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Plant-Based Natural Resource Management Strategies Using Fruits for Cholesterol Regulation

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ABSTRACT

Cardiovascular diseases remain a leading cause of global mortality, with hypercholesterolemia representing a major modifiable risk factor. Growing interest has emerged in plant-based strategies, particularly fruit utilization, as sustainable approaches for cholesterol regulation. This study aimed to systematically review the pharmacological mechanisms of fruit-derived secondary metabolites involved in cholesterol lowering and to explore their relevance within plant-based natural resource management. A systematic literature review was conducted following PRISMA guidelines using ScienceDirect, PubMed, and Google Scholar databases. Evidence from in vivo and in vitro studies demonstrates that various fruits including *Gedong Gincu* mango, sweet orange, red dragon fruit, buni fruit, Rosa roxburghii, pineapple, *Synsepalum dulcificum*, mulberry, and Hiyung cayenne pepper contain bioactive secondary metabolites such as flavonoids, phenolics, anthocyanins, carotenoids, triterpenoids, alkaloids, saponins, dietary fiber, and antioxidant enzymes. These compounds exert cholesterol-lowering effects through multiple pharmacological pathways, including inhibition of cholesterol synthesis and absorption, enhancement of bile acid excretion, modulation of lipid metabolism–related gene expression, and reduction of oxidative stress and inflammation. Several fruit-based interventions showed significant reductions in total cholesterol and LDL levels, with some demonstrating efficacy comparable to conventional hypolipidemic agents. These findings highlight the potential of fruit-based natural resources as functional, sustainable, and scientifically supported strategies for cholesterol regulation and cardiovascular disease prevention.

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1. INTRODUCTION

Cardiovascular diseases (CVDs) remain the leading cause of death globally, with dyslipidemia especially elevated cholesterol identified as a principal modifiable risk factor [1]. Recent meta-analytic evidence estimates the global prevalence of hypercholesterolemia at approximately 24.1% among adults, with dyslipidemias affecting a substantial portion of the adult population worldwide and contributing to the burden of atherosclerotic cardiovascular events [2, 3]. Elevated cholesterol levels are implicated in a large fraction of coronary heart disease and stroke cases, underscoring the persistence of hyperlipidemia as a public health challenge despite advances in pharmacotherapy and preventive efforts.

Against this backdrop, there is growing scientific interest in plant-based dietary strategies particularly the role of fruits as accessible and sustainable means to regulate cholesterol [4, 5]. Fruits are rich in bioactive compounds such as soluble fiber, polyphenols, phytosterols, and antioxidants that have been associated with mechanisms related to cholesterol metabolism, including the inhibition of cholesterol absorption, modulation of lipid pathways, and enhancement of bile acid excretion [6, 7]. Observational studies suggest that regular consumption of specific fruits, such as apples and bananas, correlates with reduced long-term mortality among individuals with dyslipidemia, indicating potential health benefits beyond conventional nutrient intake [8]. However, evidence from clinical interventions and systematic evaluations remains inconsistent, and significant heterogeneity exists in the magnitude and type of cholesterol related outcomes reported [9].

Despite this promising evidence, several important gaps constrain current understanding. Few randomized controlled trials have isolated the effect of individual fruits on cholesterol profiles over long durations, and existing dietary interventions often integrate fruits within broader lifestyle or dietary patterns, limiting causal inferences. Furthermore, the specific mechanisms through which distinct fruit bioactive exert lipid-modulating effects especially in diverse populations and in combination with other plant-based foods are not yet fully elucidated.

In parallel with health concerns, global attention toward sustainable management of plant-based natural resources has intensified, particularly within the context of food systems and non-communicable disease prevention. Fruits, as renewable biological resources, play a strategic role not only in nutrition security but also in the development of functional foods and nutraceuticals [10]. Integrating cholesterol-regulating fruits into structured resource management strategies may enhance their value chain, reduce post-harvest losses, and promote environmentally responsible utilization [11]. However, existing studies often emphasize nutritional outcomes without adequately addressing sustainability aspects, such as cultivation practices, resource efficiency, and long-term availability of fruit-based bioactive [12].

