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Hawthorn pectin: Extraction, function and utilization

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ABSTRACT:

Pectin has been widely used as emulsifiers, gelling agents, glazing agents, stabilizers, and thickeners in food products. Hawthorn pectin has a higher viscosity than other foods-derived pectin such as lemon and apple pectin. It is also reported as a multifunctional fruit substance, which reduces the risk of hyperlipidemia and dyslipidemia. Therefore, hawthorn pectin is a potential resource for the development of new drugs, functional foods, and health-care products. This review symmetrically summarized the extraction methods, physiological characteristics, functional properties, and processing technologies of hawthorn pectin. It laid a foundation for the further research of hawthorn pectin and promoted the diversified utilization of hawthorn.

1. Introduction

Pectin mainly exists in the cell wall of higher plants (Thakur et al., 1997). It is a soluble fiber composed of acidic polysaccharides with galactosaldehyde skeleton (Linares-García et al. 2015). The structure of pectin is diverse; it is comprised of as many as 17 different monosaccharides and more than 20 types of interlinkages (Voragen et al., 2009). The backbone of pectin is composed of α (1 → 4) linked d-galacturonic acid with different degree of methyl esterification. In situ, three blocks are responsible for the classification of pectin, i.e., homogalacturonan (HG), rhamnogalacturonan I (RG-I), and rhamnogalacturonan II (RG-II) (Fig. 1). HG is a linear polysaccharide representing the “smooth region” of pectin, while the other two are highly branched polysaccharides representing the “hairy region” of pectin (Christiaens et al., 2016; Mohnen 2008). Within galacturonic acid (Gal A) monomers, the carboxylic groups may be methyl-esterified; hydroxyl groups may be *O*-acetyl-esterified (Fig. 2). Interestingly, *O*-acetyl-esterification occurs predominantly at the *O*-3 position and occasionally at the *O*-2 position. Both degree of methylation and degree of acetylation have a profound impact on the functional properties of pectin (Christiaens et al., 2016; Mohnen 2008). Pectin with a degree of methyl esterification (DE) of >50% is classified as high methoxyl pectins (HMP) (Cárdenas et al. 2008), whereas that with DE of <50% is called low methoxy pectins (LMP) (Yapo 2009). The former requires the addition of sucrose and acidic environment to form a gel, while the latter form gels in the presence of calcium ions within a larger pH range. The gelation of HMP is also determinate by the average molecular weight and the DE (Cárdenas et al. 2008). As a natural food additive, pectin is widely used in the food industry (e.g. jam, jelly, and yogurt processing) because of its excellent gelation, thickening and emulsifying properties (Sun et al. 2020). Furthermore, pectin also has a variety of bioactivities such as antioxidant (Mkadmini Hammi et al., 2016), antiglycation (Chaouch et al., 2015), antitumor (Bergman et al., 2010), hypolipidemic (Zhu et al., 2015), prebiotic activities (Gómez et al., 2016), and removal of heavy metals (Lattimer and Haub 2010). Studies have reported that the functional properties of pectin are closely related to their monosaccharide composition, molecular weight, chain–chain interaction, conformation of the glycosidic bonds etc. (Funami et al., 2011; Olano-Martin et al. 2002). It was reported that pectin oligosaccharide (POS) had better functional activities than pectin (Ogutu and Mu 2017; Gómez et al., 2016).

Although pectin exists in many plant tissues, its commercial extraction and production is mainly from apple pomace and citrus peel. New sources of pectin are expected to provide new characteristics; Hawthorn (Crataegus spp.) is one of them, belonging to Rosaceae family with a genus of fruit-bearing trees or shrubs distributed in North America, East Asia, Central Asia, and Europe (Uysal and Yildirim 2014; Li et al., 2008). Most hawthorns are consumed as fresh fruit; only a few are used to prepare jellies and jams. Hawthorn has many bioactive functions, such as, aid digestion and anti-atherosclerosis. However, literature mainly focus on the phenolic compounds in hawthorn. Limited studies are

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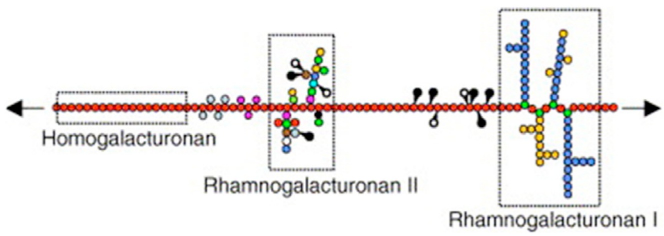

Fig. 1. Structure o f a pectin molecule (Willats et al., 2006).

