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Review

Unveiling the Potential of Apricot Residues: From Nutraceuticals to Bioenergy

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Abstract: Stone fruits, such as the apricot (*Prunus armeniaca* L.), are frequently consumed. As such, a substantial volume of apricot waste is generated at each stage of the food supply chain, including harvesting, processing, packaging, warehousing, transportation, retailing, and eventual consumption. This generates tons of waste annually on a global scale. The significant amounts of phenolics present in these wastes are primarily responsible for their antioxidant capacity and the subsequent health advantages they provide. As such, apricot pulp by-products could be a valuable reservoir of bioactive compounds, such as tocopherols, polyphenolic compounds, proteins, dietary fibers, etc. Moreover, apricot kernels are also recognized for their abundance of bioactive compounds, including polyphenols and tocopherols, which find utility in diverse sectors including cosmetology and the food industry. Both conventional and green methods are employed, and generally, green methods lead to higher extraction efficiency. The antimicrobial properties of apricot kernel essential oil have been widely recognized, leading to its extensive historical usage in the treatment of diverse ailments. In addition, apricot kernel oil possesses the capacity to serve as a viable resource for renewable fuels and chemicals. This review examines the potential of apricot waste as a source of bioactive compounds, as well as its utilization in diverse applications, with an emphasis on its contribution to health improvement.

Keywords: *Prunus armeniaca*; pulp; kernel; stone fruit; kernel oil; biofuel; antioxidant; deep eutectic solvents; extraction; bioactive compounds

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1. Introduction

Apricots (*Prunus armeniaca* L.), a widely consumed fruit worldwide, belong to the genus Prunus and the family Rosaceae [1]. Apricot trees are small- to average-sized, deciduous trees that reach a maximum height of about 8 to 12 m when fully grown. The 40 cm diameter tree trunk has a greyish-brown surface, and its outspread canopy is made up of twisted branches. The oval-shaped leaves of the tree have a pointed tip and measure 5–9 cm in length and 4–8 cm in width. The underside of the leaves have a hint of yellow, but their surface is a deep green color [2]. The flowers have five petals, a width of 2 to 4 cm, and open in April and May, contingent on the cultivar and surrounding circumstances. It takes the fruit three to six months to fully develop and ripen [3]. It is a drupe and is 3–5 cm wide, though some types can get up to 8 cm wide. The fruit has a yellow or reddish-orange color and a smooth (glabrous) or velvety (pubescent) surface. One side of the fruit has a ridge that runs down it. A single, 1.5 cm wide seed is positioned in the center of the fruit and is covered by a hard shell. Together, the seed along with the shell make up the fruit stone, which has a grooved surface and a gritty texture [4]. Figure 1 illustrates an apricot tree along with the fruit and its parts.

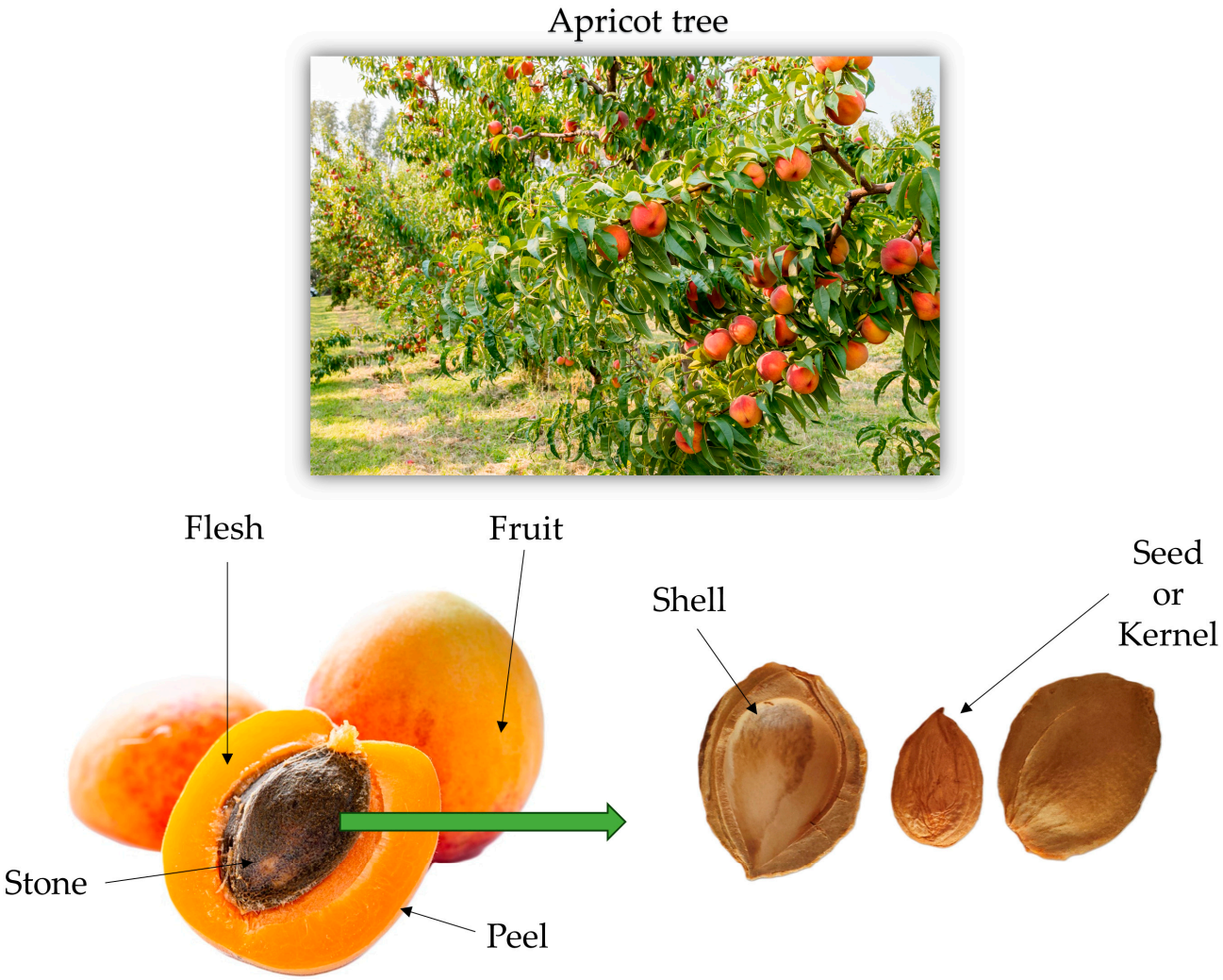

Figure 1. Apricot tree and apricot fruit constituents.

Apricots, which originated in China, were introduced to the Mediterranean region [5]. Apricots are important fruits for human nutrition and have been cultivated for a long time [6]. They are used to make juices and canned products, or eaten either fresh or dried. An estimated 40 million tons of apricots are produced annually, with Turkey and Iran leading the world's production [6]. Rich in polyphenols, vitamins and carotenoids, apricots are fruits with a high nutritional value [7]. Roughly 7% of the fruit is made up of seed, which is regarded as waste. About 18 to 38% of the seed is made up of apricot kernels, which are contained in the pit or stone. These kernels are valuable commercially because they are used to produce oil and are also used in the cosmetics industry. Additionally, apricot kernels are used in the production of food products, thermal energy storage, and the creation of antimicrobial films [8,9]. One of the initiatives to stop deaths from microbial infections, which are recognized to be a leading cause of death globally, was the creation of antimicrobial films [10,11]. Additionally, research has shown that polyphenols' ability to prevent heart disease and cancer is one of their many health benefits for people [12–14].

The United Nations projects that by 2050, there will be 9.7 billion people on the planet, up from 7.7 billion in 2019 [15]. This possibility presents a number of concerns regarding the expected twofold increase in the consumption of fuels, fossil metals, biomass, and minerals, as well as the projected 70% increase in annual waste production if current trends continue for the next 40 years [16]. These ideas contradict the trend toward a circular economy and more sustainable development. The circular economy is a production and consumption model that promotes the life span of products by advocating for practices such as recycling,

leasing, repairing, sharing, refurbishing, and reusing of existing materials and products [17]. A crucial element of the proposed circular bio-based economy involves the conversion of biomass wastes and residues into valuable commodities. It means cutting waste to a minimum. Upon reaching the end of its functional lifespan, every effort is made to retain the materials of a product within the economic system [18]. These have the potential to be productively utilized repeatedly, adding more value to the waste [19]. In alignment with the objective of a circular economy and enhanced resource efficiency, the European Union (EU) is strategically transitioning from a linear to a circular economy. This transition involves the incorporation of new inputs and resources, coupled with the conversion of waste into valuable resources [20,21]. In this context, research about circular economy and reuse of materials is of high importance. In the light of the above, our study contributes to addressing sustainable development goals (SDGs), with a specific emphasis on SDG12: responsible consumption and production. By promoting the principles of the circular economy, our research actively supports the objectives of SDG12 to ensure sustainable patterns of consumption and production. This alignment is particularly noteworthy in the context of mitigating the potential environmental impacts associated with the projected surge in global population and resource consumption.

The need for new materials that can aid in energy conservation has increased due to the worldwide crisis concerning energy resources [22]. As a by-product of processing apricots, apricot kernel shells (AKS) can be recovered and utilized again in different fields [23]. Here are a few instances of how AKS can be utilized: as a biomass fuel with a high calorific value to produce heat and electricity, as animal feed, as a highly porous material made of carbon added as a soil amendment to enhance the quality of the soil, as a lightweight building content, etc. When combined with cement, the shells can create lightweight, well-insulated concrete [24]. Given the consequences of inappropriate waste management and nonrecycling, recovering apricot kernel shells can have a major positive environmental impact as well as financial gains [25]. Nonrenewable fuels have been replaced with biofuels. Moreover, waste, vegetable, and animal oils can be used as fuels in place of conventional diesel fuels. Because fatty acids are the primary by-product of the synthesis of apricot kernels, they are regarded as a renewable fuel source [26]. A significant quantity of the apricot kernel shell is a by-product of agriculture. These by-products were once utilized as fuel in rural areas, but more recently, the creation of liquid fuel and activated carbon has been promoted. Because it is an inexpensive precursor, it is crucial to assess the potential of apricot kernel shells in the production of liquid fuel and activated carbon [27–31].

Regarding this matter, the apricot seed has attracted considerable attention in research. Apricot seeds have significant amounts of antioxidant and polyphenolic compounds, both of which have significant pharmacological roles. Foods high in fiber and low in fat are emerging developments in the food industries. Except for fats, proteins, and trace minerals, apricot kernels contain a substantial amount of dietary fiber that may be beneficial to human health. However, one must also consider the amount of macro- and micro-molecules required to maintain sufficient nutritional value. It is believed that there may be oil sources in apricot kernel seeds. Apricot kernel oil contains high levels of certain vitamins and minerals, such as potassium and magnesium. The primary objective of this review article was to investigate and analyze the possible routes for utilizing apricot by-products containing bioactive compounds (Figure 2) and their associated health benefits, as well as their positive impact on the environment. By diving into the current literature, this article aimed to shed light on the different approaches and applications that can be employed to maximize the utilization of apricot by-products, thereby enhancing human well-being.