Moreover, policy frameworks and public health guidelines increasingly advocate plant-based diets to reduce the global burden of cardiovascular diseases, yet practical guidance on optimizing fruit utilization for targeted metabolic outcomes remains fragmented. Consequently, a focused literature review is required to consolidate multidisciplinary evidence, identify strategic approaches for managing fruit-based plant resources, and support the translation of scientific findings into sustainable, health-oriented interventions for cholesterol regulation.

2. LITERATURE REVIEW

2.1 Secondary metabolites involved in cholesterol-lowering effects of Gedong Gincu mango, sweet orange and red dragon fruit

Gedong gincu mango, sweet orange, and red dragon fruit contain various secondary metabolite compounds that play a role in lowering cholesterol levels, particularly flavonoids, carotenoids, and anthocyanins, along with vitamin C, vitamin E, and dietary fiber. Pharmacologically, administration of these three fruits in juice form to hypercholesterolemic rats was proven to significantly reduce LDL levels, with the greatest reduction observed in red dragon fruit at -51.88 ± 2.21 mg/dL, followed by sweet orange at -48.36 ± 3.80 mg/dL and gedong gincu mango at -38.65 ± 3.44 mg/dL [13]. The mechanisms of action of the active compounds in gedong gincu mango, sweet orange, and red dragon fruit in reducing LDL cholesterol can be pharmacologically explained through several pathways.

2.2 ***Secondary metabolites involved in cholesterol-lowering effects of Buni fruit*** Buni fruit is known to contain various important secondary metabolites, particularly flavonoids and anthocyanins, with a relatively high anthocyanin content of approximately 141.94 mg per 100 g of fresh fruit, along with ascorbic acid, phenolic acids, vitamins, and minerals that support its biological activity. Pharmacologically, administration of buni fruit juice at concentrations of 5%, 10%, and 15% for 14 days resulted in a significant reduction in total cholesterol levels compared to the negative control, and at a concentration of 15%, the effect was nearly comparable to simvastatin as the positive control [14]. The active compounds present in buni fruit (*Antidesma bunius* L.) exhibit several complementary pharmacological activities in lowering blood cholesterol levels.

2.3 ***Secondary metabolites involved in cholesterol-lowering effects of Rosa roxburghii fruit*** Rosa roxburghii fruit vinegar (RFV) has strong potential due to its exceptionally high content of active compounds, including vitamin C (1300–3500 mg/100 g), polyphenols (108.9 mg GAE/g), flavonoids (66.23 mg RE/g), and superoxide dismutase (SOD) [15]. Pharmacologically, RFV exhibits potent hypolipidemic activity by improving lipid profiles in subjects fed a high-fat diet.

2.4 ***Secondary metabolites involved in cholesterol-lowering effects of pineapple fruit*** Dried pineapple powder was shown to contain bioactive secondary metabolites, particularly phenolic and flavonoid compounds, which contribute to its strong antioxidant activity. From 4,500 g of fresh pineapple, approximately 600 g of dried powder was obtained, representing a yield of 13.33%. The total phenolic content reached 11.17 mg GAE/100 g, while the total flavonoid content was 6.33 mg QE/100 g. Antioxidant capacity assessment using DPPH and ABTS assays demonstrated a concentration-dependent oxidant scavenging effect, with maximum inhibition observed at 12,000 μg/mL, reaching 78.38 ± 0.91% for DPPH and 97.93% for ABTS. The IC_{50} values were recorded at 5,619 μg/mL and 1,265 μg/mL for DPPH and ABTS assays, respectively. Proximate analysis further revealed that dried pineapple powder was rich in carbohydrates (87.72 g/100 g) and dietary fiber (9.07 g/100 g), while containing low fat levels (1.66 g/100 g) [16]. These findings indicate that pineapple powder possesses considerable antioxidant potential driven by its phenolic and flavonoid constituents.

2.5 ***Secondary metabolites involved in cholesterol-lowering effects of Synsepalum dulcificum fruit*** *Synsepalum dulcificum* contains a diverse profile of bioactive secondary metabolites, predominantly flavonoids, phenolic compounds, polysaccharides, and triterpenoids. In addition, the fruit pulp is rich in miraculin, a glycoprotein responsible for its characteristic taste-modifying property. Flavonoids and phenolic compounds contribute to the antioxidant capacity of the fruit, while triterpenoids such as lupeol acetate and β-amyrin acetate have been identified as major active constituents associated with lipid metabolism regulation. The presence of these metabolites indicates that *S. dulcificum* possesses a complex phytochemical composition with significant biological potential [17].

