-products generated in the food industry. The industry can use them towards the development and implementation of new ranges of health-promoting food products. Because the world population is growing, and food resources are decreasing, this trend is also important in terms of food security. The aim of this paper is to outline the concept of a technological process for industrial-scale separation of seeds from apple pomace intended for production of an edible oil with health-promoting properties.

2. Raw Material

Apple pomace remains in high quantities after apple juice pressing and can be used in many industrial sectors as a raw material [15–17]. Apple juice is one of the most popular fruit juices in the human diet. Apple production in the world is constantly growing and currently amounts to over 90 million tons per year [18]. A similar volume applies to grapes, at approximately 85 million tons [18]. The largest producer of apples is China, providing nearly half of the world's total volume [19], followed by the USA, Turkey, and Poland, with production of approximately 4.2–4.5 million tons per year each [19]. Apple production in the EU is approximately 12.5 million tons per year. Apple production in Poland has increased by over 30% over the last decade, and in 2022 it amounted to over 4.2 million tons, which is one third of the production of the entire EU [20]. Most of the apples produced in Poland are used to manufacture apple juice, apple juice concentrate, cider, and other apple products [19]. Currently, the largest producers of apple juice concentrate are China, the USA, and Poland [18,19].

After milling and pressing apples for juice, significant amounts of apple pomace remain (including peels, seed chambers, seeds, calyx, stems, and the rest of the tissue). Apple pomace constitutes approximately 25% of the weight of fresh fruit [17,21]. Drying pomace is a common practice enabling storage.

Wet apple pomace (just after juice pressing) can easily spoil during the fermentation and putrefaction processes. Therefore, to enable storage, transportation, and further processing, apple pomace is dried. Large-sized drum dryers with adjustable rotation speeds are commonly used for this purpose. Because of the high temperature of exhaust gases and the flammability of dry pomace, a countercurrent flow of gases is used. The temperature of the drying gases entering the drum is 700–900 °C, and the temperature of the gases leaving the drum is 100–120 °C. The most common uses for dried apple pomace are in the production of bio-renewable fuel as pellets and the production of pectins [17,21]. Apple pectin is a valuable by-product from both the point of view of food technology and human nutrition. Although most plant tissues contain pectin, the primary sources for industrial pectin production are citrus peels and apple pomace [17,21]. This is because of the availability of large amounts of citrus peels and apple pomace remaining after juice production. Apple pomace also has traditional uses, such as composting or as animal feed for dairy cows, sheep, or horses [22–24].

The new use of dried apple pomace described here is its use in the industrial scale production of apple seed edible oil. The direct raw materials used for obtaining this oil are seeds separated from apple pomace [25,26]. Like grapeseed oil, apple seed oil has the potential to become a valuable new by-product of apple juice and cider production. The new technological approach outlined here could increase production of apple seed oil.

In the example of Poland, we provide the volume of apple pomace and the potential yield of apple seed oil below. In Poland, approximately 80% of harvested apples, i.e., approximately 3.4 million tons, are used to produce apple juice and apple juice concentrate [19]. This scale of production results in a significant volume of apple pomace remaining, approximately 850,000 tons per year. The drying of apple pomace causes its weight to be lost by approximately 40%. As a result, approximately 510,000 tons of dried pomace are produced each year. Dried pomace contains, on average, approximately 4–7% seeds (depending on variety), which can be used for the production of apple seed oil. The oil content in apple seeds, depending on the apple variety, is 15–22% [4,7,14]. This amount of pomace contains approximately 25,000 tons of seeds, from which it is possible to obtain, depending on the method, 3.5–5 million liters of oil per year [25]. Drying the pomace and the seeds contained in it facilitates oil pressing and stabilizes the polyphenolic compounds in the seeds [27]. Pressing oil from seeds using only physical methods usually allows us to obtain about 80% of the oil contained therein [28]. Using ultrasound and solvents such as supercritical liquid CO_2, we can increase the efficiency of the process by extracting the remaining oil in an expeller [25,29]. Hypothetically, we can assume that apples are used similarly all over the world. As Polish apple production is ca. 5% of world production, we can assume that on a global scale, the amount of oil produced this way might be approximately 20 times greater than in the example given above and amount to 70–100 million liters of apple seed oil per year. Such large amounts of edible oil with a high nutritional value can be important for business, as well as food security.

Currently, apple seed oil is obtained only on a small scale in the USA, India, and Australia, mainly for cosmetic use [21,30]. They extract the oil using cold pressing with mechanical extraction and low temperatures at 80–90 °F (26–32 °C). Researchers have demonstrated that apple seed oil can alleviate skin inflammation [28,31]. However, the majority of apple seeds go to waste. Apple pomace remains after seed separation and the pressed cake that remains after oil pressing can be used to produce pectin, fiber, feed additives, or pellets. Additionally, attempts have been made to use apple pomace to produce other value-added products such as enzymes, proteins, natural flavors, ethanol, organic acids, polysaccharide preparations, and even squalene [2,30,31].