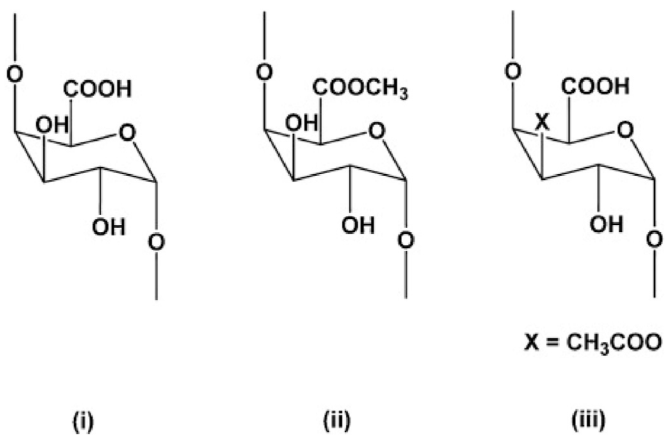

Fig. 2. Galacturonic acid (Gal A) of pectin: (i) Gal A, (ii) methylated Gal A, (iii) O-acetylated Gal A (Chan et al., 2017).

available for hawthorn pectin. Nevertheless, hawthorn pectin is attracting more research attentions due to its multifunctional properties and the better accessibility than other cultivated fruits (Zhu et al., 2015). For example, Hawthorn POSs have been added to functional foods to prevent hyperlipidemia and dyslipidemia (Zhu et al., 2013) Table 1.

The pectin content of hawthorn increases gradually during ripening stage (Li et al. 2015). A study (Linares-García et al. 2015) has shown that hawthorn pectin contains about 67% (w/w) uronic acid. The pectin extracted from hawthorn has a high Gal A content and DE, making it easy to forms gels. Compared with commercially available citrus pectin, hawthorn pectin has higher hardness, gumminess and chewiness. These characteristics indicates that hawthorn can be considered as a good source of HMP.

The functional properties of pectin depend on the DE, molecular weight, acetyl-esterification, sources, and extraction methods (Munarin et al. 2012; Schmidt et al., 2015). In situ, studies on hawthorn pectin mainly focus on the following aspects: (1) relationships between structural features and viscosity (Li et al., 2008) (2) correlations between viscoelastic performance and textural properties (Linares-García et al. 2015) (3) effect of ripening stages on pectin levels (Li et al. 2015) (4) optimization methods to achieve a higher extraction yield (Uysal and Yildirim 2014). Study on hawthorn pectin eventually revealed its superior viscosity, which is 4 to 6-fold higher than that of commercially available lemon and apple pectin (Wang et al., 2007). This might be attributed to the varied molecular structure, which use homogalacturonan and ramnogalacturonan as the main chain (Li et al., 2008).

In this review, the physiological functions, processing characteristics, extraction, modification and processing methods of hawthorn pectin were summarized, which laid a foundation for further research in hawthorn pectin and promoted the diversified utilization of hawthorn.

Table 1
Physicochemical characteristics of high methoxyl pectin of hawthorn (HMPH) and high methoxyl pectin of citrus fruits (HMPC) (Linares-García et al., 2015).

	HMPH	HMPC
Moisture (%)	11.4 ± 0.9^a	10.3 ± 0.5^a
Uronic acid content (%)	67.1 ± 3.5^b	89.0 ± 9.5^b
Methyl esterification (%)	89.1 ± 0.2^c	70.3 ± 0.5^c
Acetyl degree (%)	2.3 ± 0.06^d	1.9 ± 0.08^d
Molecular weight (kDa)	502.3	95.1

2. Extraction methods

Conventional methods for hawthorn pectin extraction include microwave extraction (Liu and Jiang 2014), ultrasonic extraction (Wang et al., 2015), acid extraction (Yarligan and Yıldırım 2014), chelating agent extraction (Chen and Zhu 2019) and enzyme extraction (Dranca and Oroian 2018; Gorlov et al., 2019). The pectin quality is directly affected by the extraction methods and the raw materials used. Pectin extracted from different methods demonstrated different functional properties and bioavailability (Shafie and Gan 2020; Adetunji et al., 2017).

