Phytochemical Composition of *Prunus spinosa* L.

Subjects: Horticulture

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Prunus spinosa L. is a perennial, thorny shrub, highly decorative for landscape and forest edges, belonging to the Rosaceae family, genus Prunus, representing one of the ancestors of *P. domestica*. Modern phytotherapeutics emphasizes the benefits of consuming parts or products based on the *Prunus spinosa* L. shrub, as it is considered a plant with functional nutritional and therapeutic properties, remarkable in various pathologies with increasing incidence. Up to now, research has shown that the polyphenols found in large amounts in the fruits of *P. spinosa* L. are biofunctional compounds. These include anthocyanins, phenolic acids, flavonoids, and coumarin derivatives.

Prunus spinosa L.   phenol compounds   oxidative stress

1. Introduction

Studies on the biologically active substances that are found in food are of great relevance in the innovation and certification of functional food products. Thus, at the global level, a great emphasis is placed on the search for plant-based foods as alternative options to prevent chronic inflammation through dietary interventions [1]. Food manufacturers aim to develop new food products that are attractive to a wide range of potential consumers while also trying to become competitive in the market. Currently, these actions can be divided into two directions, namely a return to natural and traditional products that are minimally processed and the production of functional foods, often using unconventional materials or additives. These directions have been established based on recent studies that prioritize the global effort to find technological methods for food processing that minimize the loss or degradation of biologically active phytocompounds. The fruits of *P. spinosa* L. contain high levels of phenolic compounds, which have strong anti-oxidant properties [2][3][4][5]. These compounds have potential applications in the food and phytopharmaceutical sectors [1][4][6][7][8][9]. The blackthorn can be utilized as an ingredient in various food products such as yogurt [10], ice cream [11], jam [12], wholemeal biscuits with dried fruit, gin and tonic drinks. Incorporating blackthorn into these food items would enhance their nutritional value, therefore fortifying them and improving their overall quality. The recent study conducted by Özkan (2023) [13] demonstrated that dried *P. spinosa* L. pestles exhibit high bioaccessibility of polyphenols during gastrointestinal digestion. This finding suggests that *P. spinosa* L. could be a promising option for producing beverages. The utilization of *P. spinosa* L. extracts as novel anthocyanin-based food dyes in confectionery items, such as topping on donuts and in “beijinho”, a Brazilian biscuit product, has resulted in significant changes in nutritional content [14].

Modern phytotherapeutics emphasizes the benefits of consuming parts or products based on the *Prunus spinosa* L. shrub as it is considered a plant with functional nutritional and therapeutic properties, remarkable in various pathologies with increasing incidence. Studies to date have shown that the polyphenols, which are present in significant amounts in the fruits of *P. spinosa* L., are biofunctional components, including anthocyanins, phenolic acids, flavonoids, and coumarin derivatives [4][6][15][16].

2. The Bioecology of the *P. spinosa* L. Shrub

Prunus spinosa L. is a perennial, thorny shrub, highly decorative for landscape and forest edges, belonging to the Rosaceae family, genus Prunus, representing one of the ancestors of *P. domestica* [6][17][18].

It is native to Europe (**Figure 1**), mainly central and southern Europe, except the lower half of the Iberian Peninsula, extending northwards to the southern part of the Scandinavian Peninsula [18][19].

P. spinosa L. is also widespread in western Asia and northwest Africa and is locally present in New Zealand, Tasmania, and eastern North America (USDA NRCS, The PLANTS database, 2015) [20], the Pacific Northwest and New England in the U.S. (**Figure 1**). Some authors believe that it originates in the northernmost tip of the European continent, in Scotland [21], and is commonly found in Europe, around deciduous forests, and in the temperate areas of Asia, especially in central, northern, western, and southern Anatolia. Towards the east, it reaches Asia Minor, the Caucasus, and the Caspian Sea [22]. Isolated populations have been found in Tunisia and Algeria. It is widespread in the Southern Alps, Switzerland, at altitudes up to 1600 m [23].

Species of *P. spinosa* L. are also found on the slopes of wild, uncultivated areas in several regions of Bosnia and Herzegovina [24]. It is commonly found at forest edges and openings, on sunny, rocky slopes, in ravines and river valleys, and meadows and pastures from low plains to mountains [25][26].