3. Main Technological Problem

The technological problem of the wider use of apple seeds for oil production on an industrial scale is obtaining large amounts of purified seeds, which would ensure continuity and an appropriate scale of production [32]. There are only a few entries in patent databases and scientific publications regarding the extraction of oil from apple seeds on an industrial scale. They concern the pressing and chemical extraction of apple seed powder. Only two descriptions of a method for separating apple seeds are available, and they concern centrifugation of seeds from diluted apple pulp and manual separation of seeds intended for germination.

The technology presented in this paper is our own innovative concept for solving the problem of separating seeds from dried apple pomace for oil pressing. The proposed technological line combines a series of devices commonly used in the processing of cereals, fruit, and vegetables, but its innovation lies in the fact that, for the first time, these devices have been combined into one technological line adapted to the specificity of the raw material. This is the first technological line for separating seeds from apple pomace on an industrial scale. This technology differs from the technology used in practice to extract oil from grape seeds. In production practice, the separation of grape seeds from dried grape pomace takes place on vibrating sieves [33]. The common element in both technologies is pressing oil in a screw press. With apple pomace, such separation would be ineffective because of the structure of the pomace, which contains large fragments of seeds that do not occur in grapes. For this reason, the separation of apple seeds is the main technological problem when considering pomace as a raw material for oil production on an industrial scale. The proposed technology is in the conceptual phase and requires further research, especially the construction of a prototype line and its verification on a semi-technical and industrial scale.

4. Technological Line for Separating Seeds and Pressing Oil

To solve the technological problem, this paper outlines an idea of the technological line allowing the separation of apple seeds from the dried mass of apple pomace on an industrial scale and obtaining edible oil from apple seeds by cold pressing [32]. Cold-pressed oils contain health-promoting substances, such as tocopherols, polyphenol compounds, and carotenoids, which have strong antioxidant properties and help protect against the activity of free radicals in the human body [24,34]. Therefore, these oils have found recognition in the functional food market [34,35].

The essence of the proposed technological line for obtaining apple seed oil is the use of two sections for separating seeds from dried apple pomace (Figure 1). The first separation section (A) contains a drum-sieve separator (1), rotary beaters (3), a dried pomace dosing unit (2), and containers for small fractions such as fragments of skins, seed cores, and tails (4). At the outlet, the drum-sieve separator (1) couples with a blower section (B, 5) equipped with a fan (6), an outlet for light waste fractions (6′), and a cyclone filter collecting light fractions (7). The section is paired with a tank of pre-cleaned seeds (8). The tank (8) is a dispenser for the second separation section (C), equipped with a linear vibrating screen (9), sieve belt conveyors moved on rollers with two mesh diameters, larger and smaller than the size of the seeds (10, 11), and outlets for the separated two fractions of waste (12). At the output, the linear vibrating screener couples with a blower section (D, 13) that includes a fan (14), an outlet for light waste fractions (14′), and a cyclone filter (15). The section connects to the separated seed tank (16) through a connection node. This tank (16) is also a dispenser for the pressing section (E) equipped with a screw press (17), in which the cold oil pressing process is carried out. The press couples with a container for the expeller (18) and a container for raw oil (19). The container is connected to the filtration section (F) equipped with a filter press or other oil filtration system (20), which is then connected to the bottling section (G) equipped with an oil filler for bottles (21). The description of the line is illustrative, and its performance depends on the scale of the components used.