2.6 *Secondary metabolites involved in cholesterol-lowering effects of Mulberry fruit*

Mulberry (*Morus alba* L.) contains a wide range of bioactive secondary metabolites, particularly anthocyanins and flavonols, which are responsible for its strong antioxidant properties. Phytochemical analyses have shown that mulberry fruits are rich in phenolic compounds, flavonoids, and resveratrol, all of which contribute to their biological activity. Advanced non-thermal extraction techniques, such as high hydrostatic pressure, have been reported to preserve higher levels of these metabolites compared to conventional heat treatment, thereby maintaining the antioxidant capacity and structural integrity of the bioactive compounds. The presence of these metabolites highlights the potential role of mulberry as a functional fruit with significant lipid-modulating and metabolic regulatory properties [18].

2.7 *Secondary metabolites involved in cholesterol-lowering effects of Hiyung cayenne pepper*

Hiyung cayenne pepper (*Capsicum frutescens* L. var. *hiyung*), an endemic chili variety from Tapin, South Kalimantan, contains a diverse range of bioactive secondary metabolites with pharmacological potential. The fruit is characterized by a high content of capsaicin, an alkaloid compound associated with antihyperlipidemic, antiobesity, antioxidant, and anticholesterol activities. Phytochemical analyses have identified several secondary metabolites in hiyung cayenne pepper fruit, including alkaloids, phenolic compounds, flavonoids, saponins, tannins, and triterpenoids [19]. These metabolite groups are widely reported to contribute to cholesterol-lowering effects through their antioxidant and lipid-regulating properties, indicating that hiyung cayenne pepper possesses a complex phytochemical profile with potential relevance in cholesterol metabolism.

3. METHODS

3.1 Study Design

This study was conducted as a systematic literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, reproducibility, and methodological rigor. The PRISMA framework was applied to guide the processes of literature identification, screening, eligibility assessment, and final inclusion of studies. The review focused on strategies for managing plant-based natural resources through the utilization of fruits for cholesterol regulation.

3.2 Data Sources and Search Strategy

A comprehensive literature search was performed using the Sciences Direct, PubMed and Google Scholar database, selected for its extensive coverage of high-quality, peer-reviewed, and multidisciplinary scientific publications. The search strategy employed a combination of relevant keywords and Boolean operators, including: “fruits,” “plant-based natural resources,” “cholesterol regulation,” “lipid metabolism,” “bioactive compounds,” and “functional foods.” Boolean operators (AND, OR) were used to refine and optimize the search results. The search was limited to articles published in English within the last ten years to ensure accessibility and contemporary relevance.