In Romania, *P. spinosa* L., can be found in lowland, plain areas but is more abundant in hilly areas, extending to mountainous areas with altitudes of 900–1000 m, being present at the edge of agricultural lands, decorating the landscape or on abandoned pastures, as well as on the edge of oak and beech forests [18][27][28][29].

Figure 1. The habitat of *P. spinosa* L. (Plants of the World Online. Royal Botanic Gardens, Kew, 2023) [30]. 1—In Romania, it can be found in all areas; 2—It can also be encountered on the slopes of uncultivated areas in Bosnia and Herzegovina; 3, 4—Native to central and southern Europe, except the lower part of the Iberian Peninsula, it spreads towards the north, up to the south of the Scandinavian Peninsula; 5, 6—Isolated populations in Tunisia and Algeria, being also widespread in lower and higher areas, up to 1600 meters altitude in the Southern Alps of Switzerland; 7—Locally, it can be found in New Zealand, Tasmania; 8, 9—Locally, it can be found in the east of North America, the northwest of Pacific and New England in the United States; 10—Widespread in Western Asia, temperate regions of Asia—central, Northern Western and Southern Anatolia; 11, 12, 13—Widespread in Asia Minor, Caucasus, Caspian Sea and North and Western Africa.

It is a 2–3 m shrub with dark blue-violet bark and dense, stiff, spiny branches that grow well on clay, loam, sandy, calcareous, and well-drained soils and is recommended for its ability to improve degraded land. *P. spinosa* L. is a frost- and drought-tolerant species that develops well in sunny areas, where it benefits from exposure to light, as it is a thermophilic thorny shrub. It is also found on mesic to dry soils, on the edges of oak and beech forests, or the banks of rivers with willows and poplars, making it an unlimited source of berries—raw material for the food industry. It does not require any special care [4][18][31][32][33].

The leaves are oval, 2–4.5 cm long, and 1.2–2 cm wide with a serrated edge, and the flowers are white (**Figure 2**). They have five petals, are hermaphrodite, insect-pollinated, and possess vasoprotective, anti-inflammatory, diuretic, vermicide, detoxifying (blood purifying), and spasmolytic activities [4][31][32]. The first flowers appear in early to mid-March, depending also on the temperature, continuing until mid-April [27][28][34].

The fruits of the *P. spinosa* L. shrub are small, spherical, blackish drupes (**Figure 2**), about 10–12 mm in diameter, covered with blue bloom, and have therapeutic and functional properties [35]. The flesh is greenish yellow, adherent to the stone, with a pronounced astringent aroma due to the high tannin content and an acidic taste, which is why they can only be eaten fresh when overripe and in very small quantities [36]. Harvesting time is late autumn, in

November, after the fall of the mist, due to the decrease in astringency. The fruits can be harvested even in winter because they persist well on the branches [2][19][30].

Figure 2. Different anatomical parts and phytochemicals content of *P. spinosa* L. Sources: [2][6][8][17][37][38][39][40].

Data obtained to date have reported a total polyphenol and anthocyanin content contributing significantly to the anti-oxidant capacity of *P. spinosa* L. fruit based on the rich content of cyanidin-3-rutinoside (53.5%), peonidin-3-rutinoside (32.4%) and cyanidin-3-glucoside (11.4%) [41].

The fruits have proven functional effects on heart strengthening, in myocarditis and atherosclerosis [42][43]. Ethnopharmacological sources show that *P. spinosa* L. buds, popular in southern Europe, possess antihypertensive properties [44].

3. Nutritional composition of *P. spinosa* L.

The nutritional composition and estimated energy value of the blackthorn fruits are presented in **Table 1**.

Table 1. Nutritional value of blackthorn fruits based on literature.