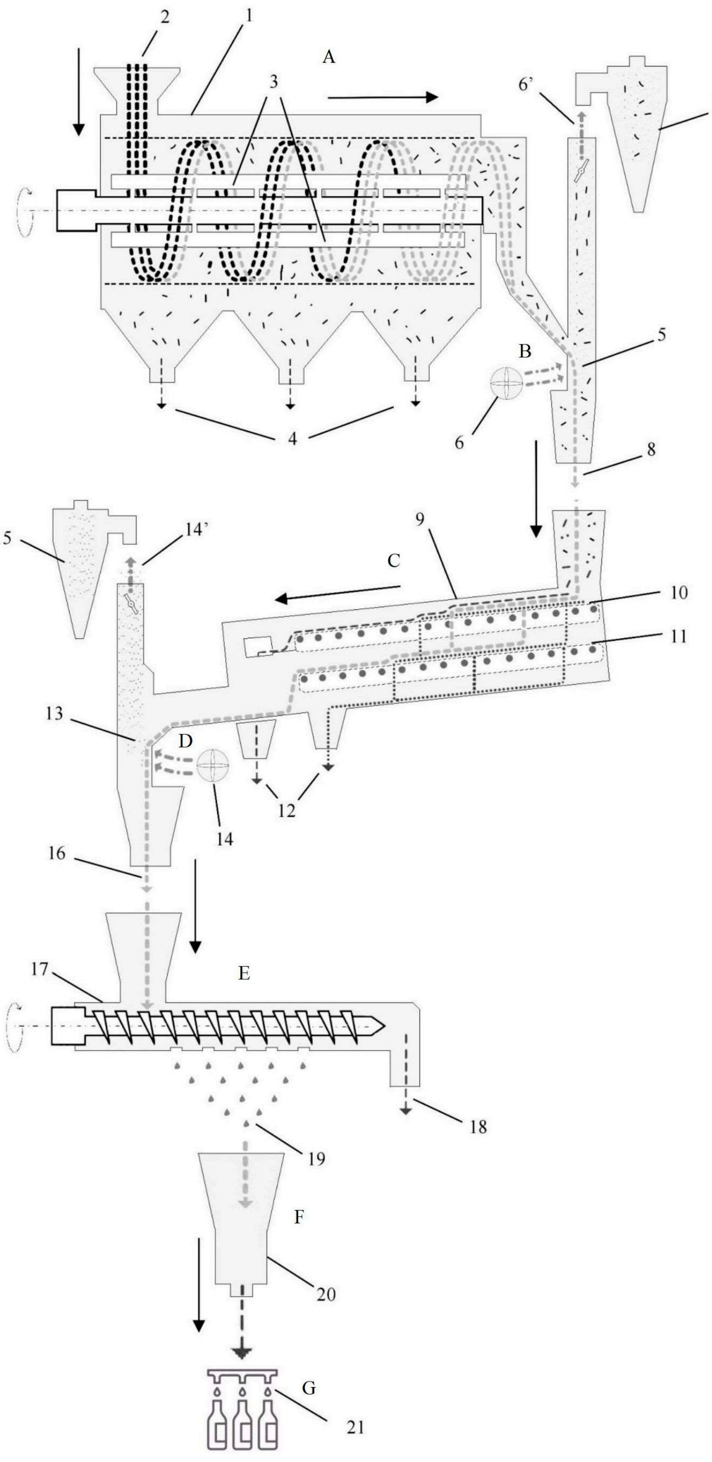

Figure 1. Technological line for the production of apple seed oil on an industrial scale: (A) initial separation section: (1) drum-sieve separator, (2) dosing unit, (3) rotating flail beaters, (4) containers for fine waste fractions; (B) first air blowing section: (5) blower unit (6) blower fan, (6′) light fractions' outlet, (7) cyclone filter, (8) pre-cleaned seeds container; (C) final separation section: (9) linear vibrating screen, (10) and (11) belt sieve and roller conveyors, (12) an outlet for larger and smaller fractions; (D) second air blowing section: (13) blower unit, (14) blower fan, (14′) an outlet for light fractions; (15) cyclone filter, (16) cleaned seeds container; (E) oil pressing section: (17) screw press, (18) waste container, (19) oil container; (F) filtering section: (20) oil filter; (G) bottling section: (21) bottling unit [own invention]. Arrows with continuous line: direction of the technological process. Arrows with dotted lines: direction of raw material movement.

5. The Production Process

In the outlined technology, the raw material is dried apple pomace remains from apple juice production. The pomace goes to the primary separation section (A), which is a drum-sieve separator (1). The drum is made of steel mesh with a mesh size half of the transverse dimension (width) of the apple seeds, i.e., from 2 to 2.4 mm. It is equipped with rotating beater elements on the horizontal axis, driven by an engine. The rotating beater elements of the separator provide momentum to larger fragments of pomace and throw them towards the inner wall of the drum, which causes the crushing of dry lumps, fragments of seeds, and skins, as well as partial dehulling of the seeds from the husks. Fixed mesh dimensions prevent seeds from leaking out when thrown against the inner wall of the drum. Particles smaller than the mesh diameter escape from the drum and are removed. Then, the material passes through the regulated forced air blowing section (B) generated by the fan, which carries away light fractions, lighter than seeds, and the remains of seed sockets, stalks, etc. The pre-cleaned seeds pass to the final separation section (C), separating the remaining impurities. This section consists of two vibrating conveyors with a sieve deck made of steel wire with a square mesh shape running one above the other with an attack angle of approximately 30°. The sieve conveyors are driven by a vibration engine with adjustable throwing force and move on rollers mounted at different heights, thanks to which the conveyor vibrates, which causes the material to be thrown during the movement. We adjust the dimensions of the drum and sieve holes in both separation sections to match the dimensions of apple seeds. The dimensions of the seeds, depending on the apple variety, are length from 7 mm to 9 mm, width from 4 mm to 4.8 mm, and thickness from 2 mm to 2.5 mm [32,36]. The mesh diameter of the upper sieve conveyor is three quarters of the seed length, i.e., from 3.5 mm to 4.5 mm, and that of the lower sieve conveyor is half of the seed width, i.e., from 2 to 2.4 mm. The vibration movement and the diameter of the meshes enable the separation of fragments larger than the size of the seeds on the upper sieve, which fall through the meshes onto the lower sieves, through which fragments smaller than the size of the seeds pass. In this way, the cleaned seeds pass through the section of the blower with a fan (D), where the air blowing carries away the light fractions. Separated residues are remnants of pulp and peels that can be used to obtain pectin and fiber preparations [17,24]. The cleaned apple seeds are directed to the oil pressing section (E). The cold pressing process is carried out on a screw press. The obtained crude oil passes through a filtration section (E) to remove solid particles, residual moisture, and clarification. The entire process uses only physical processing at low temperatures to preserve sensitive bioactive ingredients without chemical treatments. The natural, filtered, cold-pressed oil is poured into dark glass bottles in the pouring section (F), which are then transferred to the warehouse for distribution. A by-product of oil pressing is cake, i.e., de-oiled, pressed seeds. Pressing usually allows for obtaining approximately 80% of the oil from the seeds. Solvent extraction can get the rest of the oil from the cake. For this purpose, e.g., the various grades of petroleum benzin or an inert solvent, such as liquid CO_2, are in a supercritical state [20,25,28]. The cake is used for feed or protein-rich preparations. Apple seeds contain approximately 36% protein [31,36]. However, after de-oiling, the protein content in the cake is close to 45%.