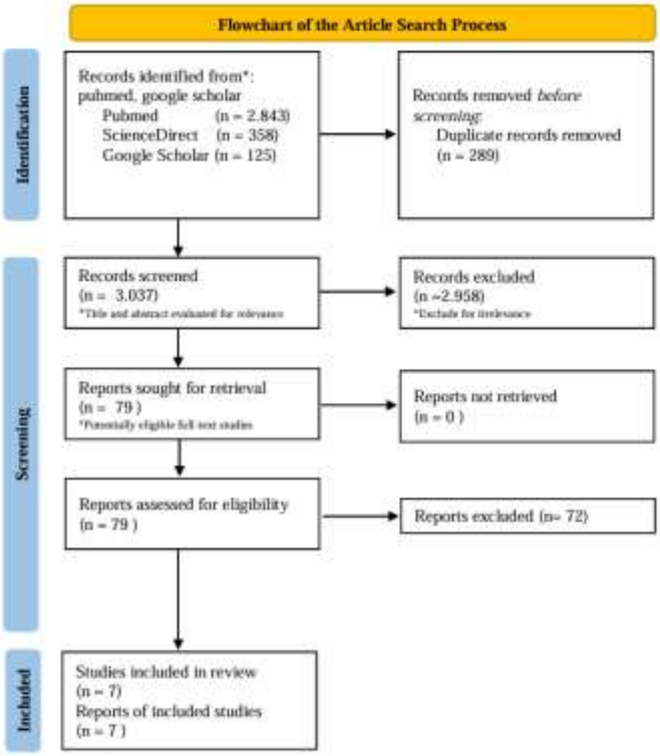

Figure 1. Flowchat of the Article Search Process

3.3 Eligibility Criteria

Clear inclusion and exclusion criteria were established prior to the screening process. Studies were included if they met the following criteria: (1) published in peer-reviewed journals, (2) focused on fruits or fruit-derived bioactive compounds as primary plant-based resources, (3) examined outcomes related to cholesterol regulation or lipid profiles, and (4) available in full-text English versions. Studies were excluded if they focused on non-fruit plant parts, did not directly address cholesterol or lipid metabolism, or were non-peer-reviewed publications such as conference proceedings, book chapters, editorials, or reports.

3.4 Study Selection Process

The study selection process followed the PRISMA flow structure. Initially, all identified records were imported into a reference management system, and duplicate articles were removed. Titles and abstracts were then independently screened to assess relevance based on the predefined eligibility criteria. Subsequently, full-text articles of potentially eligible studies were retrieved and evaluated for inclusion. Any discrepancies during the selection process were resolved through discussion to achieve consensus.

3.5 Data Extraction

Data extraction was conducted using a standardized data extraction form to ensure consistency across studies. Extracted information included authorship, year of publication, study objectives, fruit types examined, bioactive compounds identified, study design, key findings related to cholesterol regulation, and implications for sustainable management of plant-based natural resources.

3.6 Data Synthesis and Analysis

The selected studies were analyzed using a thematic synthesis approach. Key themes were identified, including cholesterol-lowering effects of fruits, mechanisms of action of fruit-derived bioactive compounds, and strategic approaches to sustainable utilization of fruit-based natural resources. A comparative analysis was performed to identify similarities and differences across studies, allowing for the identification of evidence patterns, research gaps, and directions for future research aligned with health and sustainability perspectives.

4. RESULTS AND DISCUSSION

Hypercholesterolemia is a key contributor to cardiovascular disease, leading to increased interest in natural products as lipid-lowering agents [20]. Many fruits contain secondary metabolites such as flavonoids, phenolic compounds, anthocyanins, carotenoids, alkaloids, saponins, and triterpenoids, which exert cholesterol-lowering effects through antioxidant activity, modulation of lipid metabolism, inhibition of cholesterol absorption, and enhancement of bile acid excretion [21]. This section reviews experimental evidence on selected fruits and plant sources, focusing on the pharmacological mechanisms of their bioactive secondary metabolites in reducing cholesterol levels.

Gedong Gincu mango, sweet orange, and red dragon fruit juices to hypercholesterolemic Sprague Dawley rats significantly reduced low-density lipoprotein (LDL) cholesterol concentrations compared with the high-fat diet control group. Specifically, red dragon fruit juice produced the greatest LDL reduction (-51.88 ± 2.21 mg/dL), followed by sweet orange juice (-48.36 ± 3.80 mg/dL) and Gedong Gincu mango juice (-38.65 ± 3.44 mg/dL), indicating differential hypolipidemic effectiveness among the three fruits [13].

Pharmacologically, these effects can be attributed to the abundant secondary metabolites present in the fruits, including flavonoids, carotenoids, anthocyanins, vitamin C, vitamin E, and dietary fiber, all of which have been widely implicated in lipid metabolism modulation. Flavonoids and anthocyanins exhibit strong antioxidant properties that inhibit LDL oxidation, a key step in the initiation and progression of atherosclerosis, thereby preventing the formation of atherogenic oxidized LDL particles [22]. Carotenoids and vitamin E further enhance antioxidant defenses, protecting lipoproteins from oxidative damage, while vitamin C supports hepatic cholesterol catabolism by facilitating bile acid synthesis through cholesterol hydroxylation pathways [23].

Additionally, dietary fiber present in these fruits contributes to hypocholesterolemic activity by binding bile acids in the gastrointestinal tract, reducing cholesterol absorption and increasing fecal cholesterol excretion [24]. The combination of antioxidant, metabolic, and bile acid sequestration mechanisms provides a comprehensive pharmacological basis for the observed reductions in LDL levels, with the higher anthocyanin and flavonoid content in red dragon fruit likely explaining its superior effectiveness among the juices tested [25].