With the fast development of "green chemistry", supercritical carbon dioxide extraction, subcritical water extraction and high voltage pulse electric field extraction have been applied to produce pectin (Chhouk et al., 2016; Liew et al., 2018; Marić et al., 2018). The new extraction methods preserve the natural structure of pectin, resulting into a higher antioxidant activities (Li et al., 2019). Nevertheless, the new extraction methods cannot match the conventional ones regarding extraction rate, operation convenience and primary investment. Acid extraction, enzyme extraction etc. are still preferred for a large-scale industrial production. Four types of pectin have been obtained from hawthorn wine pomace by hydrochloric acid method (HA-HP), citric acid method (CA-HP), cellulase method (E-HP) and microwave-assisted chelating agent method (MH-HP) (Sun et al. 2020). It was found that different extraction methods significantly affected the structure, physicochemical properties and antioxidant activity of hawthorn pectin. Among them, CA-HP method extracted hawthorn pectin was with the highest Gal A content and the best antioxidant activity; MH-HP method had the highest extraction rate; E-HP method extracted hawthorn pectin was with the best gelling ability. In another study, pectin was extracted from dry hawthorn powder through hot water extraction along with ultrasound or xylanase enzyme (Hou et al., 2018). It was indicated that the enzyme-assisted hot water extraction had the highest extraction yield, viscosity and degree of esterification, followed by the conventional hot water extraction. Moreover, the total phenol content and the degree of esterification of hot water extraction were the lowest. Regarding ultrasonic-assisted extraction, it showed the lowest extraction yield and the highest total sugar and polygalacturonic acid content. Ultrasonic-assisted extraction was able to obtain hawthorn pectin with the highest in vitro anti-glycation activity. Thus, industries can select an extraction method depending on their product requirement.

In addition, some experiments optimized the extraction conditions of Hawthorn pectin. The maximum extracted rate of hawthorn pectin appeared when extracted at pH 1.5/60 °C/120 min and pH 2.76/90 °C/120 min citric acid or lemon juice as an extraction solvent, respectively (Uysal and Yildirim 2014). Under the conditions of chelating agent (sodium hexametaphosphate) dosage of 1.35%, solid-liquid ratio of 1:9, microwave power of 440 W, microwave time of 80 s, the average extraction yield of Hawthorn pectin was $72.89 \pm 0.45\%$ (Chen and Zhu 2019).

The quality of hawthorn pectin is closely related to the treatment it went through; some scholars (Jiang et al., 2018) characterized the acid-extracted pectin from fermented hawthorn (FHP) and steeped hawthorn wine pomace (SHP). The degradation temperature of SHP was lower than that of FHP with a more orderly arranged molecular structure. Both FHP and SHP solutions have shear thinning characteristics, while SHP has stronger shear resistance and higher viscosity. Interestingly, FHP showed more elastic-solid ($G' > G''$) properties than SHP. The versatile characteristics of the hawthorn pectin extracted from different sources and extraction methods lead to a broad utilization prospect. For example, FHP can be used as a functional ingredient in jelly food, while SHP can be used in sticky food.

3. Functional characteristics

3.1. Antiglycation and antioxidant properties

Non-enzymatic glycation is a complicated amino-carbonyl reaction between reducing sugars and proteins, where proteins are modified by glucose, forming glycation end products (AGEs) (Rugang Zhu et al., 2019). These AGEs are one of the major risk factors of many chronic diseases including aging, arteriosclerosis, and diabetic complications (Wu et al., 2011). Pectin has been reported to have moderate antiglycation activities and antioxidant capacity in vitro (Chaouch et al., 2016; Shafie and Gan 2020).

A recent study (Shang et al., 2019) extracted hawthorn polysaccharide including neutral polysaccharide WPS (water-washed polysaccharide) as well as acidic polysaccharides SPS-1 (salt-washed polysaccharide 1), SPS-2 and SPS-3 (the eluent salt concentration is different). Typically, SPS-1, SPS-2 and SPS-3 were pectin polysaccharides, having higher (>9%) antiglycation activity than that of water-washed polysaccharides. The activity of SPS-3 was the strongest, followed by SPS-2 and SPS-1. The higher antioxidant and antigylcation activity of hawthorn pectin was related to its' higher galacturonic acid content and lower branching degree in the molecular structure. Coincidentally, Zhu et al. found the physicochemical properties of the SPS-2 degradants to be a medium molecular weight (700 Da < MW < 3000 Da) pectin oligosaccharide (MM-POS) with the highest antiglycation activity among the SPS degradants (Zhu et al., 2019).