Reference	[52][1]	[37][1]	[15][1]	[53][1]	[54]
Energy (kcal/100 g)	383.27 ± 7.09	57	154.93	249	nd

Moisture (%)	60.86 ± 1.69	54.85 ± 2.11	nd	69.37	nd
Carbohydrates (g/100 g dw)	88.51 ± 2.24	8.64	31.07 ± 0.62	nd	15.17 ± 25.83
Proteins (g/100 g dw)	2.86 ± 0.03	0.75	2.07 ± 0.04	3.4	0.99 ± 0.25
Fat (g/100 g dw)	1.98 ± 0.32	1	2.05 ± 0.12	2.06	nd
Ash	6.65 ± 2.03	nd	0.69 ± 0.04	2.72	1.18 ± 0.56
Fiber (g/100 g)	nd	9	5.79 ± 0.1	4.6	0.67 ± 0.26

The observed variations in the nutrient content of *P. spinosa* L. fruits (as shown in **Table 1**) can primarily be attributed to climatic conditions. Fruits grown in hot, dry climates are distinguishable by a lower level of moisture.

Differences were noted in the sugar content values (**Table 1**), ranging from 8.64 to 88.51 g/100 g. The variation in sugar content may be attributed to the intrinsic physicochemical properties and ripeness of blackthorn, as well as the environmental conditions [45].

An analysis of the amino acid composition of *P. spinosa* L. fruits [46] revealed that leucine was found in a concentration of 122.6 mg/100 g. This amount is equivalent to 7.66% of the FAO (Food and Drug Administration) and WHO/DRIs (World Health Organization/Dietary Reference Intakes) recommended daily allowances (RDAs).Additional essential amino acids detected in *P. spinosa* L. were Valine (87.8 mg/100 g), Phenylalanine (84.7 mg/100 g), Lysine (50.6 mg/100 g), and Threonine (47.6 mg/100 g) [46].

Fatty acids found in *P. spinosa* L. fruits include oleic acid, linoleic acid, arachidonic acid, linolenic acid, EPA (eicosapentaenoic acid), DPA (docosapentaenoic acid) and DHA (docosahexaenoic acid) [47]. Fatty acid content was dominated by monounsaturated fatty acids [47], followed by polyunsaturated fatty acids. According to the study conducted by Babalau-Fuss (2021) [47] on the analysis of fatty acid content in *P. spinosa* L. fruits, it was found that monounsaturated fatty acids (MUFA) were the most abundant, accounting for 46.20% of the total fat content. Polyunsaturated fatty acids (PUFA) were identified in a proportion of 34.54%.

Among the mineral elements identified in *P. spinosa* L., potassium had the highest amount, followed by phosphorus, calcium, and sodium. The potassium levels varied between 1035.826 and 2014.23 mg/kg, the calcium

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levels ranged from 19.36 mg/kg to 150.41 mg/kg, and the sodium levels varied between 2.56 and 534.81 mg/kg [24][48][47].

4. The Polyphenol Composition in Various Parts of the *P. spinosa* L. Shrub

Polyphenols are secondary metabolites with important and various functions in the plant world, representing an extensive group of phytochemicals. **Table 2** includes data from the most recent literature (from the last few years) on the detection of phytochemical content identified in *P. spinosa* L. fruits, leaves, flowers, and branches.

Table 2. The phytochemical composition (phenolic acids, anthocyanins, and flavonoids) of blackthorn fruits, flowers, leaves, and branches is based on literature data from the previous few years.

Organs of *P. spinosa*	Type of Sample/ Technique	Phenols	References
Fruits	Cold solution (1% BHT [*w*/*v*], 3% formic acid [*v*/*v*] in methanol) HPLC–DAD–MS	**Phenolic acids** **Cinnamic acid derivatives:** · 3-p-Coumaroylquinic acid; · 4-p-Coumaroylquinic acid 1; · Caffeic acid hexoside 1; · Caffeic acid hexoside 3; · p-Coumaric acid hexoside 1; · 3-Caffeoylquinic acid; · 4-Caffeoylquinic acid; · 5-Caffeoylquinic acid 1; · 3-Feruloylquinic acid; **Flavanols**	[65]

11. Ürkek, B.; Şengül, M.; Akgül, H.İ.; Kotan, T.E. Antioxidant Activity, Physicochemical and Sensory Characteristics of Ice Cream Incorporated with Sloe Berry (Prunus spinosa L.). Int. J. Food Eng. 2019, 15, 20180029.