Buni fruit (*Antidesma bunius* L.) has been shown to contain a rich array of bioactive secondary metabolites, including flavonoids, anthocyanins, phenolic acids, tannins, saponins, alkaloids, and steroids, which have been confirmed through phytochemical screening of ethanol extracts. Evidence from in vivo studies using male mice (*Mus musculus*) demonstrates that oral administration of buni fruit juice at various concentrations (5%, 10%, and 15%) significantly reduced total cholesterol levels compared to untreated controls, with the highest concentration approaching the cholesterol-lowering efficacy of simvastatin in experimental models [14].

Pharmacologically, the cholesterol-lowering effects of buni fruit are attributed to multiple mechanisms mediated by its secondary metabolites. Flavonoids and anthocyanins serve as potent antioxidants that reduce oxidative stress and protect lipoproteins such as LDL from oxidative modification, an important trigger of atherogenesis [22, 26, 27]. These polyphenolic compounds also modulate key enzymes in lipid metabolism, potentially inhibiting cholesterol biosynthesis and influencing lipid transport. Phenolic acids and tannins contribute further antioxidant capacity and may interfere with cholesterol absorption in the gastrointestinal tract, while saponins can form insoluble complexes with dietary cholesterol and bile acids, enhancing their fecal excretion [28-30]. The combined action of these metabolites suggests that buni fruit bioactives work synergistically through antioxidant protection, inhibition of cholesterol uptake and synthesis, and increased elimination pathways to lower circulating cholesterol levels.

Additionally, other secondary compounds such as plant sterols and triterpenoids, while less frequently studied in buni, are known from related phytochemical literature to support cholesterol reduction by competing with dietary cholesterol for incorporation into micelles and by activating reverse cholesterol transport pathways. Collectively, the metabolite profile of *Antidesma bunius* supports multiple complementary pharmacological pathways that underlie its observed hypocholesterolemic effects in experimental animals, highlighting its potential utility as a functional food or nutraceutical agent for managing elevated cholesterol.

Rosa roxburghii Tratt fruit vinegar (RFV) exhibits potent hypolipidemic activity in high-fat diet-induced dyslipidemic mice, evidenced by significant improvements in serum lipid parameters, including reductions in total cholesterol (TC), triglycerides (TG), and low-density lipoprotein cholesterol (LDL-C), as well as increases in high-density lipoprotein cholesterol (HDL-C) compared to untreated obese controls [15].

Pharmacologically, the lipid-modulating effects of RFV are attributable to its exceptionally high content of bioactive secondary metabolites. RFV contains large amounts of vitamin C (ascorbic acid), polyphenols, flavonoids, and organic acids, particularly acetic acid, which are well established for their antioxidant and metabolic regulatory properties [31]. These compounds act synergistically to counter dyslipidemia by multiple mechanisms. Vitamin C and phenolic compounds function as powerful antioxidants, neutralizing reactive oxygen species and protecting lipoproteins from oxidative modification, a process that otherwise promotes LDL aggregation and atherogenesis. Flavonoids further support lipid homeostasis by enhancing hepatic lipid metabolism and suppressing inflammatory pathways associated with fatty liver and lipid disorders.

In addition, acetic acid a major organic acid enriched during the vinegar fermentation process improves lipid metabolism by enhancing fatty acid oxidation, reducing lipid accumulation in peripheral tissues, and modulating key enzymes involved in cholesterol synthesis and breakdown [32]. The integration of these metabolic effects contributes to the overall antihyperlipidemic profile of RFV by lowering LDL-C and TC levels and by increasing HDL-C, thereby reducing the risk factors associated with metabolic syndrome and cardiovascular disease.

Pineapple (*Ananas comosus* L.) has been demonstrated to possess significant lipid-lowering and cardioprotective properties in high-cholesterol diet (HCD)-fed rats, effects that are closely linked to its rich composition of bioactive secondary metabolites and phytochemicals [16]. The fruit contains substantial amounts of phenolic compounds, including gallic acid, catechin, epicatechin, and ferulic acid, along with appreciable levels of flavonoids and dietary fiber, which together contribute to its high antioxidant potential as shown by in vitro radical scavenging assays. These metabolites are biologically active and exert pharmacological actions that go beyond simple nutrient content to modulate lipid metabolism and oxidative stress pathways associated with hypercholesterolemia.