Optimization of the process parameters should especially focus on the optimization of separator mesh sizes, blower force, and conveyor speed. These parameters should be optimized each time a production-scale line is tested.

6. Nutritional and Health Properties

A high content of PUFA—approximately 60%—characterizes apple seed oil. The composition of this oil contains the largest amount of linoleic acid (C 18:2, omega-6) in amounts ranging from 51% to 62%, followed by oleic acid (C 18:1, omega-9) from 28% to 38%, saturated acids from 7% to 9%, and erucic acid from 0.4% to 1.2% [11,12,14,32,37–41]. The content of α-tocopherol (vitamin E) ranges from 50 to 60 mg per 100 g of oil [14,25,41,42]. The physicochemical parameters of the oil are that the acid value is no more than 4.0 mg

KOH/g and the peroxide value is below 15 mmol O_2/g, which meets the requirements for cold-pressed oils [37,41]. This oil contains natural antioxidants such as tocochromanols (tocopherols and tocotrienols) as well as carotenoids and phytosterols [14,37]. This composition should be considered as health-beneficial because linoleic acid is one of the essential PUFAs that should be supplied through one's diet. Moreover, oleic acid has a protective effect on the circulatory system and is the main fatty acid in olive oil. The ratio of polyunsaturated to saturated fatty acids PUFA/SFA (P/S) in apple seed oil is approximately 7, similar to that in grapeseed oil (7.3) [27,33]. Edible fats and oils with a P/S value $\geq$ 2 are considered hypocholesterolemic [43]. Because of the high value of the P/S ratio, apple seed oil can be also considered hypocholesterolemic. Increasing the P/S ratio in one's diet is recommended for the prevention of cardiovascular diseases [43]. Because of favorable fatty acid composition, rapeseed oil is recommended in a healthy diet and is often indicated as a nutritional reference point for other edible oils [44]. The P/S ratio for rapeseed oil is 7, as is the case for apple seed oil [45]. The high content of polyunsaturated fatty acids in apple seed oil suggests its susceptibility to oxidation. However, the high antioxidant potential of this oil has been demonstrated, which protects it against oxidation. It results from the high level of natural antioxidants in the oil, such as tocopherols, tocotrienols, phytosterols, carotenoids, and squalene [30,46–50].