12. Egea, I.; Sánchez-Bel, P.; Romojaro, F.; Pretel, M.T. Six Edible Wild Fruits as Potential Antioxidant Additives or Nutritional Supplements. Plant Foods Hum. Nutr. 2010, 65, 121–129.

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· Catechin;

· Epicatechin;

· Procyanidin dimer 1;

· Procyanidin dimer 2;

· Procyanidin dimer 3;

· Procyanidin trimer 2;

Flavonols

· Quercetin triglycoside;

· Quercetin acetyl hexoside;

· Quercetin acetyl rutinoside;

· Quercetin hexosyl pentoside 2;

· Quercetin hexosyl rhamnoside;

· Quercetin-3-xyloside;

· Quercetin pentoside 2;

· Quercetin pentoside 3;

· Quercetin rhamnosyl hexoside;

· Querectin-3-galactoside;

· Quercetin-3-glucoside;

· Quercetin-3-rhamnoside;

· Quercetin-3-rutinoside;

· Isorhamnetin hexoside;

· Kaempferol pentoside hexoside;

Environ. 2010, 1, 9–20.

		· Kaempferol rhamnosyl hexoside 1; · Kaempferol rhamnosyl hexoside 2; · Kaempferol pentoside; **Flavones** · Apigenin pentoside; **Anthocyanins** · Cyanidin pentoside; · Cyanidin 3-acetylglucoside; · Cyanidin-3-glucoside; · Cyanidin-3-rutinoside; · Pelargonidin-3-glucoside; · Peonidin-3-acetylglucoside; · Peonidin-3-glucoside; · Peonidin-3-rutinoside; · Petunidin-3-rhamnoside.	
	Ethyl acetate fraction of methanol-water extract (75:25, *v*/*v*) in dried fruit UHPLC-PDA-ESI-MS	**Phenolic acids** · Protocatechuic acid 4-O-hexoside; · Protocatechuic acida; · 3-O-Caffeoylquinic acid; · p-Hydroxybenzoic acida;	[24]

from Prunus spinosa and Prunus domestica Species. Meas. Food 2023, 10, 100079.

46. Özcan, T.; Kahyaoğlu, G. Fatty Acid and Amino Acid Profiles in the Fruits of Prunus spinosa L. Subsp. Dasyphylla (Schur) Domin from Europe-in-Turkey. Adv. Mol. Biol. 2008, 1, 39–46.

· Caffeoylshikimic acid derivative;

· Vanilloyl malate hexoside;

· 3-O-p-Coumaroylquinic acid;

· p-Coumaric acid O-hexoside;

· 5-O-Caffeoylquinic acid;

· cis-3-O-Feruloylquinic acid;

· 4-O-Caffeoylquinic acid;

· Caffeic acid 3/4-O-hexoside;

· 3-O-Feruloylquinic acid;

· Vanillina;

· 4-O-Caffeoylshikimic acid;

· 4-O-Feruloylquinic acid;

· Caffeoylshikimic acid;

· Caffeoylshikimic acid;

· p-Coumaroylshikimic acid;

· Aromadendrin hexoside;

· p-Coumaroylshikimic acid;

Flavonols

· Quercetin 3-O-β-D-galactoside;

· Quercetin 3-O-(6″-O-α-L-rhamnopyranosyl)-β-D-glucopyranoside;

· Quercetin 3-O-β-D-glucopyranoside;

59. Miguel, M.G. Anthocyanins: Antioxidant and/or Anti-Inflammatory Activities. J. Appl. Pharm. Sci. 2011, 1, 7–15.

		· Quercetin 3-O-α-D-xylopyranoside; · Quercetin 3-O-α-L-arabinopyranoside; · Quercetin 3-O-α-L-arabinofuranoside; · Quercetin 3-O-(4″-O-β-D-glucopyranosyl)-α-L-rhamnopyranoside; · Quercetin 3-O-α-L-rhamnopyranoside; · Quercetin malyl-pentoside; · Quercetin acetyl-hexoside-rhamoside.	
Flowers	Defatted methanol-water extract RP-HPLC-PDA	**Phenolic acids** · 3-O-Caffeoylquinic acid (neochlorogenic acid); · 5-O-Caffeoylquinic acid (chlorogenic acid); · 4-O-Caffeoylquinic acid (cryptochlorogenic acid); · Caffeic acid; · p-Coumaric acid; **Flavanols** · (+)-Catechin; · (–)-Epicatechin; **Flavonols** · Kaempferol 3-O-α-L-arabinopyranoside-7-O-α-L-rhamnopyranoside;	[66]