Mechanistically, the phenolic and flavonoid constituents in pineapple function as potent antioxidants that mitigate the oxidative modification of lipids, a key event in the pathogenesis of atherosclerosis and hypercholesterolemia-induced cardiac injury. They reduce oxidative stress markers such as cardiac malondialdehyde (MDA) and protein carbonyl content, indicating reduced lipid peroxidation in cardiac tissues, while also lowering pro-inflammatory cytokines such as IL-6 and IL-1β, which are elevated in dyslipidemic states. The antioxidant activity of these compounds protects LDL particles from oxidative damage, thereby reducing the formation of oxidized LDL, a major contributor to endothelial dysfunction and plaque development.

In addition, the dietary fiber and phenolic matrix in pineapple may influence cholesterol metabolism by delaying intestinal absorption of cholesterol and fat, promoting fecal excretion of sterols, and indirectly enhancing hepatic lipid processing. Daily consumption of pineapple powder in HCD-fed rats not only improved serum lipid profiles including reductions in total cholesterol (TC) and low-density lipoprotein cholesterol (LDL-C) but also lowered atherogenic coefficients and cardiac risk ratios, effects that collectively point to an integrated pharmacological mechanism where pineapple secondary metabolites reduce both oxidative stress and lipid accumulation in hypercholesterolemic conditions.

Miracle fruit (*Synsepalum dulcificum*) has been shown to possess cholesterol-lowering potential in experimental animal models, with its ethanolic seed extract significantly reducing plasma total cholesterol levels in hamsters fed a high-cholesterol diet [17]. This hypocholesterolemic activity has been linked principally to its rich composition of bioactive secondary metabolites, especially triterpenoids, which were isolated from the seed extract. The two major triterpenoid constituents identified, lupeol acetate and β-amyrin acetate, decreased total cholesterol by approximately 15-20% when incorporated into the diet, suggesting that pentacyclic triterpenoid structures play a direct role in modulating lipid metabolism.

Pharmacologically, triterpenoids are understood to influence cholesterol homeostasis through multiple mechanisms, including inhibition of key enzymes involved in hepatic cholesterol synthesis, modulation of lipid absorption, and enhancement of cholesterol excretion pathways [33, 34]. Their structural similarity to sterols enables triterpenoids to compete with cholesterol for incorporation into micelles in the intestinal lumen, thereby reducing dietary cholesterol uptake and increasing fecal elimination. Additionally, these compounds exert antioxidant effects that protect lipoproteins from oxidative damage, which otherwise contributes to increased LDL retention and atherogenesis.

Beyond triterpenoids, *S. dulcificum* extracts also contain flavonoids and phenolic compounds that enhance the overall antioxidant capacity of the fruit, reinforcing its lipid-modulating effects by mitigating oxidative stress associated with dyslipidemia . Together, the presence of these metabolites triterpenoids, flavonoids, and other phenolics provides a multifaceted pharmacological basis for the cholesterol-lowering activity of miracle fruit, supporting its potential use as a functional food or natural nutraceutical for blood lipid management.

Mulberry (*Morus alba* L.) fruit extract has been demonstrated to significantly improve lipid profiles in rats fed a high-cholesterol/cholic acid diet, particularly by increasing serum high-density lipoprotein cholesterol (HDL-C) while reducing total cholesterol, triglycerides, and LDL cholesterol [18]. These effects are closely associated with the rich composition of secondary metabolites present in mulberry fruit, especially anthocyanins, flavonols, polyphenolic compounds, and resveratrol. The use of high hydrostatic pressure processing was shown to preserve higher levels of these bioactive compounds, thereby maintaining their antioxidant capacity and enhancing their biological efficacy in regulating lipid metabolism.

From a pharmacological perspective, mulberry secondary metabolites modulate cholesterol homeostasis primarily through regulation of hepatic gene expression involved in cholesterol synthesis, efflux, and bile acid metabolism. Mulberry extract suppresses the expression of sterol regulatory element-binding protein-2 (SREBP-2), a key transcription factor that promotes endogenous cholesterol synthesis. Concurrently, it upregulates liver X receptor-α (LXR-α) and its downstream targets, including ATP-binding cassette transporters ABCA1 and ABCG5, as well as cholesterol 7α-hydroxylase (CYP7A1). This coordinated regulation enhances cholesterol efflux from hepatocytes and promotes conversion of cholesterol into bile acids, facilitating its elimination from the body.

