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Review Article

An Overview on Therapeutic Potential of Apple Fruit and Leaf

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ABSTRACT

Apples (Malus domestica), a globally cherished fruit, are far more than just a tasty snack. This review dives into the extensive scientific evidence, drawing from laboratory studies, animal models, and population-wide observations, to uncover the impressive health benefits locked within various parts of the apple plant, including the well-loved fruit and its often-overlooked leaves. We'll explore their potent antioxidant and anti-inflammatory effects, their role in fighting cancer, supporting heart health, managing diabetes, protecting the brain, and even influencing our gut microbes. We'll shine a light on the key players behind these benefits, like polyphenols (flavonoids and phenolic acids), triterpenoids, and dietary fiber (pectin). This review delves into the exciting, though still developing, research on apple leaves and their unique concentration of beneficial compounds. Understanding these mechanisms offers a strong scientific foundation for embracing apples as a truly functional food.

INTRODUCTION

Depression, a prevalent and debilitating mental health condition, continues to be a major global concern, highlighting the ongoing need for diverse and effective treatment approaches. While traditional therapies like medication and counselling remain crucial, there's growing excitement around complementary strategies, particularly dietary interventions. Apples (*Malus domestica* Borkh.), a member of the Rosaceae family, are among the most cultivated and economically important fruits worldwide.[1] Beyond their pleasant taste and rich nutrient profile, apples have become a focal point of scientific inquiry for their therapeutic potential, with research now extending beyond the fruit to include parts of the plant often considered waste, like its leaves.[2] Long recognized in traditional medicine for their health-promoting qualities, apples are now seeing these ancient claims validated by modern science as specific bioactive compounds are identified and understood.[3]

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The intricate mix of vitamins, minerals, dietary fiber, and especially a wide range of polyphenols in apples significantly contributes to their profound impact on human well-being. [4] This review aims to comprehensively summarize our current scientific understanding of the pharmacological benefits derived from various parts of the apple plant. We'll focus extensively on the well-researched fruit and dedicate a specific section to the emerging insights from apple leaves, exploring their mechanisms of action and highlighting the key compounds responsible for these remarkable health effects.

2. THE POWERHOUSE COMPOUNDS IN APPLES: FRUIT AND LEAVES

The remarkable health benefits of apples come from their rich blend of phytochemicals, which can vary based on the apple variety, how ripe it is, where it's grown, how it's stored, and, notably, which part of the plant we're looking at. [5]

2.1. STAR COMPOUNDS IN APPLE FRUIT:

2.1.1 Polyphenols: These are the most abundant and extensively studied beneficial compounds in the apple fruit.

2.1.1.1 Flavonoids: Primarily found in the peel, these include powerhouses like quercetin, catechin, epicatechin, procyanidins (smaller chains of catechin and epicatechin), and anthocyanins (which give red apples their vibrant color). [6]

2.1.1.2 Phenolic Acids: Important compounds like chlorogenic acid, ferulic acid, and coumaric acid are also present. [7]

2.1.2 Triterpenoids: Found mainly in the apple peel, compounds such as ursolic acid are gaining recognition for their diverse biological activities. [8]

2.1.2.1 Dietary Fiber: Both soluble fiber (pectin) and insoluble fibers contribute significantly to digestive health and other systemic benefits. [9]

2.1.2.2 Vitamins: A notable source of Vitamin C, a powerful antioxidant. [4]

2.1.2.3 Carotenoids: While not as abundant as in some other fruits, they are present. [10]

2.2. EMERGING COMPUNDS IN APPLE LEAVES:

Traditionally dismissed or used as animal feed, apple leaves are now being recognized as a hidden treasure trove of valuable bioactive compounds.

2.2.1 Polyphenols: Apple leaves are remarkably rich in phenolic compounds, often in higher concentrations than the fruit's flesh. These include:

2.2.1.1 Flavonoids: Predominantly quercetin glycosides (like hyperoside, rutin, isoquercitrin), kaempferol glycosides, and flavan-3-ols (catechin, epicatechin). [11, 12, 13]

2.2.1.2 Phenolic Acids: Chlorogenic acid is frequently found in high amounts. [12]

2.2.2 Other Compounds: Though less researched than the fruit, leaves may also contain triterpenoids and other minor phytochemicals.

3. THE PHARMACOLOGICAL POWER FRUIT AND LEAVES OF APPLES

The extensive range of bioactive compounds found in different parts of the apple plant contributes to a wide array of scientifically documented health benefits:

3.1. ANTIOXIDANT ACTIVITY

Apples (the fruit) consistently rank high among fruits for their exceptional antioxidant capacity.

[10] This power largely comes from their high content of polyphenols, especially flavonoids like quercetin and procyanidins. These compounds effectively neutralize harmful free radicals, bind to metal ions, and prevent cellular damage, thereby protecting our cells from oxidative stress. [11] Since oxidative stress is a key player in many chronic diseases, including heart conditions, neurodegenerative disorders, and cancer, [12] regular apple fruit consumption can help lower the body's overall oxidative burden.