Animal studies indicate that the addition of apple seed oil to the diet of rats had a more beneficial metabolic effect on the body than rapeseed oil. It was shown in terms of the concentration of triacylglycerols and the atherogenic index of plasma, as well as the activity of alanine aminotransferase (ALT) and aspartate aminotransferase (AST) in plasma [43]. Furthermore, apple seed oil has been shown to have antimicrobial activity, inhibiting the growth of bacteria, molds, and yeasts at a minimum inhibitory concentration (MIC) of 0.3 g/mL to 0.6 g/mL [51]. Moreover, the cytotoxic effect of apple seed oil in vitro against specific cell lines has been described, demonstrating its potential as an anticancer agent [26,41]. This effect is probably caused by high levels of natural antioxidants [11,50]. Among these substances, the highest content was found for tocochromanols, among which alpha- and beta-tocopherol predominated, at a level almost twice as high as in cold-pressed rapeseed oil [52]. Some authors indicate the presence of small amounts of erucic acid in apple seed oil [32]. Erucic acid in excess may be harmful to health, especially to the heart muscle. For this reason, the presence of erucic acid in edible oils in the EU cannot exceed 20 g/kg of oil [53]. Apple seed oil is safe in terms of the presence of erucic acid. The erucic acid content was found to be approximately 7 g/kg of oil (from 4 to 12 g/kg of oil) [32]. For comparison, the presence of erucic acid in rapeseed oil available on the market ranges from 0.17 to 9.68 g/kg of oil [54]. The limitation of apple seed use in nutrition is the presence of amygdalin in them. When consumed significantly, amygdalin is toxic to humans due to the cyanogenic degradation products it undergoes in the gastrointestinal tract [55,56]. Amygdalin occurs in the seeds of all fruits in varying amounts. Apricot seeds contained the highest level of amygdalin, with an average of 86.0 mg/g [57,58]. In apple seeds, amygdalin occurs at an average level of 2.5 mg/g [56–58]. The extent to which amygdalin passes into the oil during the cold pressing of the seeds is small. Researchers investigated the phenomenon for apricot seeds and found that amygdalin was present in cold-pressed oil at an average level of 0.4 mg/g [59]. There are no studies available indicating the amygdalin content of apple seed oil. However, assuming the degree of amygdalin transfer from seeds to oil is Similar to apricot seeds, we can expect that apple seed oil has a level of amygdalin as low as 0.01 mg/g. These are small amounts that do not have a harmful effect and may even have a beneficial effect on the body because of their anticancer effects [57].

7. Conclusions and Future Perspectives

The idea of using apple pomace remaining after apple juice production outlined here is in line with current trends in the food industry. The new technological approach described here allows an increase in the production of apple seed oil. This suggests that apple pomace can serve as a raw material for industrial-scale production of edible oil that is rich in PUFA and has high nutritional value. In this way, large amounts of apple pomace resulting from apples juice manufacturing can be used innovatively and profitably. The main technological problem in producing apple seed oil on an industrial scale is separating the seeds from the remaining mass of dried pomace. However, the innovative technological line with two separation sections minimizes this limitation. The technological line outlined here allows the production of apple seed oil on an industrial scale. It solves the problem of separating seeds from dried apple pomace for oil pressing. The line combines a series of devices used in the processing of cereals, fruit, and vegetables, but its innovation lies in the combination of these devices into one technological line that is adapted to the specificity of the raw material. This is the first technological line for the separation of seeds from apple pomace on an industrial scale. The technology outlined here is in the conceptual phase and requires further research, especially the construction of a prototype line and its verification on a semi-technical and industrial scale. Because of the growing needs in managing post-production waste and by-products, apple seed oil produced from apple pomace on an industrial scale may become a new, attractive product in the functional food market.

Funding: This research received no external funding.

Conflicts of Interest: The author declare no conflict of interest.