Hawthorn POSs were incorporated in infant formula and studies were carried out to see the inhibition of AGEs formation under different storage conditions (Rugang Zhu et al., 2019). Storage at 25 °C and 45 °C, there was no inhibition of AGEs formation while at 65 °C, stronger inhibitory effect on the formation of AGEs (furosine, Nε-carboxymethyllysine, and Nε-carboxyethyllysine) was observed. In addition, it was also found that POSs possess the strong inhibitory effect against the formation of lipid oxidation. Therefore, addition of hawthorn pectin is beneficial for the long-term storage of infant formula. In the same study, cytotoxicity experiments were carried out using human umbilical vein endothelial cells. It was found that the infant formula supplemented with POSs had the lowest cytotoxicity, compared to the blank control and the one supplemented with galacto-oligosaccharides and fructo-oligosaccharides under accelerated storage condition (65 °C). Furthermore, the prebiotic activity of infant formula milk powder was not affected by the supplementation of POSs.

3.2. Regulation of fat digestion and absorption

Clinical studies have shown that high fat diet is a main risk of the genesis and development of obesity, insulin resistance, hyperlipidemia, cardiovascular diseases, type 2 diabetes mellitus and tumors (Bray et al. 2004; Rothstein 2006). Reducing fat consumption could be an efficient strategy. However, fats are key contributors to the formation of appearance, flavour, and texture properties of many food products. In another word, it is challenging to maintain these phytochemical and sensory properties in low-fat or fat formulated products (Heertje 2014; Nehir et al. 2012; Chung and McClements 2014). Alternatively, healthy attributes of high-fat food can be achieved by controlling lipid digestion within the small intestine, such as by restructuring the product matrix with soluble dietary fibres (Guo et al., 2017; Michas et al. 2014). Soluble dietary fibres can regulate gastrointestinal digestion and reduce the rate of intestinal uptake of a wide range of food components including fats (Brownlee 2011). The main source of water-soluble dietary fibre include pectin, gum arabic, karaya gum etc. (Harris and Smith 2006; Thakur et al. 1997). Therefore, pectin processing and regulations in food product is expected to affect lipid digestion. Compared with drug administration, dietary fiber supplementation is more acceptable for consumers with minimal side effects.

Zhu et al. (2015) compared the effects of hawthorn pectin (HP), hawthorn pectin hydrolysate (HPH) and hawthorn pectin pentasaccharide (HPPS) on cholesterol metabolism in hamsters (Zhu et al., 2015). The hamsters were fed with standard diet, high cholesterol diet (HCD) or a mixture of them. The pectin was supplied to hamsters at a dose of 300 mg per kg body weight for 4 weeks. It was found that HCD significantly increased the body weight and liver weight of hamsters. However, after the supplementation with HP, HPH and HPPS, the body weight gain of the overweight hamster was decreased by 10–40%. In addition, the fecal bile acid level after feeding HPH and HPPS were increased by >40%. Therefore, HP, HPH and HPPS can prevent hypercholesterolemia induced by high-fat diet and promote the excretion of bile acids (BA) in hamster feces. Moreover, HP had a higher cholesterol excretion capacity than HPH and HPPS. Another study (Zhu et al., 2013) found that HPPS significantly decreased the levels of serum total cholesterol (TC), low density lipoprotein cholesterol (LDL-c), and hepatic TC of the high-fat fed mice. It also decreased the gene expressions of 3-hydroxy-3-methyl-glutaryl-CoA reductase (HMGCR) and acyl-coenzyme A: cholesterol acyl-transferase (ACAT) in the liver. On the contrary, it increased the level of serum high density lipoprotein cholesterol (HDL-c), fecal bile acids, and the gene expressions of cholesterol 7α-hydroxylase (CYP7A1). Overall, administration of HPPS tend to increase the fecal TC level and to down-regulate the expressions of sterol regulatory element-binding protein 2 (SREBP-2) and LDL receptor in the liver.