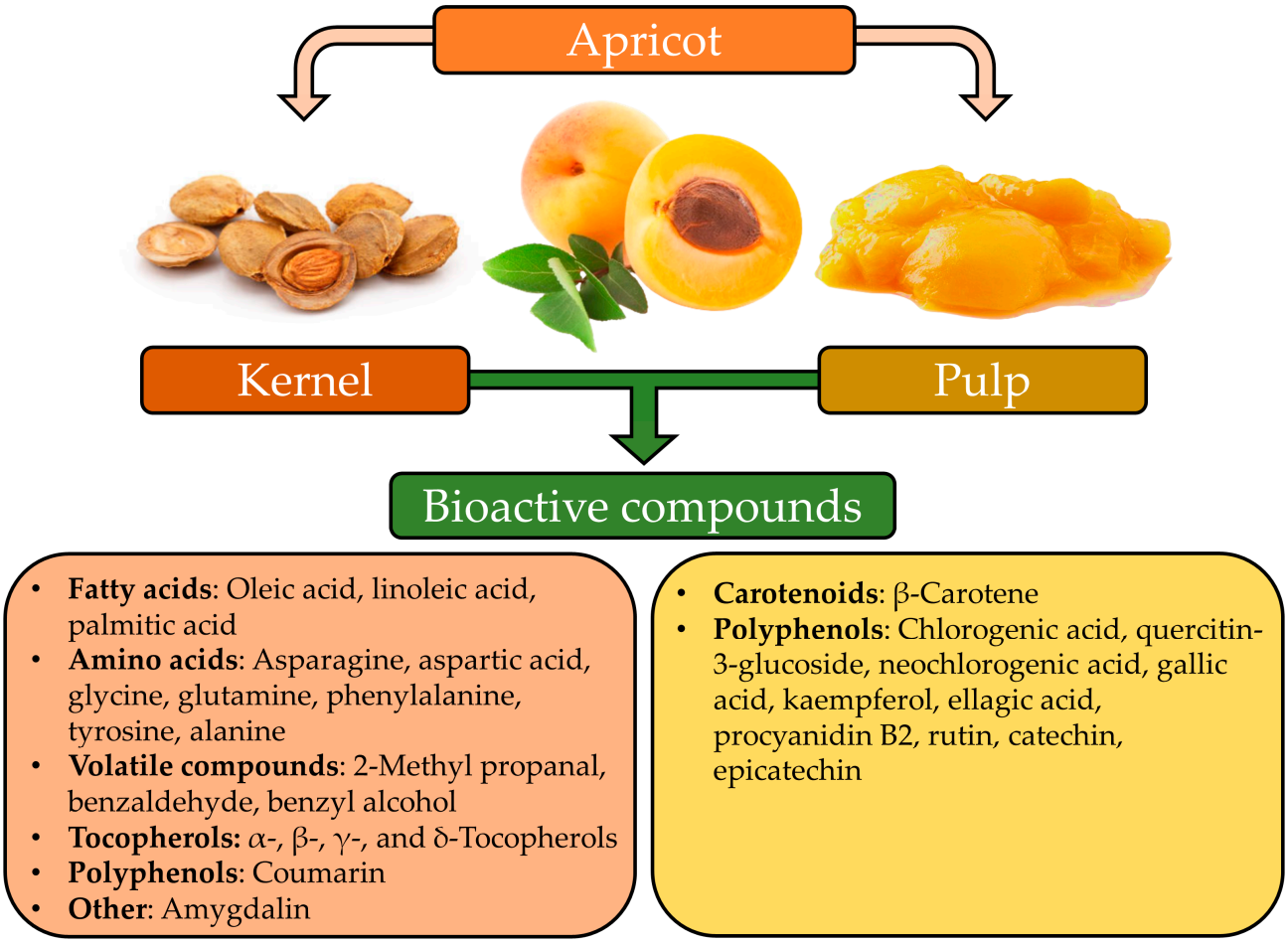

Figure 2. Apricot by-products as sources of bioactive compounds.

2. Apricot By-Products and Their Value

2.1. Apricot Kernel

2.1.1. Apricot Kernel Biomass

The investigation published by Kancabas Kilinc and Karakaya [32] involved the preparation of a suspension of apricot kernel milk, utilizing raw and roasted apricot kernels (AK) of the Hacıhaliloğlu variety. The AKs underwent a roasting procedure at 170 °C and the total lipid, protein, and ash contents of AKs and AK milk were quantified. To produce AK milk, the kernel was immersed in ultrapure water at ambient temperature and left to soak overnight. The mixture underwent agitation using a blender and was subsequently filtered through cheesecloth. Based on the results obtained from gas chromatography, oleic acid, linoleic acid, and palmitic acid were identified as the primary fatty acids. The process of roasting was observed to result in the aggregation of oil bodies in AK milk, as compared to the oil bodies in unroasted samples. The proteins present in AK milk and roasted AK milk underwent varying degrees of hydrolysis during in vitro gastrointestinal digestion. Nevertheless, it was found that pepsin-resistant proteins were present in both samples, and aggregation of the oil bodies was noticed. Furthermore, it was observed that a small number of oil bodies, varying in size, remained intact following the completion of the process of intestinal digestion of AK milk. Nevertheless, the process of disaggregation was not observed during a 120 min period of intestinal digestion of roasted AK milk. Furthermore, it should be noted that a volume of 250 mL of AK milk contains approximately 50 g of kernel, which is equivalent to a mere 12.5 mg of amygdalin. This quantity is significantly below the toxic threshold of 200 mg, a dosage that could potentially induce poisoning in a child weighing 20 kg [33].

Lolli et al. [34] assessed a single step enzymatic extraction technique, employing a protease, to simultaneously and sustainably extract oils and proteins from the seeds or/and kernels of various citrus, stone, and exotic fruits employing a one-pot protease in an aqueous medium. Among others, AKs were examined. The AK's ash protein fat and total dietary fibers were determined, and their values were 1.0, 5.237, 5.3, and 93% w/w of their dry weight, respectively. The fat content was revealed to be the second highest of all the fruits under examination, following the avocado seed. The protein hydrolysates yield of apricot seeds was ~47% but exhibited a relatively low nutritional quality due to the presence of limiting amino acids, namely histidine, methionine, and lysine. The highest amounts of amino acids identified in apricot seeds were 179 mg/g asparagine and aspartic acid, 172 mg/g glycine and glutamine, 86 mg/g phenylalanine and tyrosine, and 70 mg/g alanine. In contrast, the fruit seed/kernel oils exhibited a notable nutritional profile, characterized by a significant abundance of unsaturated fatty acids, particularly oleic acid (>25%) and linoleic acid (up to 40%).

The investigation by Makrygiannis et al. [35] examined the extraction process of polyphenols from AK biomass. In order to achieve this objective, a widely used extraction method utilizing water as the solvent was implemented. The investigation involved the examination of deep eutectic solvents (DES) in order to improve the extraction yield. DES are considered green solvents, which are of high purity, nontoxic, and biodegradable [36]. Furthermore, the investigation also encompassed the evaluation of pulsed electric field (PEF) as an independent extraction technique or as a supplementary procedure. The DES solvent was formulated through combining glycerol as a hydrogen bond donor and choline chloride as a hydrogen bond acceptor. A solution was created by mixing glycerol and choline chloride in a molar ratio of 2:1 (w/w). The mixture was placed in a glass vial that was sealed tightly and heated to a temperature between 80 and 90 °C for a period of 90 min while being agitated until the formation of a visually clear liquid. Subsequently, the DES was subjected to dilution with water, resulting in a concentration of 80% (w/w) in order to facilitate subsequent extraction processes. The samples were subjected to PEF treatment for a period of 15 min. The electric field strength used was 1.0 kV/cm, with a pulse duration of 10 μs and a pulse period of 1000 μs. Based on the findings, it was evident that the application of PEF before the extraction process led to a significant 88% rise in the total polyphenol content (TPC). Similarly, with the utilization of glycerol, choline chloride (2:1 w/w) DES resulted in a significant elevation of the TPC by approximately 70%. Upon the combination of the PEF and DES treatment, a notable increase of 173% was observed. According to the information provided above, it can be assumed that AK biomass exhibits significant potential as a rich reservoir of polyphenols, particularly when employing the suggested extraction methodology.

In addition, the same research team [37] attempted to extract oil from AKs ('Bebeco' cultivar) and analyze their composition and antioxidant properties. The study utilized samples derived from the by-products of an apricot cannery over a span of two years. A widely utilized extraction methodology was implemented, employing hexane as the solvent. Subsequently, an examination of the fatty acid composition of the oil was conducted, alongside the evaluation of its antioxidant properties through the utilization of multiple techniques. The findings of the study demonstrated that the oil derived from AKs possessed a notable abundance of oleic and palmitoleic acids, both of which have been associated with various health advantages. Regarding the volatile compounds present in the oil, the primary compounds identified were 2-methyl propanal, benzaldehyde, and benzyl alcohol. The primary constituent of the essential oil derived from the kernel was determined to be benzaldehyde. In addition, the oil displayed a diminished level of antioxidant activity, as evidenced by its capacity to effectively neutralize free radicals. In summary, the results of the study indicated that AKs possess significant potential as a valuable oil source, which can be utilized in various applications within the food and cosmetic sectors.

A study was carried out by Pop et al. [38] to quantify various compounds and their antioxidant properties from sea buckthorn berries and apricot pulp and kernels. A com-

bination of methylene, petroleum ether, and acetate in a ratio of 1:1:1 ($v/v/v$) was used for the extraction process. Carotenoids and tocopherols were separated using the reverse phase HPLC method, and the antioxidant contents were found using spectrophotometry and the fluorescence absorbance technique. Apricot pulp was found to contain 3.51 mg of carotenoids per 100 g of pulp, with β-carotene being the most abundant type. Although AK had more tocopherols than fruit pulp, γ-tocopherol was the main tocopherol found. Trolox equivalent antioxidant capacity (TEAC) was used to quantify the antioxidant capacities. It was found that apricot pulp had 0.59 μM TEAC/g of fresh weight (FW) while apricot kernel had 0.05 μM TEAC/g FW. Their findings corroborated those that indicated the antioxidant properties of apricot fruit and kernels were associated with TPC, carotenoids, and tocopherols. On the contrary, TPC decreases post-harvest, while lipophilic compounds like carotenoids and tocopherol exhibit enhanced antioxidant properties [39].