B.; Mari, M.; Guidi, L.; Ramakrishna, S.; et al. Antioxidant and Anti-Inflammaging Ability of Prune (Prunus spinosa L.) Extract Result in Improved Wound Healing Efficacy. Antioxidants 2021, 10, 374.

· Kaempferol 3-O-β-D-xylopyranoside-7-O-α-L-rhamnopyranoside (lepidoside);

· Kaempferol 3,7-di-O-α-L-rhamnopyranoside (kaempferitrin);

· Kaempferol 3-O-α-L-arabinofuranoside-7-O-α-L-rhamnopyranoside;

· Kaempferol 3-O-β-D-xylopyranoside;

· Kaempferol 3-O-(4’’-O-β-D-glucopyranosyl)-α-L-rhamnopyranoside (multiflorin B);

· Kaempferol 3-O-α-L-arabinofuranoside (juglanin);

· Kaempferol 3-O-α-L-rhamnopyranoside (afzelin);

· Kaempferol 7-O-α-L-rhamnopyranoside;

· Kaempferol 3-O-(2’’-O-E-p-coumaroyl)-α-L-arabinofuranoside-7-O-α-Lrhamnopyranoside;

· Kaempferol 3-O-(6’’-O-α-L-rhamnopyranosyl)-β-D-glucopyranoside;

· Kaempferol 3-O-(2’’-O-E-p-coumaroyl)-α-L-arabinofuranoside.

· Kaempferol;

· Quercetin 3-O-(6’’-O-α-L-rhamnopyranosyl)-β-D-glucopyranoside (rutin);

· Quercetin 3-O-(2’’-O-β-D-glucopyranosyl)-α-L-arabinofuranoside;

83. Gandhi, G.R.; Jothi, G.; Antony, P.J.; Balakrishna, K.; Paulraj, M.G.; Ignacimuthu, S.; Stalin, A.; Al-Dhabi, N.A. Gallic Acid Attenuates High-Fat Diet Fed-Streptozotocin-Induced Insulin Resistance via Partial Agonism of PPARγ in Experimental Type 2 Diabetic Rats and Enhances Glucose

		· Quercetin 3-O-β-D-glucopyranoside (isoquercitrin); · Quercetin 3-O-β-D-galactopyranoside (hyperoside); · Quercetin 3-O-α-D-xylopyranoside (reinutrin); · Quercetin 3-O-α-L-arabinopyranoside (guaiaverin); · Quercetin 3-O-(4''-O-β-D-glucopyranosyl)-α-L-rhamnopyranoside (multinoside A); · Quercetin 3-O-α-L-arabinofuranoside (avicularin); · Quercetin 3-O-α-L-rhamnopyranoside (quercitrin); · Quercetin;	
Leaves	70% (*v*/*v*) aqueous-methanolic extract UHPLC-PDA-ESI–MS	**Phenolic acids** · 3-O-caffeoylquinic acid (neochlorogenic acid); · 3-O-p-coumaroylquinic acid; · 3-O-feruloylquinic acid; · 4-O-caffeoylquinic acid (cryptochlorogenic acid); **Flavanols** · procyanidin type-B dimer; · procyanidin type-B dimer;	[67]

· (+)-catechina;

Flavonoids

· kaempferol 3-O-a-L-arabinopyranoside-7-O-a-L-rhamnopyranosidea;

· kaempferol 3-O-b-D-xylopyranoside-7-O-a-L-rhamnopyranoside (lepidoside);

· quercetin 3-O-(200-O-b-D-glucopyranoside)-a-L-arabinofuranosidea;

· kaempferol 3,7-di-O-a-L-rhamnopyranoside (kaempferitrin);