Furthermore, hawthorn pectin penta-oligogalacturonide can inhibit BA reabsorption in ileum and improve cholesterol metabolism. It was speculated that hawthorn pectin penta-oligogalacturonide could be apical sodium-dependent bile acid transporter competitive inhibitor rather than BA sequestrant in inhibiting BA reabsorption in ileum and improving cholesterol metabolism (Zhu et al., 2017). Other result indicated that hawthorn pectin penta-oligogalacturonide is applicable as a dietary supplement for the prevention of fatty liver and oxidative damage (Li et al., 2014). Additionally, Li et al. suggested that continuous hawthorn pectin pentaoligosaccharide ingestion may be used as dietary therapy to prevent obesity and cardiovascular diseases (Li et al., 2013). Their recent study has shown that the intake of dietary hawthorn pectin can regulate the expression of fatty acid synthesis related genes and increase the blood insulin level (Li et al., 2017).

Hawthorn POS has been reported to have beneficial effects against high-fat diet (Li et al., 2019); it significantly reduced the total liver fat content and the levels of hepatic pro-inflammatory factors, tumor necrosis factor (TNF)-α and interleukin-6 (IL-6), while increased the level of interleukin-10 (IL-10). Compared with high-fat control group, hawthorn POS significantly decreased the protein expression of nuclear factor kappa-B (NF-κB). It also decreased the mRNA receptor levels that interact with protein kinase 1 (RIP1), NF-κB induced kinase (NIK), IκB kinase-α (IKKα), TNF α and its receptor 1 (TNFR1), and receptor related factor 2 (TRAF2). However, expressions of AMP-activated protein kinase (AMPK) and silent information regulator T 1 (SIRT 1) were up-regulated by hawthorn POS. The results showed that hawthorn POS had a significant inhibitory effect on liver inflammation, including inhibition of NF-κB activation. Fig. 3 presents the specific impact mechanism.

Pectin extracted from different sources showed various digestion behaviors under simulated gastrointestinal conditions (Zhou et al., 2021). For example, water-soluble pectin (WSP) extracted from hawthorn (HWSP), apple (AWSP), peach (PWSP), and carrot (CWSP) possessed different structures. The molecules of HWSP were of small size with extended short and linear main chain, forming a certain amount of aggregations in the solution. The molecules of PWSP were of large size with long and branched chains, forming intensive network structure. Therefore, the apparent viscosity of HWSP and PWSP solutions were both higher than those of AWSP and CWSP (due to the aggregations or

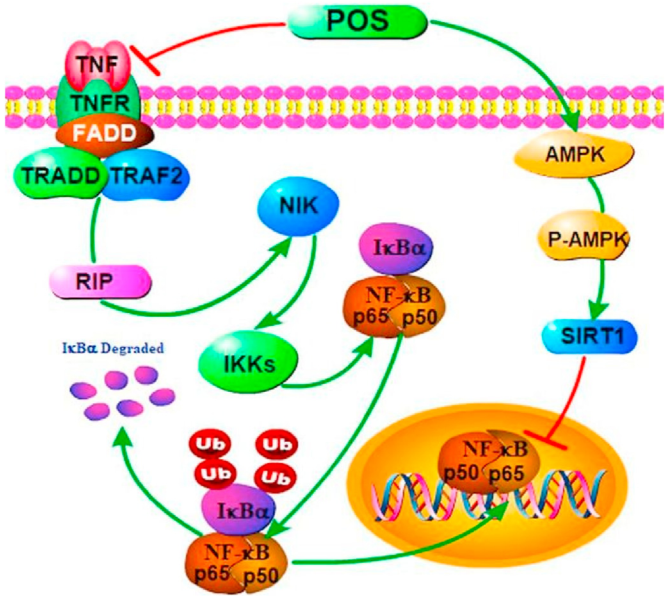

Fig. 3. Hawthorn pectin oligosaccharide (POS) regulation pathway of high-fat-diet fed mice. Tumor necrosis factor (TNF), Nuclear factor kappa-B (NF-κB), protein kinase 1 (RIP1), NF-κB-inducing kinase (NIK), IκB kinase-α (IKKα), TNFα and its receptors 1 (TNFR1), receptor-associated factor 2 (TRAF2), AMP-activated protein kinase (AMPK) and silent information regulator T 1 (SIRT1) were labeled with different colors. (Li et al., 2019).

network structure). Moreover, PWSP showed better anti-shear ability than HWSP due to the strong cross-linking force between molecular chains. The inhibitory effect of WSPs on lipid digestion decreased with the following order: PWSP > HWSP > CWSP > AWSP, which can be well related with their rheological property. In a word, pectin with larger molecular weight and highly branched chains result in a stronger intermolecular interaction, representing a better inhibitory effect against lipid absorption.