2.1.2. Apricot Kernel Oil

Gupta et al. [40] aimed to determine the principal characteristics, such as fruit, stone, and kernel weight, as well as the kernel and oil recovery of apricots *(Prunus armeniaca* Linn.). The attributes were evaluated in stones gathered from various places within Himachal Pradesh. Additionally, the physicochemical characteristics of the crude oil were also analyzed. The oil was obtained through a filter press. The average weight of apricot fruits varied from 8.0 to 15.1 g, while the percentage of stone recovery ranged from 12.7 to 22.2%. The weight of the stone itself was found to be between 1.78 and 1.92 g. Moreover, the analysis revealed that the recovery rate of the kernel ranged from 30.7 to 33.7%, while the kernels yielded crude oil ranging from 45.6 to 46.3%. The research findings indicated that the hue of AKO was observed to be yellow. Additionally, the acid value, peroxide value, iodine value, and saponification value were determined to be within the ranges of 2.27 to 2.78 mg potassium hydroxide (KOH)/g, 5.12–5.27 meq/kg, 100.2 to 100.4 g I_2/100 g, and 189.8 to 191.3 mg KOH/g oil, respectively. The analysis of the fatty acid composition of the oil revealed that the predominant fatty acids present were oleic acid (62.07–70.6%), linoleic acid (20.5–27.76%), linolenic acid (0.4–1.42%), and palmitic acid (5.0–7.79%). In contrast, palmitoleic acid was found in smaller quantities (0.48–0.70%). The oil exhibited a vitamin E content ranging from 72 to 107 mg per 100 g. The fatty acid composition of apricot oils suggests their potential suitability as edible oils. Additionally, the presence of vitamin E in these oils makes them appropriate for incorporation into cosmetic and hydrating creams designed for dry skin, as well as for the creation of massage oils and for applications in industries [41].

Zhang et al. [42] assessed the in vivo possibility of apricot kernel oil (AKO) cardioprotective effects against myocardial ischemia-reperfusion in a rat model. Five distinct groups of rats were utilized in the experiment: sham-operated, ischemia-reperfusion, low dose AKO-treated ischemia-reperfusion, medium dose AKO-treated ischemia-reperfusion, and high dose AKO-treated ischemia-reperfusion. Food and water were made available to all rats without restriction. The low dose was AKO + ischemia-reperfusion, the medium dose was AKO + ischemia-reperfusion, and the high dose was AKO + ischemia-reperfusion; the groups were administered a daily dosage of 2, 6, and 10 mL/kg of body weight of AKO, respectively, for a duration of 14 days prior to the ischemia-reperfusion procedure. AKO significantly decreased both the size of infarcts and the proportion of infarct weight to total heart weight, as evidenced by the staining of tetrazolium chloride. AKO showed cardioprotective effects against myocardial ischemia–reperfusion injury by reducing infarct size and serum creatine kinase and glutamic-oxaloacetic transaminase activity. In order for the myocardium to produce creatine kinase and glutamic-oxaloacetic transaminase, myocardial cells that are damaged or destroyed should rupture or render the cardiac membrane permeable, thereby allowing enzymes to escape. These enzymes enter the bloodstream and increase serum concentration. This effect was observed in all three AKO-treated groups when compared to the group subjected to ischemia-reperfusion. Similar beneficial effects were also observed on the activities of serum creatine kinase and aspartate aminotrans-

ferase. The activities of myocardial catalase, superoxide dismutase, glutathione peroxidase, and constitutive nitric oxide synthase, along with the concentrations of nitric oxide that exhibited an increase in AKO-treated rats. Conversely, the content of malondialdehyde and inducible nitric oxide synthase decreased in these rats. The AKO was also characterized for its composition. Total phenol content, determined using the Folin–Ciocalteu method, was 0.18 ± 0.02 mg GAE (gallic acid equivalent)/g. The fatty acid composition of the AKO was evaluated via gas chromatography–mass spectrometry (GC-MS), and found to consist of 66.4% oleic acid, 25.5% linoleic acid, 4.8% palmitic acid, 1.2% stearic acid, 1.1% palmitoleic acid, 0.5% linolenic acid, 0.2% peanut monoenoic acid, 0.2% erucic acid, and 0.1% arachidic acid. Tocopherol content was assessed through high-performance liquid chromatography (HPLC) and it was 22.0 mg/100 g oil of the AKO. The results of this study indicated that AKO exhibited significant cardioprotective properties, indicating its potential as a dietary supplement for the management and prevention of myocardial infarctions.

The research carried out by Karaboğa et al. [43] examined the potential gastroprotective properties of AKO of ethanol-induced gastric ulcer in a rat model. Male Wistar albino rats were divided into three distinct groups for the purpose of the experiment: control, ethanol, and AKO + ethanol. The fatty acid composition of AKO was analyzed through GC-MS. The operational definition of the gastric ulcer index was the percentage of the gastric mucosa that was comprised of ulcerated tissue. Gastric tissue was analyzed via immunohistochemical iNOS staining, TUNEL staining for apoptosis detection, ELISA for quantification of gastric IL-10 and IL-6 expression, and assays for catalase, malondialdehyde, and superoxide dismutase. In contrast to the control group, the ethanol-treated group exhibited a more pronounced manifestation of gastric ulcers, increased concentrations of MDA, inducible nitric oxide synthase-positive and TUNEL-positive cells, and elevated levels of IL-6. The group treated with a combination of AKO and ethanol demonstrated a notable reduction in gastric lesions in comparison to the group treated solely with ethanol. AKO exhibits protective properties on the gastric mucosa of rats when exposed to ethanol-induced injury. This protective effect is attributed to its anti-inflammatory, antioxidative, and antiapoptotic properties. Consequently, the application of AKO may prove beneficial in mitigating the severity of gastric ulcers.

Pavlović et al. [44] assessed the levels of fatty acid, tocopherol, and amygdalin in AKOs utilizing two different methods, namely cold pressing and supercritical carbon dioxide (SC-CO_2) extraction. During the SC-CO_2 process, the oil was collected over a period of 5 h at a pressure of 300 bar and a temperature of 40 °C until the complete extraction of oil from the raw material. The tocopherol concentration in cold-pressed oil was notably reduced (94 mg 100/g of oil) in comparison to SC-CO_2 oil (50–252 mg/100 g of oil). The β- and γ-tocopherols exhibited prominence in cold-pressed oil, whereas the presence of α-tocopherol was not discernible. The total tocopherol concentration underwent a gradual decrease during the SC-CO_2 extraction process, especially between the first collection at 1 h and the final collection at 5 h. The concentration decreased from 252 mg/100 g of oil to 50 mg/100 g of oil. The fatty acid composition analysis revealed that palmitic, oleic, and linoleic acids were the most abundant in SC-CO_2 extracts, accounting for 5.93%, 57.33%, and 33.81%, respectively. These proportions were comparable to the fatty acid composition of cold-pressed oil, which consists of 5.48%, 62.73%, and 29.18% palmitic, oleic, and linoleic acid, respectively. The amygdalin content in cold-pressed oil was found to be a modest quantity of 0.40 mg/g of oil, while oil obtained through the SC-CO_2 extraction method exhibited a slightly lower amygdalin content of 0.20 mg/g of oil. Based on established protocols, oils generated through both methodologies exhibited a level of quality that is deemed acceptable for consumption, as evidenced by their low peroxide number, free fatty acid content, insoluble impurities, and moisture content.

The chemical and biological characteristics of AKOs derived from five different varieties cultivated in Poland were examined and analyzed by Stryjecka et al. [45]. The oils were extracted through Sohxlet with *n*-hexane and then subjected to a water bath. The oils that were extracted exhibited an iodine value (g of I_2/100 g of oil) peaking at 99.2.

Additionally, a refractive index of 1.4675 was observed at a temperature of 40 °C. It was determined that these oils had a saponification value of 189 mg of KOH/g of oil and contained 0.68 percent unsaponifiable matter. In relation to the oxidation state, the specific extinction values of the oils were recorded as 2.55 and 0.94, respectively, at wavelengths of 232 nm and 268 nm. Furthermore, it was ascertained that the peroxide value was 1.40 meq O_2/kg, and the p-anisidine value was 1.42 meq O_2/kg. The most prevalent fatty acid identified in the oils was oleic acid (70.70%), with linoleic acid (22.41%), palmitic acid (3.14%), stearic acid (1.4%), linolenic acid (0.90%), and palmitoleic acid (0.70%) following suit. The oils obtained from the five distinct apricot cultivars contained varying concentrations of α-, β-, and γ-tocopherols, which were as follows: 19.6 to 40.0 mg/kg, 315.4 to 502.3 mg/kg, and 28.3 to 58.5 mg/kg, respectively. The range of values for the antioxidant capacity of the AKOs, as determined via the ferric reducing-antioxidant power (FRAP) assay, was 1.07 to 1.38 mM Fe^{2+}/L. Furthermore, the analysis revealed that the concentrations of TPC and β-carotene in these oils varied between 42.3–66.8 μg/g and 0.85–1.22 mM gallic acid/L, respectively. The findings suggested that, among the cultivars that were examined, the 'Somo' cultivar exhibited the highest oil content and possessed the greatest antioxidant activity. The findings of the research indicate that apricot seeds possess the potential to serve as a viable oil source, which can be utilized in both dietary and cosmetic contexts.

Next, Hao et al. [46] used apricot kernel as a primary substance employed for the purpose of conducting a comparative analysis of the production output of AKO. This analysis involved the application of three distinct extraction techniques, namely the pressing method, ultrasonic-assisted extraction method, and Soxhlet extraction method. The pressing method was applied after the drying of kernels for 10 to 50 min and then the oil was obtained via cold pressing. The ultrasonication procedure employed petroleum ether as a solvent and the power was set at 240 W for a duration of 50 min, at 80 °C and a solid-to-liquid ratio of 1:7. The Sohxlet extraction also utilized petroleum ether as a solvent and it was carried out for 3 h. The validation of the optimal extraction conditions were additionally conducted using GC-MS, Fourier transform infrared spectroscopy (FT-IR), and SEM. The AKO was found to contain palmitic acid and stearic acid as its primary fatty acids. Additionally, the combined proportion of *cis*-oleic acid and *cis*-linolenic acid accounted for a significant portion, totaling 93% of the composition of the oil. The highest yield was observed for the AKO obtained through Soxhlet extraction. Nevertheless, the Soxhlet method exhibited certain limitations, including elevated energy consumption, protracted extraction duration, and suboptimal efficiency. Subsequently, the ultrasonic-assisted extraction method was subjected to nuclear magnetic resonance (NMR) analysis, which reaffirmed the presence of numerous unsaturated fatty acids in the AKO.