References

1. Yao, Y.; Xu, B. New insights into chemical compositions and health promoting effects of edible oils from new resources. *Food Chem.* **2021**, *363*, 130363. [CrossRef] [PubMed]
2. Fidelis, M.; de Moura, C.; Kabbas, T.; Pap, N.; Mattila, P.; Mäkinen, S.; Putnik, P.; Bursać Kovačević, D.; Tian, Y.; Yang, B.; et al. Fruit Seeds as Sources of Bioactive Compounds: Sustainable Production of High Value-Added Ingredients from By-Products within Circular Economy. *Molecules* **2019**, *24*, 3854. [CrossRef] [PubMed]
3. Julibert, A.; del Mar Bibiloni, M.; Tur, J.A. Dietary fat intake and metabolic syndrome in adults: A systematic review. *Nutr. Metab. Cardiovasc. Dis.* **2019**, *29*, 887–905. [CrossRef] [PubMed]
4. Kandemir, K.; Piskin, E.; Xiao, J.; Tomas, M.; Capanoglu, E. Fruit Juice Industry Wastes as a Source of Bioactives. *J. Agric. Food Chem.* **2022**, *70*, 6805–6832. [CrossRef] [PubMed]
5. Kapcsándi, V.; Lakatos, E.H.; Sik, B.; Ádám, L.; Székelyhidi, R. Characterization of fatty acid, antioxidant, and polyphenol content of grape seed oil from different *Vitis vinifera* L. varieties. *Oilseeds Fats Crops Lipids* **2021**, *28*, 30. [CrossRef]
6. De Cássia de Souza, R.; Souza Machado, B.A.; de Abreu Barreto, G.; Leal, I.L.; Pereira dos Anjos, J.; Umsza-Guez, M.A. Effect of Experimental Parameters on the Extraction of Grape Seed Oil Obtained by Low Pressure and Supercritical Fluid Extraction. *Molecules* **2020**, *25*, 1634. [CrossRef]
7. Jin, Q.; O'Keefe, S.F.; Stewart, A.C.; Neilson, A.P.; Kim, Y.T.; Huang, H. Techno-economic analysis of a grape pomace biorefinery: Production of seed oil, polyphenols, and biochar. *Food Bioprod. Process.* **2021**, *127*, 139–151. [CrossRef]
8. Ahmadi, S.M.; Siahsar, B.A. Analogy of physicochemical attributes of two grape seeds cultivars. *Cienc. Investig. Agrar.* **2011**, *38*, 291–301. [CrossRef]
9. Garavaglia, J.; Markoski, J.J.; Oliveira, A.; Marcadenti, A. Grape seed oil compounds: Biological and chemical actions for health. *Nutr. Metab. Insights* **2016**, *9*, 59–64. [CrossRef]
10. Abbas, A.; Anwar, F.; Ahmad, N. Apple (*Malus pumila*) Seed Oil. In *Fruit Oils: Chemistry and Functionality*; Ramadan, M., Ed.; Springer: Berlin, Germany, 2020; pp. 495–504.
11. Akšić, F.M.; Lazarević, K.; Šegan, S.; Natić, M.; Tosti, T.; Ćirić, I.; Meland, M. Assessing the Fatty Acid, Carotenoid, and Tocopherol Compositions of Seeds from Apple Cultivars (*Malus domestica* Borkh.) Grown in Norway. *Foods* **2021**, *10*, 1956.
12. Fromm, M.; Bayha, S.; Carle, R.; Kammerer, D.R. Comparison of fatty acid profiles and contents of seed oils recovered from dessert and cider apples and further Rosaceous plants. *Eur. Food Res. Technol.* **2012**, *234*, 1033–1041. [CrossRef]
13. Montañés, F.; Catchpole, O.J.; Tallon, S.; Mitchell, K.A.; Scott, D.; Webby, S.F. Extraction of apple seed oil by supercritical carbon dioxide at pressures up to 1300 bar. *J. Supercrit. Fluids* **2018**, *141*, 128–136. [CrossRef]
14. Pieszka, M.; Migdał, W.; Gasior, R.; Rudzińska, M.; Bederska-Łojewska, D.; Pieszka, M.; Szczurek, P. Native oils from apple, blackcurrant, raspberry, and strawberry seeds as a source of polyenoic fatty acids, tocochromanols, and phytosterols: A health implication. *J. Chem.* **2015**, *2015*, 659541. [CrossRef]
15. Gołębiewska, E.; Kalinowska, M.; Yildiz, G. Sustainable Use of Apple Pomace (AP) in Different Industrial Sectors. *Materials* **2022**, *15*, 1788. [CrossRef] [PubMed]
16. FAOSTAT. Apples—Crops and Livestock Products. Available online: https://www.fao.org/faostat/en/#data/QCL (accessed on 8 September 2023).
17. Bugała, A. Raport o rynku jabłek. *Agro Ind.* **2022**, *24*, 55–59.