3.3. Other functions

Pectin possesses a broad-spectrum of antibacterial activity. Among all the food fibres, it is the only one, which is effective against the most widely distributed pathogenic and opportunistic microorganisms (Men'shikov et al., 1997). The concomitant emergence of research on natural antibacterial materials and new usages of pectin polysaccharides, has led to a renaissance of research into the physiological properties of this versatile polysaccharide ubiquitous in plants and fruits (Ciriminna et al., 2020).

Minimal inhibitory concentration (MIC) and minimal bactericidal concentration (MBC) have been determined for hawthorn POSs with different polymerization degrees (Wang et al. 2018). Results showed that POSs with average polymerization degree of 3 had the strongest antibacterial effect (especially effective for *Escherichia coli*, *Bacillus subtilis* and *Staphylococcus aureus*). It is speculated that POSs exerted antibacterial activity by damaging the cell membrane permeability and integrity, resulting in the leakage of cell contents. This could cause an adverse effect on the metabolic activity and consequently inhibits bacterial growth.

Hawthorn POS also showed protective effects against oxidative damage and photoaging induced by ultraviolet B (UVB). For HaCaT cells, the cell viability significantly decreased after UVB exposure. After low-(5 μg/Ml) and high-dose (10 μg/Ml) hawthrown POS treatment, a significant ($P < 0.05$) growth promoting effect on UVB-irradiated HaCaT cells were observed (Liu et al., 2018) Table 2.

4. Processing and utilization of hawthorn pectin

4.1. Emulsion preparation and stabilization

Demand for natural food ingredients and emulsifiers has increased in the last decades. Cuevas-Bernardino and coworkers studied the interfacial adsorption behavior of hawthorn pectin at the oil-water interface (Cuevas-Bernardino et al., 2016). The physicochemical characteristics, intrinsic viscosity, adsorption dynamics and emulsifying properties of two hawthorn accessions pectin (HP50 and HP55) were evaluated. It was indicated that the HMP of hawthorn possess good emulsifying properties

Table 2
Functional properties of hawthorn pectin (POSs = pectin oligosaccharides, HP = hawthorn pectin, HPH = hawthorn pectin hydrolysate, HPPS = hawthorn pectin pentasaccharide).

Materials	Active ingredients	Research Model	Functional properties	References
Hawthorn polysaccharide	Salt-washed polysaccharides	In vitro, BSA/glucose model	Strong antioxidant and antiglycation activity	Shang et al. (2019)
Hawthorn polysaccharide	POSs	BSA/glucose model	High antiglycation activity	(R. Zhu et al., 2019)
Hawthorn polysaccharide	POSs	BSA/glucose model	Inhibit the glycation formation of infant formula milk powder	(Rugang Zhu et al., 2019)
Hawthorn pectin	HP; HPH; HPPS	High- cholesterol diets fed mice	Prevent hypercholesterolemia; Improve hepatic lipid accumulation; Promote fecal bile acid excretion	(R.-G. Zhu et al., 2015)
Hawthorn pectin	HPPS	High-fat diet fed mice	Obvious anti-hypocholesterolemic effect on hypercholesterolemic mice	(R. Zhu et al., 2013)
Hawthorn pectin	Hawthorn pectin pentaoligosaccharide	High-fat diet fed mice	Improve hepatic lipid metabolism; Activate PPARα; Interrupt fat digestion and absorption.	(T.-p. Li et al., 2013)
Hawthorn pectin	Hawthorn pectin pentaglaracturonide	High-fat diet fed mice	Inhibit fatty acid synthesis; improve insulin sensitivity	(S. Li et al., 2017)
Hawthorn pectin	Hawthorn pectin penta-oligogalacturonide	High-fat diet fed mice	Prevent fatty liver and oxidative damage	(T. Li et al., 2014)
Hawthorn pectin	Hawthorn pectin penta-oligogalacturonide	High-cholesterol diet fed mice	Affect intestinal bile acids absorption; Downregulate the FXR-FGF15 Axis	(R. Zhu et al., 2017)
Hawthorn pectin	POSs	High-fat diet fed mice	Inhibit liver inflammation; Inhibition on NF-kB activation.	(T. Li et al., 2019)
Water-soluble pectin (WSP) isolated from hawthorn, peach, apple, and carrot	Pectin	In vitro digestion	Strong intermolecular interaction; Good inhibitory effect on lipid digestion	Zhou et al. (2021)
Hawthorn pectin	POSs at different polymerization degrees	Bacteriostatic circle	High antibacterial activity for POSs with average polymerization degree of 3	(Wei Wang et al., 2018)
Hawthorn pectin	Pectin Oligogalacturonide	In vitro culture of HaCaT cells	Protective effect against UVB radiation-induced oxidative damage and photoaging.	(S. Liu et al., 2018)