2.1.3. Apricot Kernel Shell

Demiral and Kul [47] focused on investigating the primary characteristics and quantities of liquid and solid products resulting from the pyrolysis process of apricot kernel shell. The experiments were conducted under controlled conditions in a nonmoving environment, utilizing heating rates of 10 °C/min and 50 °C/min. The pyrolysis temperatures ranged from 400 °C to 550 °C, and the flow rates of the sweep gas (nitrogen) varied between 50 and 200 cm^3/min. The highest recorded yields of bio-oil and char were 26.3% (at a temperature of 500 °C) and 35.2% (at a temperature of 400 °C), respectively. The optimal heating rate was 50 °C/min and the nitrogen flow rate was 150 cm^3/min. Char yield was maximized when temperatures and heating rates were kept to low levels. Thermal treatment resulted in a minor alteration in the morphology of the charred apricot kernel shell; the formation of new craters on the surface contributed to the expansion of the surface area. It has been observed that the liquid products exhibited potential utility as liquid fuels, while the solid product demonstrated favorable characteristics for adsorption applications, primarily attributable to its notable surface area.

The principal aim of the investigation conducted by Hrichi et al. [48] was to offer an all-encompassing examination of the lipid and polyphenolic makeup of a range of

extracts, utilizing solvents including ethanol, dichloromethane, chloroform, and ethyl acetate. The present investigation was carried out utilizing extraction techniques at elevated temperatures, in conjunction with GC and HPLC coupled with mass spectrometry. In all extracts, a comprehensive analysis revealed the presence of six diacylglycerols and eighteen triacylglycerols. The prevailing constituents were identified as dioleoyl-linolein, triolein, and dilinoleyl-olein, with varying percentages ranging from 19.0 to 32.8%, 20.3 to 23.6%, and 12.1 to 20.1%, respectively. In greater elaboration, the utilization of ethyl acetate, a solvent with medium polarity, resulted in the most pronounced signal for all peaks. Subsequently, chloroform and dichloromethane, solvents with medium polarity, yielded lower signals. Conversely, the employment of ethanol, a polar solvent, exhibited the least efficiency in extraction. The signal of ethanol was found to be significantly diminished for the most saturated triacylglycerols, whereas dichloromethane exhibited the lowest proportions of diacylglycerols. In accordance with the findings, the analysis of the complete fatty acid composition indicated that the dichloromethane extract exhibited the lowest proportion of linoleic acid (C18:2n6) while containing the highest concentration (exceeding 60%) of oleic acid (C18:1n9). The ethyl acetate and ethanol extracts contained a higher concentration of polyphenolic compounds, including coumarin derivatives and amygdalin, which have demonstrated pharmacological properties such as antitumor, anticoagulant, and anti-inflammatory effects.

Manić et al. [49] studied the correlation between the slow pyrolysis mechanism of apricot kernel shell biomass and the influence of its principal components, specifically lignin, hemicelluloses, and cellulose, and the pyrolysis properties were evaluated via nonisothermal simultaneous thermal analysis. A nonisothermal reaction occurs when the temperature of the solvent is reduced to a level below its boiling point. Isothermal reactions, on the other hand, ensure that the temperature remains constant across the entire system. The feasibility of utilizing the four-step (parallel) reaction model to analyze the gradual pyrolysis process has been assessed in the context of the semi-global model. The present model explicitly disregards the evaluation of robust interactions among the different biomass constituents, which were referred to as pseudo-components. The validation of the model's valorization was accomplished via process optimization. The pyrolysis rate curves of apricot kernel shells, which were influenced by different heating rates, were effectively separated into distinct decomposition rate curves. In addition to the pyrolysis of hemicelluloses and cellulose, the model presented in this study differentiated between primary and secondary lignin reactions. These reactions contributed to the release of gaseous products, primarily carbon monoxide (CO) and carbon dioxide (CO_2), as well as the formation of char in the solid residue, resulting in an increased yield of biochar.

The research article by Hekimoğlu et al. [50] introduced a novel composite material that exhibited improved impermeability and enhanced properties compared to the natural ones. They applied a eutectic mixture of lauric acid and capric acid, to a ratio of 36:64, into the framework of activated carbon derived from apricot kernel shells. The activated carbon derived from apricot kernel shells combined with artificially produced phase change materials was then integrated in various ratios into a cement-pumice-based mortar. The goal of this project was to create energy-efficient building materials with the specific goal of improving building thermal performance. Experiments were used to evaluate the composite phase change of the material's morphological, physical, thermal stability, mechanical strength, thermal energy storage, and solar thermoregulation properties. Compressive strength values of cement-pumice-based mortar samples with thermal energy storage capability denoted as thermal energy storage cement-pumice-based mortar samples, were determined to be 6.8, 4.3, and 2.1 MPa for samples 1, 2, and 3, respectively. The thermal regulation performances should be taken into consideration when accepting the relatively lower mechanical strength values. The observed porosity of sample 3 was approximately 26%, with water adsorption measuring around 24%. The FT-IR analysis yielded evidence supporting the notion that there was a high degree of chemical compatibility between activated carbon derived from apricot kernel shells and phase change materials. The dif-

ferential scanning calorimetry analysis revealed that the activated carbon derived from apricot kernel shells/phase change materials composite exhibited a melting temperature of 21.58 °C and a latent heat capacity of 126.8 J/g. These values fell within the range of 18.93 to 20.51 °C and 10.55 to 30.32 J/g, respectively, for the thermal energy storage composite phase change materials. The thermogravimetric analysis findings revealed that the operational temperature of the activated carbon derived from apricot kernel shells/phase change materials composite was significantly below the threshold temperature at which thermal degradation occurs. The solar thermoregulation performance test results indicated that the constructed thermal energy storage and cooling phase change material provided significant benefits through cooling during the day and heating during the night. The proposed activated carbon derived from apricot kernel shells/phase change materials composite -integrated cement-pumice based mortar's combination of favorable properties makes it a highly promising material for innovative thermal energy storage applications in construction elements. Below in Table 1, the results of the research performed on apricot kernels are summarized.

Table 1. Apricot kernel and its applications.

By-Product	Application	Type of Solvent	Results	Ref.
Kernel	Preparation of a suspension of AK milk	–	Primary acids: palmitic acid, oleic acid, and linoleic acid, low amygdalin concentration on 250 mL milk	[32]
Kernel	Oil extraction	One-pot protease in aqueous medium	~47% protein yield 179 mg/g asparagine & aspartic acid 172 mg/g glycine & glutamine 86 mg/g phenylalanine & tyrosine 70 mg/g alanine Oleic acid > 25% & linoleic acid ~40%	[34]
Kernel	Polyphenol extraction, DES, and PEF utilization to improve extraction yield	Glycerol:choline chloride 2:1 (*w*/*w*) (DES) PEF treatment: 1 kV/cm, 10 µs pulse duration & 1000 µs pulse period	PEF prior to extraction: 88% TPC [1] increase DES: 70% TPC increase PEF and DES: 173% TPC increase	[35]
Kernel	Oil extraction, analysis, and antioxidant properties	Hexane solvent	Oleic acid and palmitoleic acid in abundance, volatile compounds 2-methyl propanal, benzaldehyde, and benzyl alcohol, benzaldehyde in essential oil, antioxidant activity decreased through time (TPC ~3%, TFC [2] ~18.7%, FRAP ~4.5%, DPPH ~5.2%)	[37]
Kernel and pulp	Compounds quantification and antioxidant properties	Methylene, petroleum ether, and acetate, 1:1:1 (*v*/*v*/*v*)	γ-Tocopherol main compound, 3.51 mg of carotenoids/100 g pulp Antioxidant activity pulp 0.51 µM TEAC [3]/g FW and kernel 0.05 µM TEAC/g FW	[38]

Table 1. *Cont.*

By-Product	Application	Type of Solvent	Results	Ref.
Kernel and kernel oil	Determination of principal characteristics of the fruit	–	Fruit weight: 8–15 g Stone recovery 12.7–22.2% Stone weight: 1.78–1.92 g Kernel oil recovery: 30.7–33.7% Vitamin E: 72–107 mg/100 g	[40]
Kernel oil	In vivo potential cardioprotective effects on myocardial IR	–	Significant cardioprotective properties, a potential dietary supplement	[42]
Kernel oil	Gastroprotective properties	–	Anti-inflammatory, antioxidative, and antiapoptotic properties	[43]
Kernel oil	Fatty acid, tocopherol, and amygdalin levels	–	5.93% Palmitic acid, 57.33% oleic acid, and 33.81% linoleic acid, 0.20 mg/g amygdalin	[44]
Kernel oil	Chemical and biological characterization	*n*-hexane	Iodine value 99.2 g of I_2/100 g of oil, saponification value 189 mg KOH/g oil, peroxide value 1.40 meq O_2/kg, 70.70% oleic acid, 22.41% linoleic acid, 3.14% palmitic acid, 1.40% stearic acid, 0.90% linolenic acid, and 0.70% palmitoleic acid, FRAP value 1.07–1.38 mM Fe^{2+}/L, TPC 0.85–1.22 mM GAE ^{4}/L and β-carotene content 42.3–66.8 µg/g	[45]
Kernel oil	Comparative analysis of AKO	Ultrasonication & Sohxlet applied petroleum ether solvent	Soxhlet was a more effective technique	[46]
Apricot kernel shell	Investigation of primary characteristics and quantities of liquid and solid products from pyrolysis	–	Bio-oil yield 26.3% at 500 °C and 150 cm^3/min flow rate	[47]
Kernel extracts	Analysis of the fatty acid, lipid, and polyphenolic composition	Dichloromethane, chloroform, ethyl acetate, ethanol	19.0–32.8% dilinoleyl-olein, 20.3–23.6% dioleoyl-linolein, 12.1–20.1% triolein, ethyl acetate and ethanol had higher TPCs	[48]
Kernel oil	Correlation between slow pyrolysis mechanism and its primary constituents	–	An increased yield of biochar when CO and CO_2 were released	[49]
Kernel shell	Novel material with enhanced properties	Mixture of lauric acid and capric acid to a ratio of 36:64	Melting temperature of 21.58 °C and a latent heat capacity of 126.8 J/g	[50]

Table 1. *Cont.*

By-Product	Application	Type of Solvent	Results	Ref.
Kernel shell	Green synthesis of Pd-nanoparticles	–	High reduction of organic dyes, multiple recoveries and reusable material, catalytic activity	[51]
Kernel oil	Impact of various roasting temperatures	–	Peroxide values 0.46–0.82 meq/kg, acid values 0.60–1.40 mg KOH/g, phenol content 54.1–71.5 µg GAE/g, 53 volatile compounds	[52]

[1] Total polyphenol content; [2] Total flavonoid content; [3] Trolox equivalent activity capacity; [4] Gallic acid equivalents.