· kaempferol 3-O-a-L-arabinofuranoside-7-O-a-L-rhamnopyranosidea;

· quercetin 3-O-a-L-arabinofuranoside (avicularin);

· kaempferol hexoside-pentoside;

· kaempferol 3-O-a-L-arabinofuranoside (juglanin);

· kaempferol 3-O-a-L-rhamnopyranoside (afzelin);

· quercetin acetyl-hexoside-rhamnoside;

· kaempferol acetyl-hexoside-rhamnoside;

· kaempferol 7-O-a-L-rhamnopyranosidea;

· kaempferola;

		· kaempferol 3-O-(2”-E-p-coumaroyl)-a-L-arabinofuranoside-7-O-a-L-rhamnopyranoside.	
Branches	Lyophilized extract HPLC/MS	**Phenolic acids** · Protocatechuic acid; · Gallic acid; · Caffeic acid; **Proanthocyanidins or flavan-3-ols** · Ent-(epi)-catechin-(2α→O→7,4α→8)-(epi)-catechin-3′-O-gallate; · Ent-(epi)-afzelechin-(2α→O→7,4α→8)-(epi)-catechin-3′-O-gallate; · Ent-(epi)-gallocatechin (2α→O→7, 4α→8)(epi)-catechin; · Ent-(epi)-catechin (2α→O→7, 4 α→8)-catechin; · Ent-(epi)-gallocatechin (2α→O→7, 4α→8)-(epi)-catechin; · Ent-(epi)-catechin (2α→O→7, 4 α→8)-(epi)-catechin; · Ent-(epi)-afzalechin (2α→O→7, 4α→8) catechin; · Epigallocatechin; ·Ent-(epi)-afzalechin (2α→O→7, 4α→8)-(epi)-catechin; · Gallocatechin;	[6]

ith diode aphy with diode array detection coupled to an electrospray tandem mass spectrometer; RP-HPLC-PDA—Reversed-phase high-performance liquid chromatography coupled with diode array detection; HPLC/MS—High-performance liquid chromatography coupled to mass spectrometry.

	[49]	· Epicatechin; · Catechin; · Epiafzelechin; · Afzelechin;
[50]		**Coumarins** · 5-hydroxy-6-methoxy-7-O-β-D-glucosyl coumarin; · 5-hydroxy-6-methoxy-7-O-β-D-rhamnosyl coumarin;
[51]		**Flavonols** · Quercetin 3-O-rutinoside; · Kaempferol 3,7-O-dirhamnoside; ·Kaempferol 3-O-arabinoside-7-O-rhamnoside; kaempferol 3-O-arabinoside; [6] [52][53] · Quercetin; · Kaempferol

5. The Effect of Bioactive Compounds Found in the Blackthorn Fruits in the Treatment of Various Diseases

Oxidative stress is one of the major pathological mechanisms that occurs during the inflammatory process, affecting the integrity of cells by destroying lipids, proteins, and nucleic acid [54]. It represents a disruption of the pro-oxidant/anti-oxidant balance with a key role in the development of many chronic diseases such as CVD, stroke, diabetes, some cancers, and certain neurodegenerative disorders. Anti-oxidant phenolic compounds possess at least one aromatic ring that includes hydroxyl groups, and the anti-oxidant capacity of these compounds is mainly due to their tendency to chelate metals [55].

Phenols and polyphenols are considered a group of compounds with the highest anti-oxidant activity due to their property to scavenge ROS, limit ROS production by inhibiting the activity of oxidative enzymes and the chelation of trace elements, and increase the efficacy of endogenous antioxidants [56]. The low redox potential of flavonoids, due to proton donation, allows them to reduce highly oxidized free radicals such as peroxides, alkoxyl, hydroxyl, and peroxide radicals [57].

Polyphenols and anthocyanins have strong anti-oxidant activity, significantly reducing the harmful effects of free radicals that are produced by reactive oxygen species [58][59]. The total polyphenols and anthocyanins content in the powder extract obtained from blackthorns, dried at 30 °C, recorded values of 340.23 (mg GAE/g DW) and 180.2 (C3GE mg/g DW), respectively [60].