and moderate stabilizing ability. On the contrary, it is well known that the pectin extracted from citrus peel and apple pomace are not recommended as emulsifying agents (Dickinson 2003). In addition, the emulsion made from hawthorn pectin and other substances can also be used as a coating of fresh agricultural products to preserve quality attributes in postharvest storage. The results showed that the emulsions and films made with HP were equal to or better than those made with citrus pectin (Lozano-Grande et al., 2016). Pectin is also used as Pickering emulsion stabilizers. In a recent study, pectin extracted from hawthorn wine pomace was used as Pickering emulsion stabilizers (Jiang et al., 2020). This study has demonstrated the sustainable utilization of hawthorn waste for producing value-added products.

4.2. Gelation

The pectin in hawthorn belongs to HMP, which forms gel under acidic condition in presence of sucrose. Linares-García et al. studied the viscoelastic behavior and the texture properties of hawthorn pectin gels (HMPH) (Linares-García et al. 2015). The characteristics of HMPH were compared with commercial citrus gels (HMPC). The G' values (elastic component) of HMPH-, and HMPC-gel (1% pectin at pH 3.0) were 2567, and 1177 Pa, respectively. The G'' values (viscous component) of HMPH-, and HMPC-gels were 494, and 253, respectively. Both HMPH and HMPC gels exhibited viscoelastic solid behavior with predominant elastic characteristics. The viscoelastic behaviors of the gels were analyzed using the Burger model. It was found that hardness of the HMPH gels was almost 10-folds higher than that of the HMPC gels. In addition, the gumminess, and chewiness of the HMPH gels were, respectively 31-, and 46-fold higher than those of the HMPC gels. Similarly, hawthorn flavor solidified yoghurt was produced from fresh milk and hawthorn juice (Lu et al., 2007). It was found that hawthorn pectin was the major substance affecting the sensory and physical properties of the hawthorn yoghurt. Overall, studies have proven that hawthorn pectin plays an important role in hawthorn gel formation. Modification of hawthorn pectin's structure can further regulate the gelation process.

4.3. Modification of hawthorn pectin

Pectin, in its' structurally intact form, cannot be digested and absorbed in the human gastrointestinal tract due to the large molecular weight and poor solubility, thereby limiting its practical application in the medical field. Increasing evidence demonstrates that modified pectin (MP) has better functional properties, biological activities, and pharmaceutical bioactivities than native pectin (Chen et al., 2015; Maxwell et al., 2012; Zhang et al., 2015). At present, chemical and enzymatic modification technologies are widely used for the preparation of MP. Chemical methods are difficult to control and easily cause environmental pollution, whereas enzymatic methods are often associated with high production cost (Gogate and Prajapat 2015). New technologies (e.g. ultrasound processing) has been used in the preparation of MP due to the good environmental friendliness, moderate controllability, high efficiency, and low cost (Wang et al., 2018).

Zhu et al. studied the hawthorn pectin modification by ultrasonic assisted Vitamin C/H_2O_2 regulation method (Zhu et al., 2019). Under the optimized condition, the hawthorn pectin possessed a reducing sugar content of >50%. Another study investigated the effects of ultrasonication on the degradation kinetics, structure properties, and antioxidant activity of hawthorn pectin (Chen et al., 2019) and found that when ultrasonication time was extended, the intrinsic viscosity for different hawthorn pectin concentrations decreased. The ultrasonic degradation of hawthorn pectin reaction conformed to the first-order kinetic equation. As the reaction rate constant (k) decreased, hawthorn pectin concentration increased. When ultrasonic time was 10 min, the Gal A increased and the DE decreased compared with control. Additionally, the particle size, turbidity, and gel properties of hawthorn pectin decreased with the decease of reaction rate constant. The molecular weight of Hawthorn pectin and its distribution all decreased after ultrasonic treatment. FTIR analysis indicated that ultrasonic treatment did not change pectin's primary structures. SEM analysis showed that the surface characteristic of ultrasonic treatment pectin was different from that of native pectin. Moreover, in was confirmed that ultrasonic treatment significantly improved the antioxidant activity of hawthorn pectin in vitro.