2.2. Apricot Pulp

2.2.1. Antioxidant Activity of Apricot Pulp

The purpose of the study carried out by Cheaib et al. [53] was to assess the impact of infrared and heat-assisted extraction as pretreatment extraction methods on extracts derived from lyophilized apricot pomace. Subsequently, the objective was to evaluate the preservation of polyphenol levels and their corresponding bioactivities, specifically antiradical and antibacterial properties, in the lyophilized extract. Through the utilization of either heat-assisted extraction or infrared pretreatments, followed by lyophilization, a dried form of an aqueous extract was acquired. The results of this research demonstrated that the infrared sample yielded lyophilized extracts with marginally lower reductions in polyphenol content, antiradical activity, and antibacterial activity than the heat-assisted extraction samples. The results of the HPLC analysis indicated that the lyophilized infrared and heat-assisted extracts exhibited the presence of identical phenolic compounds (rutin, catechin, and epicatechin) as observed in the liquid extracts (from both processes) but with a reduced yield. However, the polyphenol content, as well as the antiradical and antibacterial activities, exhibited a small decline in the lyophilized samples compared to the heat-assisted extracts. Following the lyophilization process, the lyophilized extracts were found to contain the same phenolic compound content. This observation may provide an explanation for the retention of their biological activities, particularly in the infrared samples.

Next, the same research team [54], aimed to investigate the means of enhancing the value of industrial food by-products through the utilization of environmentally sustainable extraction techniques. In that case, a comparative analysis was undertaken to assess the efficacy of various technologies, namely ultrasounds (US), microwaves (MW), and infrared (IR), in terms of their impact on polyphenol yield and bioactivity derived from apricot pomace. IR demonstrated superior efficacy in terms of yielding the highest polyphenol content 10 mg GAE/g dry matter (DM)), flavonoid content (6 mg CE/g DM), and tannin content (3.6 mg/L). In terms of effectiveness, IR extraction was succeeded by microwave, ultrasound, and subsequently solid-liquid extraction. The inhibitory activity of the infrared extract derived from apricot pomace was found to be the most potent against all the gram-positive strains investigated, including methicillin-resistant *Staphylococcus aureus*, *Staphylococcus aureus*, methicillin-resistant *Staphylococcus epidermidis*, and *Staphylococcus epidermidis*. Additionally, it also exhibited inhibitory effects against a single gram-negative strain, *Escherichia coli*. Furthermore, it is worth noting that the antiradical activity of the infrared extracts was significantly higher (40%) compared to the microwave (31%), ultrasounds (28%), and solid-liquid (15%) extracts. The utilization of HPLC enabled the determination and measurement of rutin in all extracts. Additionally, the presence of catechin was observed in the extracts of IR (3.1 µg/g DM), MW (2.1 µg/g DM), and US (1.5 µg/g DM). The presence of epicatechin was observed solely in the IR extract at a concentration of 4 µg/g DM, indicating the specific affinity of infrared for this compound. The utilization of SEM demonstrated that the infrared technique resulted in the most

significant cellular and structural harm in apricot pomace. This observation may provide an explanation for the efficacy of this technology.

As a follow-up to the two above-mentioned studies, the same research team [55] evaluated and compared the biological effects, specifically antiradical, antioxidant, and antimicrobial properties, of phenolic compounds derived from apricot pomace and kernels. This evaluation was conducted utilizing both solid-liquid and infrared technology. The infrared pomace extract demonstrated the highest levels of polyphenolic content (10.8 mg GAE/g DM), flavonoid (6.3 mg CE/g DM), and tannin (3.6 mg/L) yields. Additionally, it exhibited the most potent inhibitory activity against all gram-positive bacterial strains tested, as well as against the gram-negative strain *E. coli*. In addition, the highest antiradical capacity was observed in this extract for both the DPPH and ABTS assays. With regard to its overall antioxidant activity, the pomace acquired via the infrared technique demonstrated the most pronounced level of activity. The process of determining and quantifying a range of phenolic compounds found in apricot pomace, such as epicatechin, catechin, and rutin, was made possible through the application of HPLC. Furthermore, gallic acid and caffeic acid were detected in apricot kernels. The results of the research demonstrated that the application of infrared technology produced enhanced results with respect to the extraction efficiency and biological activity of the substances extracted, when compared to the solid/liquid approach.

Vorobyova et al. [56] attempted to evaluate the extraction of polyphenols from apricot pomace using DES-based ultrasound-assisted extraction. The DES were prepared by combining choline chlorine and lactic acid at a 1:2 ratio with 30% v/v water. The primary phenolic compounds that could be extracted from apricot pomace consisted of soluble conjugated flavonoids and various phenolic compounds, including chlorogenic acid, 1-caffeoylquinic acid, and caffeic acid. The antioxidant properties of apricot extracts were assessed using the DPPH, ABTS, and phosphomolybdenum assays. The findings of this study indicate that the apricot pomace extract contained choline chloride; lactic acid possesses a significant capacity to scavenge DPPH and ABTS radicals, with scavenging percentages of approximately 70 and 60%, respectively. These results suggest that the extract has the potential to serve as a valuable reservoir of bioactive compounds. For the extract obtained from the choline chloride, the lactic acid exhibited the highest recorded values for TPC and TFC, measuring 80.75 $\pm$ 1.85 mg GAE/g and 47.41 $\pm$ 1.20 mg QE/g, respectively. After the DES-based ultrasound-assisted extraction, the sample underwent substantial degradation, resulting in several notable alterations to the original material.

The research carried out by Hong et al. [57] was a high-throughput screening and characterization of phenolic compounds found in waste from stone fruits, specifically peach, nectarine, plum, and apricot. Analysis was conducted using liquid chromatography-electrospray ionization-quadrupole time-of-flight mass spectrometry (LC-ESI-QTOF-MS/MS). Additionally, the potential antioxidant activities of these phenolic compounds were investigated. Stone fruits are known for their high phenolic content, which plays a significant role in their antioxidant potential and the subsequent health benefits they offer. The results of the antioxidant analysis revealed that plum waste exhibited higher levels of TPC (0.94 $\pm$ 0.07 mg GAE/g) and TFC (0.34 $\pm$ 0.01 QE/g). On the other hand, apricot waste demonstrated a higher concentration of total tannin content (TTC) (0.19 $\pm$ 0.03 mg catechin equivalents (CE)/g) and DPPH activity (1.47 $\pm$ 0.12 mg ascorbic acid equivalents (AAE)/g. However, it was noted that the waste generated from nectarines demonstrated a superior antioxidant capacity as determined via the total antioxidant capacity (TAC) and ferric reducing-antioxidant power (FRAP) assays (0.91 $\pm$ 0.02 mg AAE/g) and 0.98 $\pm$ 0.02 mg AAE/g, respectively. On the contrary, the antioxidant capacity of the waste derived from peaches was found to be greater than that of the waste derived from other stone fruits, as determined via the 2,2′-azino-bis-(3-ethylbenzothiazoline)-6-sulfonic acid (ABTS) assay (0.43 $\pm$ 0.09 mg AAE/g). The present study involved the analysis of phenolic compounds in waste from stone fruits grown in Australia. This analysis was carried out using two analytical techniques: liquid chromatography coupled with LC-ESI-QTOF-MS/MS and

high-performance liquid chromatography with photodiode array detection (HPLC-PDA). The LC-ESI-QTOF-MS/MS analysis yielded results that suggested the presence of 59 phenolic compounds in peach (33 compounds), nectarine (28 compounds), plum (38 compounds), and apricot (23 compounds). The results of the HPLC-PDA analysis indicated that p-hydroxybenzoic acid was the most abundant phenolic acid detected in the waste of stone fruits (18.64 $\pm$ 1.30 mg/g). Additionally, quercetin was identified as the most prominent flavonoid at 19.68 $\pm$ 1.38 mg/g. Hence, it can be deduced that stone fruit waste contains a wide range of phenolic compounds and exhibits antioxidant properties. The results of this study possess the capacity to enhance the application of stone fruit by-products across multiple industries, including the food, feed, nutraceutical, and pharmaceutical sectors.

The objective of the study published by Jan et al. [58] was to investigate the impact of canning and storage on the physicochemical, mineral, and antioxidant properties, as well as the phenolic composition, of apricot wholes, halves, and pulp. The results pertaining to physicochemical properties indicated that the apricot pulp exhibited higher levels of total soluble solids, titratable acidity, total sugars, and ascorbic acid (37.15%, 1.39%, 20.74%, and 7.21 mg/100 g fresh weight (FW), respectively) compared to apricot wholes and halves during the entire storage duration. The apricot pulp was found to contain significant amounts of potassium, phosphorus, zinc, copper, iron, and manganese. It was observed that the mineral composition of the pulp was slightly affected by the processes of canning and storage. During the storage period, the presence and quantity of bioactive substances in apricot pulp, wholes, and halves were determined using reversed-phase HPLC. The analysis revealed higher concentrations of chlorogenic acid (34.45 mg/kg FW), quercitin-3-glucoside (16.78 mg/kg FW), neochlorogenic acid (26.52 mg/kg FW), gallic acid (5.37 mg/kg FW), kaempferol (14.22 mg/kg FW), ellagic acid (6.02 mg/kg FW), procyanidin B2 (8.80 mg/kg FW), and epicatechin (9.87 mg/kg FW) in apricot pulp compared to apricot wholes and halves. The apricot pulp exhibited the highest total phenolic content, measuring 13.76 GAE mg/100 g FW. This was followed by whole apricots, which had a TPC of 8.09 GAE mg/100 g FW, and halves, which had a TPC of 6.48 GAE mg/100 g FW. It is worth noting that the TPC decreased significantly over the storage period for all three types of apricots. The antioxidant properties of the apricot pulp were evaluated using DPPH, ABTS+, MCA, and BCBA assays. The results indicated higher levels of antioxidants in the apricot pulp, with values of 92.23 TEAC μg/g DW, 92.33 TEAC μg/g DW, 33.80 TEAC μg/g DW, and 68.40 TEAC μg/g DW for DPPH, ABTS+, MCA, and BCBA, respectively. These findings suggested a positive correlation between the presence of bioactive compounds and the observed antioxidant activity in the apricot pulp. Hence, the utilization of apricot pulp, which is rich in essential nutrients, minerals, phytochemicals, and antioxidant constituents, holds potential for global consumption as a source of nutraceuticals and antioxidants.