18. Martău, G.A.; Teleky, B.E.; Ranga, F.; Pop, I.D.; Vodnar, D.C. Apple Pomace as a Sustainable Substrate in Sourdough Fermentation. *Front. Microbiol.* **2021**, *12*, 3850. [CrossRef] [PubMed]
19. Lyu, F.; Luiz, S.L.; Perdomo Azeredo, D.R.; Cruz, A.G.; Ajlouni, S.; Ranadheera, C.S. Apple Pomace as a Functional and Healthy Ingredient in Food Products: A Review. *Processes* **2020**, *8*, 319. [CrossRef]
20. Bernat, P.J. Jakie są prognozy dla rynku jabłek na rok 2023? *Sad Nowocz.* **2023**, *1*, 55–59.
21. Malhi, N.; Carragher, J.; Saarela, M.; Pahl, S. *A Review of Opportunities to Recover Value from Apple and Pear Pomace*; Fight Food Waste Cooperative Research Centre: Adelaide, Australia, 2021; pp. 4–29.
22. Dhillon, G.S.; Kaur, S.; Brar, S.K. Perspective of apple processing wastes as low-cost substrates for bioproduction of high value products: A review. *Renew. Sustain. Energy Rev.* **2013**, *27*, 789–805. [CrossRef]
23. Gullón, B.; Falqué, E.; Alonso, J.L.; Parajó, J.C. Evaluation of apple pomace as a raw material for alternative applications in food industries. *Food Technol. Biotechnol.* **2007**, *45*, 426–433.
24. Putra, N.R.; Rizkiyah, D.N.; Abdul Aziz, A.H.; Che Yunus, M.A.; Veza, I.; Harny, I.; Tirta, A. Waste to Wealth of Apple Pomace Valorization by Past and Current Extraction Processes: A Review. *Sustainability* **2023**, *15*, 830. [CrossRef]
25. Ferrentino, G.; Giampiccolo, S.; Morozova, K.; Haman, N.; Spilimbergo, S.; Scampicchio, M. Supercritical fluid extraction of oils from apple seeds: Process optimization, chemical characterization and comparison with a conventional solvent extraction. *Innov. Food Sci. Emerg. Technol.* **2020**, *64*, 102428. [CrossRef]
26. Kumar, M.; Barbhai, M.D.; Esatbeyoglu, T.; Zhang, B.; Sheri, V.; Dhumal, S.D.; Rais, N. Apple (*Malus domestica* Borkh.) seed: A review on health promoting bioactivities and its application as functional food ingredient. *Food Biosci.* **2022**, *50*, 102155. [CrossRef]
27. Ma, Q.; Bi, J.; Yi, J.; Wu, X.; Li, X.; Zhao, Y. Stability of phenolic compounds and drying characteristics of apple peel as affected by three drying treatments. *Food Sci. Hum. Wellness* **2021**, *10*, 174–182. [CrossRef]
28. Cheng, M.H.; Dien, B.S.; Singh, V. Economics of plant oil recovery: A review. *Biocatal. Agric. Biotechnol.* **2019**, *18*, 101056. [CrossRef]
29. Gasparini, A.; Ferrentino, G.; Angeli, L.; Morozova, K.; Zatelli, D.; Scampicchio, M. Ultrasound assisted extraction of oils from apple seeds: A comparative study with supercritical fluid and conventional solvent extraction. *Innov. Food Sci. Emerg. Technol.* **2023**, *86*, 103370. [CrossRef]
30. Scortichini, S.; Appignanesi, D.; Zannotti, M.; D'Amato, C.A.; Lenti, L.; Maggi, F.; Ferraro, S.; Fiorini, D.; Giovannetti, R. Fatty acid composition, squalene and elements in apple by-products: Comparison between ancient cultivars and commercial varieties. *Eur. Food Res. Technol.* **2022**, *248*, 1541–1551. [CrossRef]
31. Barreira, J.C.M.; Arraibi, A.A.; Ferreira, I.C. Bioactive and functional compounds in apple pomace from juice and cider manufacturing: Potential use in dermal formulations. *Trends Food Sci. Technol.* **2019**, *90*, 76–87. [CrossRef]
32. Kolanowski, W.; Zakrzewska, M. Apple processing wastes as potential source of new edible oil. *J. Food Nutr. Res.* **2019**, *58*, 92–98.
33. Martin, M.E.; Grao-Cruces, E.; Millan-Linares, M.; Montserrat de la Paz, S. Grape (*Vitis vinifera* L.) Seed Oil: A Functional Food from the Winemaking Industry. *Foods* **2020**, *9*, 1360. [CrossRef]
34. Grajzer, M.; Szmalcel, K.; Kuźmiński, Ł.; Witkowski, M.; Kulma, A.; Prescha, A. Characteristics and Antioxidant Potential of Cold-Pressed Oils—Possible Strategies to Improve Oil Stability. *Foods* **2020**, *9*, 1630. [CrossRef]
35. Chen, C.; Razali, U.H.; Saikim, F.H.; Mahyudin, A.; Noor, N.Q. Morus alba L. Plant: Bioactive Compounds and Potential as a Functional Food Ingredient. *Foods* **2021**, *10*, 689. [CrossRef] [PubMed]
36. Kumar, S.; Sharma, P.C. Process protocol for mechanical separation of fruit core and seeds from apple fruits. *Int. J. Farm Sci.* **2017**, *7*, 147–153.
37. Matthäus, B.; Özcan, M.M. Oil content, fatty acid composition and distributions of vitamin-E-active compounds of some fruit seed oils. *Antioxidants* **2015**, *4*, 124–133. [CrossRef]
38. Bada, J.C.; León-Camacho, M.; Copovi, P.; Alonso, L. Characterization of apple seed oil with Denomination of Origin from Asturias, Spain. *Grasas Aceites* **2014**, *65*, e027.
39. Madera, R.R.; Suarez Valles, B. Characterization of apple seeds and their oils from the cider-making industry. *Eur. Food Res. Technol.* **2018**, *244*, 1821–1827.
40. Yukui, R.; Wenya, W.; Rashid, F.; Qing, L. Fatty Acids Composition of Apple and Pear Seed Oils. *Int. J. Food Prop.* **2009**, *12*, 774–779. [CrossRef]
41. Walia, M.; Rawa, K.; Bhushan, S.; Padwad, Y.S.; Singh, B. Fatty acid composition, physicochemical properties, antioxidant and cytotoxic activity of apple seed oil obtained from apple pomace. *J. Sci. Food Agric.* **2014**, *94*, 929–934. [CrossRef]
42. Górnaś, P.; Mišina, I.; Ikase, L. Crab Apple (*Malus* spp.) Seed Tocopherol Profile: Impact of Genotype, Species, Purpose and Rootstock. *Agronomy* **2022**, *12*, 2736. [CrossRef]
43. Willet, W.C. Dietary fats and coronary heart disease. *J. Intern. Med.* **2012**, *272*, 13–24. [CrossRef]
44. Amiri, M.; Raeisi-Dehkordi, H.; Sarrafzadegan, N.; Forbes, S.C.; Salehi-Abargouei, A. The effects of Canola oil on cardiovascular risk factors: A systematic review and meta-analysis with dose-response analysis of controlled clinical trials. *Nutr. Metab. Cardiovasc. Dis.* **2020**, *30*, 2133–2145. [CrossRef]
45. Beyzi, E.; Gunes, A.; Buyukkilic Beyzi, E.; Konca, Y. Changes in fatty acid and mineral composition of rapeseed (*Brassica napus* ssp. *Oleifera* L.) oil with seed sizes. *Ind. Crops Prod.* **2019**, *129*, 10–14.
46. Górnaś, P.; Lacis, G.; Mišina, I.; Ikase, L. Tocopherols in Cultivated Apple *Malus* sp. Seeds: Composition, Variability and Specificity. *Plants* **2023**, *12*, 1169. [CrossRef] [PubMed]