5. Hawthorn pectin and hawthorn products

The pectin content in hawthorn fresh fruit is as high as 6.4% (Wang et al., 2009). The rich pectin content and its versatile functions have led to a variety of hawthorn products, such as hawthorn jellies, hawthorn fruit teas and hawthorn cakes. However, hawthorn pectin is not always playing a beneficial role in hawthorn processing. For instance, it may damage the smooth and clear appearance of fruit juice, resulting in juice precipitation. In a word, the adverse effects and beneficial influences of hawthorn pectin coexist in many hawthorn products.

5.1. Adverse effects and corresponding strategies

Hawthorn pectin exerts its adverse effects during juice processing. Fruit juices rich in pectin and starch are often encountered with high turbidity, affecting its shelf life. Therefore, reduction of pectin is a practical approach to increase the juicing yield. Feng et al. optimized the enzymatic degradation conditions of hawthorn pectin and reported that the hawthorn pectin content was effectively reduced at the pectinase dose of 0.9% at 48 °C for 4 h (Feng et al., 2018). Wang et al. quantified the enzymatic hydrolysis rate using different pectinase and suggested that the highest pectin removal rate was achieved by using Pectinex Yield MASH pectinase (Wang et al., 2020). Yang et al. immobilized pectinase/glucoamylase (I-PG) on sodium alginate (SA) and graphene oxide (GO) composite beads for pumpkin-hawthorn juice (Yang et al., 2019). After treated with I-PG, the soluble solids, light transmittance, and reducing sugar content were significantly increased, while the pectin and total sugar content were significantly decreased. The application of I-PG provides an effective and feasible method to improve the storage stability and quality of pumpkin-hawthorn juice.

5.2. Beneficial influences and implications

Pectin plays a vital role in the production of hawthorn gels (e.g., hawthorn slices, hawthorn jellies, and hawthorn cakes). For these products, hawthorn pectin is gelatinous at pH 2.0–3.5 and at sugar content of >55%. Hawthorn strips is a manufacturing step after hawthorn cake processing. In this stage, regulation of hawthorn pectin is critical because it determines the hardness and elastic properties. A standard hawthorn pulp mixture should adhere to each other with good toughness, which maintains the intact shape of the pulp after gelation and ease the further operation (Yu 2009).

Fruit tea is a cloudy pulp juice. The commercial fruit tea should avoid layering and precipitation. In the industry, two strategies have been developed: 1) high-pressure homogenization; and 2) addition of thickening agents. In order to obtain a stable fruit tea, one or more thickeners (e.g., sodium carboxymethyl cellulose, xanthan gum, pectin, and agar) are added to the product, followed by a high pressure homogenization process. Interestingly, hawthorn fruit contains appropriate pectin to achieve the thickening effect. Thus, it is not necessary to add thickeners in hawthorn fruit teas, which not only simplifies the process but also saves the cost (Xu 1998).

6. Conclusions

Hawthorn pectin is a multifunctional food substance. The degradation products of pectin have better biological activity than pectin itself. The degradants of hawthorn pectin mainly include pectin hydrolysate and pectin oligosaccharide, which possess properties such as anti-oxidation, anti-glycation, blood lipid reduction, hepatoprotection, anti-bacterial, and regulating cholesterol metabolism. In addition, hawthorn pectin plays an important role in food processing such as thickeners, emulsifiers, leavening agents, and gelling additives. Different extraction methods and different hawthorn sources result into different physico-chemical characteristics and functional properties of hawthorn pectin. The conventional extraction method of hawthorn pectin gives the product with high molecular weight and poor solubility. Modern technologies such as ultrasound and microwave technologies have been applied for hawthorn pectin extraction and modification, showing an enhanced functional property. Such emerging technologies will continuously advance the processing of hawthorn pectin and promote the development of new hawthorn products.

CRediT authorship contribution statement

Li Li: Literature review, graph and figures, Writing – original draft. **Xianli Gao:** Manuscript edition. **Jiguang Liu:** Guidance on the topic selection, Manuscript edition. **Bimal Chitrakar:** Grammar check, Manuscript edition. **Bo Wang:** Co-corresponding author, literature review, manuscript edition, response to the reviewers' comments. **Yuchuan Wang:** Corresponding author, guidance on the topic, structure and details, manuscript submission, response to the reviewers' comments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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