The work presented by Makrygiannis et al. [59] focused on the examination of the extraction process for antioxidant polyphenols and carotenoid pigments from discarded apricot pulp. Response surface methodology was utilized in both cases to optimize the extraction parameters. As for the polyphenols, the researchers discovered that the most favorable extraction yield (specifically, 28.6 mg GAE/g of dw) was attained by utilizing a DES composed of glycerol, citric acid, and L-proline in a molar ratio of 2:1:1. Additionally, a liquid-to-solid ratio of 100 mL/g and a heating temperature of 80 °C for a duration of 155 min were found to be optimal conditions for extraction. Similarly, the most effective method for extracting carotenoids (specifically, 171.2 mg β-carotene equivalents per 100 g of DW) was found to be the extraction of apricot pulp using a mixture of *n*-hexane, acetone, and ethanol in a ratio of 2:1:1 ($v/v/v$) at a temperature of 47 °C for a duration of 60 min. The methods that were proposed exhibited a high level of efficiency and have the potential to be utilized as an alternative to the conventional methods that have been employed thus far.

The objective of Suo et al. [60] investigation was to extract carotenoids from waste apricot flesh via ultrasound-assisted corn oil extraction, and analyze the type and concentration of carotenoids in the extracted samples. The ultrasonication applied had a maximum power of 200 W. Additionally, the researchers sought to investigate the potential utilization of

these extracts in the food industry. The extraction conditions were optimized to enhance efficiency and effectiveness. Under the optimized conditions, the total carotenoid content was determined to be 42.75 mg/100 g of DW. The experiment was conducted for a duration of 60 min, with a temperature of 41.53 °C. The power utilized during the experiment was 200 W. The solid-to-liquid ratio employed was 0.10 g/mL. Phytoene was found to be the predominant carotenoid in the corn oil extracts with the highest concentration. An investigation was conducted to examine the color of corn oil extracts under conditions of elevated temperature. The degradation of carotenoids within the corn oil extracts was observed under conditions of elevated temperatures. The astringency (a^*) of fries fried with the chosen corn oil extracts exhibited a 7.31-fold increase compared to the a^* of corn oil. This study offers insights into the sustainable recovery of carotenoids and the utilization of waste apricot flesh for environmental and economic benefits.

The research conducted by Stramarkou et al. [61] focused on enhancing the efficiency of the phenolic compound extraction process from peach pulp and apricot kernels and pulp via the ecofriendly methods of ultrasound and microwave-assisted extraction. Prior to the extraction procedure, the pulps were dried using freeze, vacuum, and hot air-drying methods. In addition to the traditional extraction solvents of water and ethanol, the water was in a ratio of 8:2 v/v and researchers explored the utilization of DESs derived from choline chloride/urea at a 1:2 v/v ratio and a natural DES obtained from choline chloride with lactic acid at a 1:2 v/v ratio. Both DES solvents were mixed with water at a ratio of 7:3 v/v. These alternative solvents offer ecological advantages, making them appealing options for extraction processes. In order to determine the most favorable conditions for extraction, various values of extraction time, ultrasonic power, and solvent-to-dry solid ratio were investigated. A mathematical model was subsequently formulated to establish a correlation between these parameters and the extraction yield. The quantification of phenolic compounds and the assessment of antioxidant activity were accomplished using UV-Vis spectroscopy and HPLC techniques. The findings indicated that for ethanol, water was the most efficient solvent for extracting apricot kernels. Additionally, it was observed that the DES technique was more effective at extracting apricot pulp, while natural DESs were more suitable for extracting peach pulp. The extraction yields achieved were 25.65, 26.83, and 17.13% for apricot kernels, apricot pulp, and peach pulp, respectively. In summary, it can be concluded that both categories of fruit waste exhibited a substantial presence of valuable compounds. Moreover, the utilization of DESs in the extraction of fruit by-products has demonstrated efficacy and holds promise as a viable alternative. Therefore, the untapped quantities of waste can be utilized through straightforward methodologies and inventive solvents.

2.2.2. Other Applications

The research by Tsiaka et al. [62] focused on the integration of underutilized high-energy extraction techniques, specifically ultrasound-assisted extraction, and microwave-assisted extraction, along with the implementation of experimental design and metabolomics. The objective was to establish an integrated analytical platform for a comprehensive investigation of plant metabolomics and phytochemical profiling. This could be achieved through the advancement of contemporary pipelines for the retrieval and utilization of medicinal natural substances/extracts from plant waste materials. They investigated the extraction of carotenoids from apricot by-products, specifically the pulp, as a case study. The utilization of ethanol as a solvent in the microwave-assisted extraction method resulted in higher carotenoid yields when compared to the ultrasound-assisted extraction method, which employed a 1:1 mixture of chloroform and methanol, as well as the traditional extraction technique. The classification of extracts-based alterations in coextractives with respect to the extraction conditions was accomplished by employing metabolomic profiling based on nuclear magnetic resonance. It was discovered that carotenoids were present in lower concentrations in extracts, which also contained branched-chain amino acids as coextracts. It was discovered that the extracts comprising medium levels of carotenoids also contained

choline, unsaturated fatty acids, and sugar alcohols. However, conversely, the extracts with the highest carotenoid content were observed to have a high concentration of sugars. In general, the proposed pipeline has the capability to yield various phytochemical fractions containing bioactive compounds that can cater to the specific requirements of diverse industrial sectors, such as cosmetics and nutraceuticals.

Demiray et al. [63] intended to investigate the production of bioethanol from apricot pomace using *Kluyveromyces marxianus*, marking the first instance of such research. Optimization of crucial fermentation parameters, including pretreatment methods, biomass and cellulase loading, and duration, was undertaken. *K. marxianus* exhibited production of 30.09 g/L of ethanol when cultivated in a medium containing 20% washed apricot pomace and a cellulose enzyme loading of 120 Filter paperase unit FPU/g. The washed fraction of apricot pomace yielded the highest ethanol concentration of 30.09 g/L when subjected to a 120 FPU enzyme load. Additionally, the volumetric productivity of ethanol production was measured at 1.25 g/L h^{-1}. In contrast, when 60 FPU were present, a concentration of 29.49 g/L ethanol was observed, along with a productivity of 1.22 g/L h^{-1}. These results closely resemble those obtained when 120 FPU were utilized. The experimental results indicated that the utilization of 15 FPU/g cellulose enzyme resulted in the highest theoretical yield and ethanol yield values, which were observed to be 94.7% and 0.50 g/g, respectively. The findings of this study indicate that apricot pomace shows potential as a viable raw material to produce bioethanol.

A comparative analysis was performed by Baississe et al. [64] on the structural characteristics and emulsifying properties of pectin derived from apple pomace and apricot pulp. Pectins were extracted from apple pomace and apricot pulp through solubilization at a temperature range of 80 to 82 °C in an acidified medium consisting of 0.5 N hydrochloric acid at a pH of 1.5 for a duration of 60 min. The variation in pectin content is contingent upon the specific product and the solvent employed for the precipitation process. Pectins exhibit a substantial ash content ranging from 10.0 to 13.0%, along with a notable galacturonic acid content ranging from 33.8 to 57%. The pectins that underwent precipitation with aluminum chloride exhibited a high degree of methylation, with values of 67.2 and 53.9% for apricot and apple, respectively. Conversely, pectins that were precipitated with aluminum sulfate displayed a low level of methylation, with percentages of 41.2 and 31.01% for apple and apricot, respectively. Apricot pectins exhibited a higher protein content (ranging from 3.06 to 3.93%) and contained a greater concentration of phenolic compounds (ranging from 2.75 to 6.20 µg/mg) in comparison to apple pectins. The pectins that were examined in this study underwent depolymerization, resulting in a range of molecular weights from 886.99 to 3388.65 g/mol. The emulsifying activity of the extracted pectins demonstrated their ability to act as surfactants, with emulsifying activity values ranging from 37.03 to 45.87. This activity is closely associated with the structure of pectin, specifically with the presence of proteins, phenolic compounds, and low molecular weight components. The stability of emulsions that have been prepared can be attributed to the phenomenon of electrostatic repulsion, which arises from the presence of charged molecules such as proteins and pectin.

Dinçel Kasapoğlu et al. [65] attempted to optimize the extraction procedure of cellulose nanocrystals (CNCs) from apricot pomace (AP) through the utilization of response surface methodology. The optimization was based on the extraction yield, and the resulting CNCs were subjected to characterization using various analytical techniques, including FT-IR spectroscopy, SEM, transmittance electron microscopy (TEM), thermogravimetric analysis (TGA), and X-ray diffraction (XRD). The highest CNC yield, amounting to 34.56%, was achieved when the sulfuric acid concentration was 9.5 M and the reaction time was 60 min. The FT-IR analysis revealed a gradual removal of noncellulosic components from the pomace. The nanocrystal underwent a morphological analysis utilizing SEM and TEM. The diameter of the CNCs ranged from 5 to 100 µm, and they were observed as discrete fibers. The thermogravimetric analysis conducted on the CNC sample demonstrated excellent thermal stability at a temperature of around 320 °C. It was determined that the crystalline index of the cellulose nanocrystals produced via acid hydrolysis was 67.2%. In brief, the

results of this investigation suggest that AP has the potential to serve as a viable and environmentally friendly source for the production of value-added compounds, specifically CNCs, which can contribute to the establishment of a circular economy. Table 2 presents the results of the research performed on the apricot pulp.

Table 2. Apricot pulp and pomace and their applications.

By-Product	Application	Solvent	Results	Ref.
Pomace	Evaluation of two pretreatment extraction techniques	–	Infrared had a lower TPC [1], antiradical activity, and antibacterial activity compared to the heat-assisted one	[53]
Pomace	Enhancement of the value of industrial food by-products	–	IR [2] extraction: TPC 10 mg GAE [3]/g DM, TFC 6 mg CE/g DM, tannins 3.6 mg/L	[54]
Pomace and Kernels	Evaluation of antiradical, antioxidant, and antimicrobial properties	–	IR pomace: TPC 10.8 mg GAE/g DM, TFC [4] 6.3 mg CE [5]/g DM, tannins 3.6 mg/L, Inhibitory activity against Gram-positive bacteria and *Escherichia coli*	[55]
Pomace	Polyphenol extraction	Choline chlorine and lactic acid at a 1:2 ratio with 30% *v*/*v* water	TPC 80.75 ± 1.85 mg GAE/g, TFC 47.41 ± 1.20 mg QE/g, DPPH 70% scavenging, ABTS 60% scavenging	[56]
Fruit waste	–	–	TFC 0.19 ± 0.03 mg CE/g, DPPH activity 1.47 ± 0.12 mg AAE/g	[57]
Wholes, halves, and pulp	Impact of canning and storage on physicochemical, mineral, and antioxidant properties	–	Pulp: total soluble solids 37.15%, titratable acidity 1.39%, total sugars 20.74%, ascorbic acid 7.21 mg/100 g fw, TPC 13.76 GAE mg/100 g FW, DPPH 92.23 TEAC µg/g DW, ABTS+ 92.33 TEAC µg/g DW, MCA 33.80 TEAC µg/g DW, and BCBA 68.40 TEAC µg/g DW	[58]
Pulp	Examination of the extraction process in antioxidant polyphenols and carotenoid pigments	DES glycerol, citric acid, and L-proline at a 2:1:1 ratio	TPC 28.6 mg GAE/g dw, carotenoids 171.2 mg β-carotene equivalents/ 100 g dw	[59]
Waste flesh	Carotenoid extraction	Corn oil as a solvent	Total carotenoid content 42.75 mg/100 g dw	[60]
Kernel and pulp	Optimization of the extraction process	Water and ethanol 8:2 *v*/*v*, DESs of choline chloride and urea at a 1:2 *v*/*v* ratio & choline chloride and lactic acid at a 1:2 *v*/*v* ratio	Extraction yields: 25.65% kernel 26.83% pulp	[61]
Pulp	Establishment of an integrated analytical platform for plant metabolomics and phytochemical profiling	Ethanol, chloroform, and methanol at 1:1 *v*/*v*, methanol	Ethanol as a solvent on microwave-assisted extraction yielded the highest TPC	[62]

Table 2. *Cont.*

By-Product	Application	Solvent	Results	Ref.
Pomace	Bioethanol production	Ethanol	15 FPU/g, theoretical yield 94.7%, ethanol yields 0.50 g/g	[63]
Pulp	Analysis of pectins	0.5 M Hydrochloric acid	Pectins ranged from 10 to 13%, protein content from 3.06 to 3.93%, phenolic compounds from 2.75 to 6.20 µg/mg	[64]
Pomace	Optimization of extraction conditions of cellulose nanocrystals from apricot pomace	–	34.56% CNC yield	[65]

[1] Total polyphenol content; [2] Infrared; [3] Gallic acid equivalents; [4] Total flavonoid content; [5] Catechin equivalents.