Table 3 presents the mechanisms of action of the bioactive compounds identified in *P. spinosa* L. and their associated beneficial effects.

Table 3. Mechanisms of action and beneficial effects of nutritional-functional compounds of *P. spinosa* L.

Bioactive Compounds	Health Effect	Main Outcomes	References
Flavonoids (Quercitin, Rutin)	Neurogenerative effect	**-acetylcholinesterase inhibition -monoamine oxidase inhibition -↓ peroxyl radical capture and oxidation -neurotrophic action -maintenance of physiological functions of vital organs**	[61][62]
Flavonoids	Cardiovascular effect	-inhibition of pro-inflammatory enzymes -anti-atherosclerotic effects -anti-atherothrombotic effects -modulation of lipid metabolism, -normalization of the LDL/HDL ratio, -improving capillary permeability -improved endothelial function, vasodilatory effects -↑ release of nitric oxide and uncoupling of endothelial nitric oxide synthesis -↓ oxidative DNA damage	[41][63][64][65][66][67][68]
Proantocianidine		-modulates lipid metabolism, -↑ anti-oxidant capacity of plasma, - improve vascular functions -↓ platelet activity	[41][69]
Cianidin-3-rutinoside		-improve lipid ↓ mechanisms, -inhibition of lipolytic digestive enzymes -inhibition of lipid absorption processes -anti-oxidant activity on ROS, -antiglycating activity -cardioprotective activity mixed competitive inhibition of pancreatic lipase and pancreatic cholesterol esterase -inhibition of cholesterol mycelial formation linked to primary and secondary bile acid	[41][70][71]

Bioactive Compounds	Health Effect	Main Outcomes	References
		-inhibition of cholesterol mycelial absorption in the proximal jejunum.	
Cianidin-3-glucoside		-↑ tissue tolerance to ischemic injury -↓ risk of cardiovascular disease, hypertension, -capacity to scavenge ROS -↓ oxidative stress, enhancing inflammatory responses	[70][72]
Cianidin-3-glucoside Cianidin 3-rutinoside	Diabetes and associated metabolic diseases	↓ risk of diabetes and obesity ↓ postprandial glucose by inhibition of pancreatic α-amylase and intestinal α-glucosidase -modulates postprandial blood glucose by inhibiting carbohydrate digestive enzymes -↓ glucose transport in the small intestine. -inhibit glucose uptake in colorectal adenocarcinoma epithelial cells	[72][73]
Phenolic acids	Anticancer effect	-cytotoxic activity on some cancer cell lines -induction in vitro of endogenous anti-oxidant mechanisms -modulation of Nrf2 transcription factors, a regulator of cellular resistance to oxidative damage, -↓ disruption of the pro-oxidant/anti-oxidant balance with a key role in some cancers	[16][17][74][75]
Anthocyanins		-unchanged dietary absorption and incorporation into cells, -major contribution to establishing anti-oxidant activity, reducing cancer risk	[2][52][64][76][77][78]
Phytosterols		-anticancer activity on prostate cancer	[76]
Cianidin-3-glucozide		↓ cancer risk due to the ability to scavenge ROS	[75]

↓—decrease; ↑—increase.

Data presented in specialized literature conclude that the fruits of the *P. spinosa* L. shrub manifest astringent, diuretic, antidiarrheal, antidysentery, and antibacterial effects and are recommended for stomach pain, diarrhea, dysentery, kidney disease, nephritis, biliary dyskinesia, common colds, whooping cough [79], respiratory disorders [42][80], cardiovascular pathologies [42], diabetes, and obesity but also as digestive stimulants [80].

These nutritional and therapeutic properties have been attributed to the different bioactive molecular components of polyphenols and anthocyanins, identified in significant amounts in the blackthorn fruit [60]. The dominant classes of phenolic compounds present in the extracts of the blackthorn fruit [15] are hydroxycinnamic acid derivatives (44.4%), anthocyanins (32.7%), and flavonoid derivatives (21.1%), which is in agreement with data presented in recent literature [74][81][82].