47. Fromm, M.; Bayha, S.; Kammerer, D.; Carle, R. Identification and Quantitation of Carotenoids and Tocopherols in Seed Oils Recovered from Different Rosaceae Species. *Agric. Food Chem.* **2012**, *60*, 10733–10742. [CrossRef]
48. Górnaś, P.; Seglina, D.; Lacis, G.; Pugajeva, I. Dessert and crab apple seeds as a promising and rich source of all four homologues of tocopherol (a, b, g and d). *LWT—Food Sci. Technol.* **2014**, *47*, 211–214. [CrossRef]
49. Górnaś, P.; Rudzińska, M.; Segkuna, D. Lipophilic composition of eleven apple seed oils: A promising source of unconventional oil from industry by-products. *Ind. Crops Prod.* **2014**, *60*, 86–91. [CrossRef]
50. Kaseke, T.; Opara, U.L.; Fawole, O.A. Fatty acid composition, bioactive phytochemicals, antioxidant properties and oxidative stability of edible fruit seed oil: Effect of preharvest and processing factors. *Helyon* **2020**, *6*, e04962. [CrossRef]
51. Fotschki, B.; Jurgoński, A.; Juśkiewicz, J.; Zduńczyk, P. Metabolic effects of dietary apple seed oil in rats. *Food Sci. Technol. Qual.* **2015**, *98*, 220–231. [CrossRef]
52. Górnaś, P.; Soliven, A.; Seglina, D. Seed oils recovered from industrial fruit by-products are a rich source of tocopherols and tocotrienols: Rapid separation of a/b/g/d homologues by RP-HPLC/FLD. *Eur. J. Lipid Sci. Technol.* **2015**, *117*, 773–777. [CrossRef]
53. Commission Regulation (EU) 2019/1870 of 7 November 2019 amending and correcting Regulation (EC) No 1881/2006 as regards maximum levels of erucic acid and hydrocyanic acid in certain foodstuffs. *Off. J. Eur. Union* **2019**, *289*, 37.
54. Russo, M.; Yan, F.; Stier, A.; Klasen, L.; Honermeier, B. Erucic acid concentration of rapeseed (*Brassica napus* L.) oils on the German food retail market. *Food Sci. Nutr.* **2021**, *9*, 3664–3672. [CrossRef]
55. Bolarinwa, I.F.; Orfila, C.; Morgan, M.R.A. Determination of amygdalin in apple seeds, fresh apples and processed apple juices. *Food Chem.* **2015**, *170*, 437–442. [CrossRef]
56. Opyd, P.M.; Jurgoński, A.; Juśkiewicz, J.; Milala, J.; Zduńczyk, Z.; Król, B. Nutritional and health-related effects of a diet containing apple seed meal in rats: The case of amygdalin. *Nutrients* **2019**, *9*, 1091. [CrossRef] [PubMed]
57. Jaszczak-Wilke, E.; Polkowska, Ż.; Koprowski, M.; Owsianik, K.; Mitchell, A.E.; Bałczewski, P. Amygdalin: Toxicity, Anticancer Activity and Analytical Procedures for Its Determination in Plant Seeds. *Molecules* **2021**, *26*, 2253. [CrossRef] [PubMed]
58. Senica, M.; Stampar, F.; Veberic, R.; Mikulic-Petkovsek, M. Fruit Seeds of the *Rosaceae* Family: A Waste, New Life, or a Danger to Human Health? *J. Agric. Food Chem.* **2017**, *65*, 10621–10629. [CrossRef] [PubMed]
59. Vidović, S.; Vladić, J.; Popović, L.; Moslavac, T.; Jakobović, S.; Jokić, S. Recovery of Tocopherols, Amygdalin, and Fatty Acids from Apricot Kernel Oil: Cold Pressing Versus Supercritical Carbon Dioxide. *Eur. J. Lipid Sci. Technol.* **2018**, *120*, 1800043.