3. Nutritional Value

The current state of nutritional sciences has persuaded people to follow a healthy diet [66]. Fruits have many components that are good for health and are valuable sources of wholesome nutrition. As people grow increasingly aware of the impacts of climate change, they are embracing plant-based diets, reducing waste, and seeking alternative resources for therapeutic and health advantages [66]. The apricot seed research has become extremely important in this regard. Antioxidant and polyphenolic compounds with important pharmacological roles are present in significant amounts in apricot seeds. Nevertheless, the quantity of macro- and micro-molecules necessary to preserve adequate nutritional value must also be taken into account [6,67].

The amount of protein, oil, sugars, and fiber content of apricot seed kernels is high [68]. Apricot seed kernel oil and almond oil share many similarities in terms of their intended uses [69]. Sweet bakery recipes and desserts can benefit from the nutty flavor of apricot oil [70]. Food companies in Germany and the United States are already producing fixed oil containing apricot seed oil. Due to the distinctive composition of unsaturated fatty acids, this oil is receiving increased attention on a global scale [71]. Protein, carbs, crude fiber, moisture, crude fat, and total phenol contents are among the main chemical components, which are present in 14.6–27.1%, 17.5–35.6%, 11.85–13.6%, 27.4–38.8%, 2.1–3%, and 0.036–0.072%, in that order, according to Akhone et al. [9]. Gezer et al. [72] discovered comparable levels of protein and moisture, which were reported as amounts per 100 g as 15.72–18.7% and 2.46–3.25%, respectively.

Apricot kernels are served as an appetizer in certain regions of Turkey, Pakistan, and India [9], but the majority of them are either wasted, or very little of this by-product is utilized to make fuel. Therefore, in order to use apricot seed kernel in food, its sugar content needs to be biochemically characterized. Certain Chinese apricot varieties have demonstrated that sugars determine the sweetness and sourness of the fruit flesh and kernel, and that sweetness rises as the fruit ages [73]. Furthermore, a study was conducted to examine the sugar content of apricot seed kernels. Every fruit was collected at its peak ripeness over a period of two years, from various locations. The results of the experiment indicated that apricot seed kernels contained a significant amount of sugar, with sucrose, glucose, and fructose being the most prevalent sugars. The results also indicated that the sugar ratio, however, was dependent upon the fruit ripening period and harvesting stage at the time of collection [74].

New trends in the food industry exploration are foods high in fiber and low in fat. The substantial quantity of dietary fiber present in apricot kernels, along with fats, proteins, and trace minerals, holds the potential to enhance human health. Consuming it can promote a healthy gastrointestinal system and play a positive role in the absorption of cholesterol. Additionally, the fiber content has antidiabetic and antiobesity properties [9]. Research found that the percentage of total dietary fiber was 35.14 [75]. These results are comparable

to those of other studies [75,76]. A plentiful resource that can function as a natural prebiotic for gut microbiota is dietary fiber. Further research is required to determine how apricot seed fiber can be added to various foods as a nutritious and value-added ingredient [77].

The seeds of the apricot kernel are thought to contain potential oil sources. High concentrations of minerals, including magnesium and potassium, as well as certain vitamins, can be found in apricot kernel oil. Apricot seed flour exhibits the highest potassium content among orange, apple, paprika, and guava seeds [67]. Apricot seed flour also contains significant amounts of calcium, iron, potassium, and sodium. It should be also emphasized that the concentration and composition of minerals in apricot seeds vary among different apricot varieties based on the geographical origin of the fruit. The presence of these minerals indicates the condition of the soil and the amount of minerals they have taken up from it [78]. Nature is full of α-tocopherol, which can transform into vitamin E. Large amounts of α-, β-, and γ-tocopherols can be found in apricot seed oil. Especially γ-tocopherols are utilized to stabilize the oils. Apricot oil is a desirable functional food due to its rich content of active vitamin E compounds, which provide essential nutrients [79,80]. Uluata et al. [81] carried out a comparison study of the extraction method-based total tocopherol contents, including the α-, β-, γ-, and δ-tocopherol micronutrients. The study revealed that the cold press extraction method preserves a higher amount of tocopherol compared to the solvent extraction solution of apricot seed. Similarly, β-carotene from apricot seed flour acts as a precursor to vitamin A. Apricot kernels include trace elements like iron and zinc as well as micro-amounts of vitamins C and B6. In addition to that, the fruit seed contains significant organic acids like malic acid [82].

Apricot kernels have a higher phenolic content rate than apricot flesh, according to various research analyses. There are several advantages to the phenolic compounds derived from apricot seed kernels. They have an antimicrobial, anticancer, and antioxidant effect. They also help to the prevention of coronary heart disease. The phenolic content of the fruit consists of mainly phenolic acid and flavonoids. Researchers have examined the phenolic content of apricot seeds and their possible applications in the food and health sectors [83].

Apricot seeds can serve as a functional food due to their rich protein content and the combination of components they possess, which contribute to their antibacterial, anticancer, and antioxidant properties. The ingredients of apricot seeds and oils differ in consistency across different regions. Apricot seed kernel and oil can be utilized in various ways. Multiple studies have extensively investigated the diverse uses of apricot seed, particularly in the domains of medicine and the food industry [84]. It has been discovered that all of the apricot fruit kernels and oil components are of high nutritional value [82]. Rich components in apricot seed and oil have antioxidant properties that help prevent a variety of human diseases. These antioxidant components are widely recognized for their ability to prevent cardiovascular diseases. Phenolic compounds play a crucial role in this context as they induce a reduction in the oxidation of low-density lipoproteins (LDL). Specifically, the process of LDL antioxidation plays a vital role in lowering cholesterol levels and maintaining cardiovascular well-being. The antioxidation properties of apricot components enhance the body's defense mechanism by combating free radicals and reducing their oxidative impact. Parkinson's and Alzheimer's disease can develop as a result of brain cell damage caused by free radicals and increased oxidative stress [82]. The vitamins found in various apricot seed and oil varieties are essential for the oxidation pathways that guard against diseases like cancer, hemoglobinuria, and coronary heart disease. Apricot seeds contain a substantial quantity of fiber that has the ability to attach to or impede bile acids, thereby potentially reducing cholesterol levels in specific instances. In this manner, the risk of liver failure is greatly decreased and healthy liver cells are preserved [67].

Apricot flavonoids also function as antioxidants and help prevent and treat several conditions like Alzheimer's, Parkinson's, and heart disease. Certain apricot cultivars have demonstrated a noteworthy level of total flavonoid content [85]. Excessive amounts of reactive oxygen species and free radicals in the human body can cause significant damage to essential macromolecules like nucleic acids and proteins, potentially resulting in internal

tissue harm. These conditions can lead to internal inflammation, cancer, ulcers, and heart diseases. Apricot fruit seed and oil, with their abundant phytochemicals, possess the capacity to mitigate or even avert diseases caused by reactive oxygen species and free radicals. According to comparative analysis, apricot seed has a high concentration of metabolites that provide the fruit kernel with strong antioxidant properties that help fight and prevent cancer, inflammation, and chronic illnesses [78]. This is due to their abundance of nutrients and high levels of vitamins, minerals, fiber, antioxidants, polyphenols, and various other biologically active compounds, which serve as valuable sources of energy [86].

Around the world, cardiovascular illnesses are regarded as one of the leading causes of death [87]. High homocysteine, hypertension, and cholesterol are the main causes of these disorders [88]. Because apricot kernels are high in fiber, DPPH radical scavengers, and phenolic compounds, they may help prevent cardiovascular disease. All of these elements contribute to lowering cholesterol and oxidizing free radicals to lessen cardiac damage [67]. Research conducted in vivo on animals reveals that providing apricot kernels to the animals can lower their disease incidence by 10 to 20%. Additionally, higher antioxidant capacities were observed in the rats after the apricot kernel was added to their diet. The observed changes encompassed reduced iron levels, elevated total phenolic contents, and enhanced DPPH radical scavenging [9]. Moreover, the flavonoids present in apricot seeds can reduce the risk of developing cardiovascular disease. Flavonoids and other polyphenols have been shown to have the capacity to inhibit platelet aggregation in laboratory experiments, thus lowering the likelihood of developing heart disease. They can control the apoptotic process and lessen vascular inflammation. It was also observed that adding AKO to the diet of rats significantly improved their lipid profile. Additionally, studies in which apricot kernel protein was hydrolyzed and employed in vitro to determine its potential to regulate hypertensive activity were conducted [89].

Additionally, apricot seeds can prevent liver damage. An investigation into the hepato-protective properties of apricot kernels was conducted in vitro on albino animals. The dosage was administered orally, and the seeds were extracted in ethanol. The notable study's conclusion stated that there had been a decrease in the liver-damaging enzymes alkaline phosphatase, aspartate transaminase, and alanine aminotransferase. An increase in these enzyme levels in the bloodstream indicates damage to the liver cells. A different set of animals received dried apricot kernel in their diet instead of ethanol extract, resulting in a decrease in the levels of aspartate transaminase and alanine aminotransferase in their serum [90].