One of the dominant classes of polyphenols in blackthorn fruit is anthocyanins [83]. The total phenolic content and unique polyphenols analyzed by HPLC–DAD of the *P. spinosa* L. fruit have shown high levels of rutin and 4-hydroxybenzoic acid, followed by gallic and transsynaptic acids [5]. Total polyphenol content was positively correlated with anthocyanin content and anti-oxidant activity of fruit juice [84], including significant phytosterol content with a significant impact on prostate cancer [2].

In studies conducted with the purpose of determining antioxidant and antimicrobial activity, it has been shown that the *P. spinosa* L. fruit extract (PSF) exhibits antimicrobial activity against potentially pathogenic Gram-negative and Gram-positive bacteria [85][86]. The study examining [87] the influence of *P. spinosa* L. and *P. padus* L. seed extracts with methanol and dichloromethane on 16 pathogenic bacteria led to the observation that the methanolic extract of *P. spinosa* L. showed good activity against all tested strains. The results of this study are also supported by the results of the comparative study of three species, wild blackberry, cornus mas, and *P. spinosa* L. [88], where it was shown that *P. spinosa* L. has the highest antibacterial activity compared to the other two species.

The in vivo experimental investigation of oxidative stress induced by a high-fat diet in rats, supplemented with a minimal dose of streptozotocin, a naturally occurring nitrosourea derivative with chemotherapeutic effect, led to results demonstrating that the fruit extract of *P. spinosa* L. has a dose-dependent anti-oxidant capacity in both liver and brain [5]. It has also been shown to exhibit cellular anti-oxidant activity by inhibiting the hemolysis of human erythrocytes [5].

Based on the in vitro analysis of native primary polyphenols and phenolic metabolites found in the standardized flower extract from *P. spinosa* L., one study has emphasized their protective effects on human plasma components, especially fibrinogen, isolated in the human plasma matrix. It has also been shown that, based on the analytes tested in amounts of 1–5 g/mL in vivo, a significant reduction of structural changes of fibrinogen molecules under peroxynitrite-induced oxidative stress conditions has been obtained. In particular, a decrease in the oxidation and/or nitration of amino acid residues, including tyrosine and tryptophan, and the formation of high-molecular-weight aggregates [8] have been observed.

The leaf extracts showed antimicrobial, antidiabetic, and antitumor effects, representing an easily accessible natural source of bioactive compounds with potential application in food supplements and phytopharmaceuticals [89].

Experimental data presented in the specialized literature show that anthocyanins can exert therapeutic activities on diseases associated with oxidative stress, for example, coronary heart disease and cancer [90]. Specialized biochemical data have shown that anthocyanins are absorbed from the diet in an unchanged form [64] and are incorporated at the cellular level, both in the plasma membrane and in the cytosol [78], being one of the main classes of flavonoids that significantly contribute to the establishment of anti-oxidant activity with the potential to interact with biological systems, conferring antibacterial enzyme inhibition effects, cardiovascular protection, and overt anti-oxidant effects.

Blackthorn fruits are a rich source of antioxidants and can exert a strong protective effect on tartrazine-induced toxicity. The protective effects of *P. spinosa* L. fruit powder on hematological, biochemical parameters, and organic lesions in Wistar rats were analyzed after daily administration of the food additive tartrazine, dissolved in water, for 7 weeks [6][35]. Following this study, the results had a significant effect on improving the studied parameters.

Research that analyzed the ability of phenolic compounds to interact with biological systems that modulate gene expression was one of the postulated mechanisms to explain some of the health benefits of these compounds, which are found in *P. spinosa* L. fruits [91]. From a chemical point of view, phenolic compounds are molecules with one or more phenyl rings and one or more hydroxyl groups, capable of reducing reactive oxygen species and conferring redox properties. The in vitro studies have demonstrated the strong anti-oxidant activities of most of these compounds [77], inducing endogenous anti-oxidant defense mechanisms by modulating transcription factors such as Nrf2, which is a central factor and regulator of cellular resistance to oxidative damage, thus being a therapeutic target in aging-related diseases [92][93]. These properties give phenolic compounds sanogenic properties, which are considerable in the prevention of chronic diseases associated with oxidative stress, such as cardiovascular and neurodegenerative diseases, diabetes, and various types of cancer [94][95].