Interestingly, apple leaves also show significant antioxidant capabilities, often matching or even surpassing the fruit's flesh or peel in certain tests, thanks to their abundant polyphenol content. [11, 14] Studies indicate that extracts from apple leaves can effectively scavenge damaging radicals, reduce harmful iron compounds, and prevent fat oxidation, suggesting they are a promising natural source of antioxidants. [12, 13]

3.2. ANTI-INFLAMMATORY EFFECTS

Chronic low-level inflammation is a common thread in many non-communicable diseases. The polyphenol**s** in apple fruit actively combat inflammation by influencing various inflammatory pathways. They can block the activity of pro-inflammatory enzymes like cyclooxygenases (COX) and lipoxygenases (LOX), and also reduce the production of inflammatory signaling molecules such as TNF-α, IL-1\beta, and IL-6. [15, 16] Quercetin, a standout flavonoid in apples, has been particularly studied for its ability to stabilize immune cells, reduce histamine release, and inhibits inflammatory gene expression. [17]

Apple leaf extracts have also demonstrated impressive anti-inflammatory properties in laboratory and animal studies. These effects are often linked to their high concentrations of flavonoids, including quercetin glycosides. Research indicates their ability to inhibit nitric oxide (NO) production and suppress pro-inflammatory cytokines in immune cells stimulated by harmful substances. [11, 14] This opens doors for potential therapeutic uses in managing various inflammatory conditions.

3.3. ANTI-CANCER PROPERTIES

Numerous laboratory and animal studies suggest that apples (the fruit) hold significant anti-cancer potential. This power is largely due to their rich polyphenol content, which can disrupt different stages of cancer development through several mechanisms:

3.3.1 Inhibiting cell proliferation: Apple extracts and isolated compounds have been shown to stop the growth of various cancer cell lines, including those from the colon, breast, lung, and liver. [16, 20]

3.3.2 Inducing apoptosis: Polyphenols can trigger programmed cell death in cancer cells, essentially forcing them to self-destruct. [20]

3.3.3 Antioxidant and anti-inflammatory effects: By reducing DNA damage and chronic inflammation, these compounds can prevent cancer from starting and spreading. [15, 16]

3.3.4 Modulating signaling pathways: Compounds like ursolic acid found in apple peel have been shown to influence pathways crucial for cancer cell survival and metastasis. [8]

3.3.5 Chemoprevention: Large population studies frequently show a link between higher apple consumption and a reduced risk of certain cancers, notably colorectal, breast, and lung cancers. [18, 19]

While still limited, emerging research suggests that apple leaf extracts may also possess anti-cancer properties. Their rich phenolic content, particularly specific flavonoid glycosides, could play a role in controlling cell proliferation and inducing apoptosis in certain cancer cell lines, mirroring findings for the fruit. [11, 22] However, this area is still in its early stages and requires more dedicated investigation.

3.4. CARDIOPROTECTIVE EFFECTS

Apples (the fruit) contribute significantly to cardiovascular health through a multi-pronged approach:

3.4.1 Reducing LDL oxidation: Polyphenols prevent the oxidation of low-density lipoprotein (LDL), a critical step in the hardening of arteries (atherosclerosis). [23]

3.4.2 Improving endothelial function: Flavonoids can boost the availability of nitric oxide, leading to wider blood vessels and improved blood flow. [26]

3.4.3 Lowering blood pressure: Some studies suggest a modest reduction in blood pressure, possibly linked to better endothelial function and anti-inflammatory actions. [27]

3.4.4 Cholesterol lowering: Pectin, the soluble fiber, can bind to bile acids in the gut, increasing their excretion and subsequently lowering cholesterol levels in the blood. [28]

3.4.5 Antiplatelet effects: Certain apple compounds may reduce platelet stickiness, thereby lowering the risk of blood clots. [29]

Though direct human studies on the cardiovascular benefits of apple leaves are scarce, their high flavonoid content, especially quercetin glycosides, points towards potential heart-protective effects. Quercetin is well known for its ability to improve the health of blood vessel linings and help regulate blood pressure. [17, 26] More targeted research on how apple leaf extracts specifically impact cardiovascular markers is certainly warranted.

3.5. ANTI-DIABETIC PROPERTIES:

Apples (the fruit) can play a beneficial role in metabolic health, including managing and preventing diabetes:

3.5.1 Blood glucose regulation: Dietary fiber, especially pectin, slows down the digestion and absorption of carbohydrates, leading to a more gradual rise in blood sugar levels after meals. [34]

3.5.2 Improved insulin sensitivity: Some apple polyphenols, particularly quercetin, have been shown to enhance insulin sensitivity in preclinical models. [35]

3.5.3 Inhibiting carbohydrate-digesting enzymes: Certain apple extracts can inhibit enzymes like αglucosidase, further reducing sudden spikes in blood glucose after eating. [36]

3.5.4 Epidemiological evidence: Multiple meta-analyses have connected higher apple consumption with a reduced risk of developing type 2 diabetes. [37]

Apple leaf extracts show promising anti-diabetic potential in preclinical studies. They have been shown to inhibit α-amylase and α-glucosidase enzymes, which are crucial for carbohydrate breakdown and glucose absorption. This suggests a mechanism for helping manage postprandial hyperglycemia (high blood sugar after meals). [11, 38]

These findings indicate that apple leaves could be a valuable natural source of compounds with anti-diabetic properties.