An age-related neurodegenerative disease is Alzheimer's disease. Reduced acetylcholine levels in the cerebrospinal fluid, amyloid beta buildup, and asymmetric protein phosphorylation, which results in the formation of neurofibrils and raises oxidative stress in the brain, are the pathophysiological features of the disorder [91]. The FDA-approved medication has extremely severe side effects and is ineffective and inefficient in curing the illness [92]. Apricot seed kernels have pharmacological effects for neuroprotection as well as anticancer, cardio-protective, antibacterial, and hepato-protective qualities [66]. A study was conducted to record the antiacetylcholine and neuroprotective characteristics of bitter and sweet kernels. An investigation was conducted to examine the impact of both alcoholic and aqueous extracts on PC12 neuron cells. The results showed that a water-based extract of the bitter apricot kernel exhibited the most effective antiacetylcholine activity and neuroprotective effects in PC12 neurons [91]. A separate investigation was carried out, wherein apricot seed extracts were formulated using an ethanol-based solvent. The Ellman method was utilized to determine the inhibition concentration values against the enzyme acetylcholinesterase to evaluate the inhibitory capacity of the apricot seed extracts. The apricot seed extracts exhibited notable inhibitory effects on the enzyme acetylcholinesterase, which is responsible for the conversion of acetylcholine to choline. According to the study's findings, apricot seed extract in ethanol could take the place of a prescription medication for neurodegenerative diseases [93]. According to a different study, amygdalin can decrease fibroblast cells and inhibit the transforming growth factor TGF β1 [94]. Additionally,

amygdalin possesses inherent properties that effectively safeguard against renal injury caused by inflammation.

For many years, synthetic antibiotics have been used to treat bacterial infections; however, they have unfavorable side effects and can increase bacterial resistance. Natural antibiotics derived from plants that possess antimicrobial qualities offer a viable substitute for treating various kinds of microbial infections. The antibacterial properties of apricot seed extract have demonstrated encouraging results against both Gram-positive and Gram-negative bacteria as well as fungi [95]. Moreover, apricot extracts stop *Helicobacter pylori* and *Mycobacterium tuberculosis* from growing. [89]. The absence of an outer cell membrane in apricot seeds allows their phenolic contents to effectively hinder the growth of Gram-positive bacteria [55]. Studies have indicated that apricot seed cold press oil inhibits *Acinetobacter baumannii*, and that cellular metabolism is highly sensitive to this effect. This strain is especially dangerous in a hospital setting because it can proliferate in both wet and dry areas. The remarkable ability of cold press apricot seed oil to safely and effectively control this pathogen has been demonstrated. Apricot seed oil has demonstrated efficacy against mature *S. aureus* biofilms and the capacity to eliminate the cellular metabolism of pathogenic bacteria [96].

According to other studies, apricot seed oil has antibacterial properties against some strains of bacteria and yeast [97]. In order to determine the minimum inhibitory concentration (MIC) required to eradicate the microorganisms, they employed the disc diffusion technique. The researchers assessed the effectiveness of the apricot seed oil by quantifying the size of the inhibition zone (IZ). According to their findings, apricot seed oil effectively inhibited Gram-positive bacteria, such as *S. aureus* and *Bacillus subtilis*. Furthermore, compared to Gram-negative bacteria, the inhibitory effect on colonies of Gram-positive bacteria was further intensified. Additionally, it was discovered that apricot seed oil inhibited the growth of certain yeast strains. The primary cause of skin infections and a common fungus found on human skin, *Candida parasilopsis*, was successfully combated in their experiment using a very low concentration of apricot oil [98].

One of the most important bioactive compounds contained in apricot kernel is amygdalin. This is the reason for the bitterness in the seeds. It is a cyanogenic glycoside that occurs naturally and is occasionally referred to as vitamin B17. It has historically been utilized in Chinese herbal medicine [99]. Additionally, it can be utilized for the treatment of migraine, hypertension, persistent inflammation, specific gastrointestinal disorders, as well as dermatological conditions such as furuncle, acne vulgaris, and dandruff [94]. Furthermore, several studies have demonstrated that amygdalin targets cancer cells without endangering healthy cells in the body. Amygdalin's mode of action is characterized by stopping the cell cycle, which causes cancer cells to undergo apoptosis. Occasionally, interactions between amygdalin and the β-glucosidase enzyme result in the generation of hydrocyanic acid, which kills cells [100]. Research shows that because normal body cells contain the enzyme rhodanese, hydrogen cyanide does not affect them. This enzyme reduces the toxicity of hydrocyanic acid and converts it into a nontoxic substance [90]. However, amygdalin's cyanogenic qualities have also been extensively documented to have negative effects on human health. It is imperative to bear in mind that amygdalin is harmless and does not pose a risk. However, as it deteriorates, the residual by-products such as hydrogen cyanide may become poisonous. The enzymes and gastric acids present in the digestive tract of the stomach initiate the process of breaking down food. Therefore, it is advisable to be cautious when ingesting bitter seed kernels [101]. It is well known that amygdalin is toxic and deadly in animals if 0.1–0.2 g is consumed. Additionally, it is advised against humans consuming 20–30 bitter apricot kernels daily, although because sweet apricot kernel contains little amygdalin, eating them is thought to be safe. Additionally, it is advised that the bitter apricot kernels undergo detoxification before ingestion. This minimizes the possibility of any possible toxicity. A number of easy methods are suggested, such as boiling, roasting, fermenting, and drying bitter apricot kernels [102]. Many researchers concentrate on amygdalin-based anticancer therapy, and numerous in vitro

studies are being conducted in this area. Nevertheless, the translation of that in vitro research into in vivo experimentation remains necessary. Furthermore, more research is needed to fully understand the distribution of amygdalin in apricot seeds. Further research is also needed on the de-bittering of seeds and the safety of amygdalin in edible apricot seeds [101].

The kernel of the apricot fruit is also a rich source of fiber, tocopherols, minerals, vitamins, and phytochemicals [80]. The lipids in apricot seed kernels are arranged into the form of an oil body, wherein a layer of proteins and phospholipids coats triglyceride molecules [32]. It is possible to extract the oil from the apricot seeds, which is a cheap and highly nutritious food source. One of the most crucial and prevalent components of apricot seeds is protein. The apricot kernel has enormous potential to be regarded as a valuable nutritional food, which includes a rich concentration of fat and protein [32,96]. A significant amount of essential oils from apricot seeds are also available for use as edible products. AKO contains significant minor compounds and unsaturated fatty acids that make it suitable for use in the food processing sector [71]. It is also mentioned that apricot seed is a great substitute for other emulsifiers in the food industry due to its high content of unsaturated fatty acids, such as mono- and di-glycerols. Apricot seed oil may be able to stabilize food emulsion products, such as shortenings [103]. Because of the addition of fiber, proteins, and minerals to baked goods to extend their shelf life, apricot seeds can also be used in the baking industry. Additionally, seed flour is a great source of protein that can add value to the process of making ice cream and yogurt [9]. Apricot seed flour is a viable option for usage in protein/energy drinks due to its low molecular protein content. Its protein content is easily absorbed and provides a useful source of energy [104]. The cereal industry can make use of apricot seed flour. When combined with wheat flour, it can also raise the bread's protein content [105]. To improve the flavor and nutritional value of Turkish coffee, experiments were conducted to add apricot kernels. Turkish coffee's phenolic contents rose after the apricot kernel was added, and there was also a 15% increase in antioxidant activity. Additionally, it was determined that adding apricot kernel flour improved the storage stability of Turkish coffee [106]. Another study also concluded that, due to its high protein and mineral content, apricot seed flour might be utilized as a food enrichment ingredient in a variety of processed foods [107]. However, they also recommended that, when necessary, detoxification come first before introducing food. The study concluded with the high content of polyphenols, unsaturated fatty acids, and amino acids in apricot seeds [108]. These characteristics give the fruit seeds a great deal of potential for use in the production of fermented milk and juice beverages as well as fermented meat products, which are healthier functional foods. A unique application of apricot seed content is in foods created especially for individuals with dietary sensitivities. In this context, a study was carried out in which the methanol-based extract of apricot seeds was used to extract the β-galactosidase enzyme. To create cheese without lactose, the enzyme underwent additional purification.

4. Conclusions and Future Perspectives

Apricots have been extensively studied in the scientific literature, revealing a plethora of nutrients and biologically active compounds present within their composition. The comprehensive analysis of their nutritional and functional properties has yielded valuable insights into the potential health benefits associated with their consumption. In the realm of combating illness and safeguarding optimal health, these substances assume pivotal roles. Apricots exhibit promising attributes as a functional food owing to their notable anti-inflammatory properties. In the context of the subject matter at hand, the present review functions as a valuable asset for scholars engaged in further investigations pertaining to nutraceuticals, as well as entrepreneurs with a vested interest in the commercialization of said fruit.

The apricot kernel has extensive applications in numerous industries, including food, cosmetics, pharmaceuticals, and more, as it is utilized in the cosmetic industry to create

hair and skin products. In contrast, the demand for sweet apricots is higher than that for bitter ones because the bitter apricot contains amygdalin, a compound that limits its applications, particularly in the food industry. Nevertheless, various extraction techniques have demonstrated remarkable efficacy in eliminating or diminishing the bitter taste of apricot kernel. Further research is required to determine methods for reducing the amygdalin content of the kernel so that it can be utilized as an enrichment and additional beneficial source without altering the flavor of the food product. Consequently, due to its exceptional technofunctional and therapeutic properties, apricot kernel remains an excellent research subject, particularly in the food and pharmaceutical industries. Sectors may deem the apricot kernel a viable ingredient on account of its economical and environmentally sustainable characteristics.

By properly utilizing the apricot waste, farmers can increase their profits by decreasing the expenses associated with animal feeding. Additionally, this practice can yield a variety of value-added products and contribute to waste management and the mitigation of environmental pollution. Furthermore, additional developments in the valorization of industrial food by-products pertain to medical applications, where substantial expansion potential has been identified, as exemplified by apricot by-products. Since the abovementioned waste is promising for various applications, further studies must be undertaken to develop pilot facilities, so that further commercialization can be feasible.

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Abbreviations

The following abbreviations are used in this manuscript:

AK	Apricot Kernel
AKO	Apricot Kernel Oil
AKS	Apricot Kernel Shell
AAE	Ascorbic acid Equivalents
CNC	Cellulose Nanocrystals
DES	Deep Eutectic Solvent
DM	Dry Mass
DW	Dry Weight
FRAP	Ferric-Reducing Antioxidant Power
FT-IR	Fourier Transform Infrared
FW	Fresh Weight
GAE	Gallic acid Equivalents
GC-MS	Gas Chromatography-Mass Spectrometry
HPLC	High-Performance Liquid Chromatography
NMR	Nuclear Magnetic Resonance
PEF	Pulsed Electric Field
SC-CO_2	Supercritical Carbon Dioxide
TPC	Total Polyphenol Content
TEAC	Trolox Equivalent Antioxidant Capacity

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