In addition to transcriptional regulation, mulberry fruit extract exerts post-transcriptional effects by suppressing hepatic microRNA-33 (miR-33) expression. miR-33 is known to negatively regulate genes involved in HDL formation and reverse cholesterol transport. Inhibition of miR-33 leads to increased expression of ABCA1, apolipoprotein A-1 (ApoA-1), and lecithin-cholesterol acyltransferase (LCAT), thereby promoting HDL biogenesis and maturation. The combined antioxidant, transcriptional, and post-transcriptional actions of mulberry secondary metabolites explain their potent lipid-modulating effects and highlight mulberry fruit as a promising functional food for improving cholesterol metabolism and preventing dyslipidemia.

Hiyung cayenne pepper (*Capsicum frutescens* L. var. *hiyung*), an endemic chili from Tapin, South Kalimantan, contains multiple classes of bioactive secondary metabolites that have demonstrated potential in reducing cholesterol levels *in vitro*. Phytochemical screening of the 70% ethanol extract of hiyung cayenne pepper fruit revealed the presence of alkaloids, triterpenoids, phenols, saponins, tannins, and flavonoids, indicating a complex phytochemical profile associated with lipid-modulating properties [19].

Pharmacologically, these secondary metabolites are likely to contribute to cholesterol lowering through several complementary mechanisms. Capsaicin, a major alkaloid in cayenne pepper, has been widely reported to influence lipid metabolism by enhancing fatty acid oxidation, modulating thermogenesis, and reducing lipid biosynthesis, thereby potentially reducing cholesterol accumulation. Flavonoids, phenolic compounds, and tannins exhibit strong antioxidant activity that can protect lipoproteins such as LDL from oxidative modification, which otherwise promotes atherogenesis and increases cholesterol deposition in arterial walls [22, 35]. Saponins and triterpenoids may interfere with intestinal absorption of cholesterol by forming insoluble complexes with bile acids and dietary lipids, promoting their fecal excretion and reducing circulating cholesterol.

The cholesterol-lowering activity of the hiyung cayenne pepper extract was confirmed in *in vitro* assays, where increasing extract concentrations (20-100 μg/mL) produced progressively higher percentages. of cholesterol reduction, ranging from 53.62% to 74.91%, indicating a dose-dependent effect. These findings support the notion that the combined action of the identified secondary metabolites through antioxidant protection, inhibition of cholesterol absorption, and modulation of lipid metabolism pathways underlies the extract's potential as a natural hypocholesterolemic agent.

5. CONCLUSION

The available evidence indicates that various fruits contain bioactive secondary metabolites such as flavonoids, phenolics, anthocyanins, carotenoids, triterpenoids, alkaloids, saponins, dietary fiber, and antioxidant enzymes that play important roles in lowering cholesterol levels. Fruits such as *Gedong Gincu* mango, sweet orange, red dragon fruit, Buni fruit, Rosa roxburghii, pineapple, *Synsepalum dulcificum*, mulberry, and Hiyung cayenne pepper contain bioactive compounds including flavonoids, phenolic acids, anthocyanins, carotenoids, triterpenoids, alkaloids, saponins, dietary fiber, and antioxidant enzymes, which act through complementary pharmacological mechanisms. These mechanisms include inhibition of cholesterol synthesis, enhancement of bile acid excretion, modulation of lipid absorption, improvement of lipoprotein metabolism, regulation of gene expression related to cholesterol homeostasis, and attenuation of oxidative stress and inflammation associated with hypercholesterolemia. Experimental evidence from in vivo and in vitro studies consistently demonstrates significant reductions in total cholesterol and LDL levels, as well as improvements in HDL profiles, with some fruit-based interventions showing effects comparable to conventional hypolipidemic agents. Collectively, these findings highlight the strategic value of fruit utilization in plant-based natural resource management as a scientifically supported, functional, and sustainable approach for cholesterol regulation and the prevention of dyslipidemia-related cardiovascular diseases.

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