3.6. NEUROPROTECTIVE EFFECTS

Exciting research highlights the potential of apples (the fruit) to safeguard brain health and positively influence mood:

3.6.1 Antioxidant and anti-inflammatory actions: By reducing oxidative stress and inflammation in the brain, apple polyphenols can protect neurons from damage, which is vital in preventing neurodegenerative diseases like Alzheimer's and Parkinson's. [29]

3.6.2 Enhancement of cognitive function: Animal studies suggest that regular apple consumption or apple derived compounds can improve memory and learning abilities, possibly by boosting synaptic plasticity and neurotransmission. [30]

3.6.3 Mood regulation: Recent preclinical studies (published in March and June 2025) indicate that apple fruit extracts might possess antidepressant-like effects. This is thought to occur by modulating neurotransmitter levels (such as serotonin and GABA), reducing brain inflammation, and promoting the growth of new brain cells (neurogenesis) in the hippocampus, a brain area crucial for mood. [31, 32]

3.6.4 Gut-brain axis modulation: The prebiotic effect of apple pectin encourages a healthy gut microbiome, which is increasingly recognized as a vital player in brain function and mood regulation. [33]

While research directly on the neuroprotective or antidepressant effects of apple leaves is less extensive compared to the fruit, it's a promising area. Given their high content of neuroprotective flavonoids like quercetin and kaempferol derivatives, which are known to cross the blood-brain barrier and exert antioxidant and antiinflammatory effects in the brain, it's plausible that apple leaf extracts could also contribute to brain protection. [11, 24] More focused research is certainly needed to confirm these potential benefits.

3.7. GUT MICROBIOTA MODULATION AND DIGESTIVE HEALTH:

The high fiber content of apple fruit, especially pectin, makes apples excellent prebiotics. Pectin resists digestion in the upper digestive tract and ferments in the colon, providing vital nourishment for beneficial gut bacteria like *Bifidobacterium* and *Lactobacillus* species. [12]

3.7.1 Improved gut barrier function: A thriving gut microbiota, nurtured by apple fiber, helps maintain the integrity of the intestinal barrier, which reduces systemic inflammation. [19]

3.7.2 Production of SCFAs: The fermentation of pectin by gut bacteria produces short-chain fatty acids (SCFAs) such as butyrate, acetate, and propionate. These SCFAs serve as energy sources for colon cells, influence immune function, and have widespread metabolic effects. [19]

3.7.3 Laxative effect: Insoluble fiber adds bulk to stool, promoting regular bowel movements and helping to prevent constipation. [9]

While apple leaves don't provide the same amount of bulk fiber as the fruit, their polyphenol content can still influence the gut microbiota. Polyphenols are known to have a prebiotic-like effect, shaping the composition and activity of gut bacteria, which can indirectly contribute to overall gut health. [24,33] This area warrants further specific investigation.

4. INDUSTRIAL AND COMMERCIAL APPLICATIONS:

Malus domestica has considerable industrial importance because of its rich phytochemical content and global availability. Its fruit, leaves, and by-products are used across major commercial sectors, including food and beverages, nutraceuticals, pharmaceuticals, cosmetics, and environmental sustainability.

4.1 Food and Beverage Industry

Apples remain central to the food industry due to their taste, nutritional value, and processing versatility. Common processed products include apple juice, cider, vinegar, jams, jellies, purees, and dehydrated forms such as apple chips and powders. Apple-based ingredients are also incorporated into bakery products for added fiber and improved texture. Functional food applications involve fortifying products with apple polyphenols and pectin to enhance antioxidant activity, develop sugar-reduced formulations, and support digestive health [40].

4.2 Nutraceutical and Herbal Supplement Industry

Apple fruit and leaves are increasingly used for nutraceutical formulations. Polyphenol-rich extracts containing quercetin, catechins, phloridzin, and chlorogenic acid are employed in antioxidant and metabolic health supplements. Pectin and pomace-derived fibers are used for cholesterol reduction and prebiotic support, making apple components valuable for digestive wellness and metabolic regulation [41].

4.3 Pharmaceutical Industry

Bioactive compounds such as ursolic acid, oleanolic acid, and various flavonoids from apple peel and leaves are being explored as leads for anti-inflammatory, antidiabetic, hepatoprotective, and anticancer drug development. Standardized apple extracts with strong antioxidant properties are also used to enhance the stability and therapeutic efficacy of pharmaceutical formulations [42].

4.4 Cosmetic and Personal Care Industry

Apple-derived ingredients are popular in skincare and haircare. Polyphenols and triterpenoids contribute to antiaging, skin-brightening, and collagen-boosting effects, while apple stem cell extracts are incorporated into premium rejuvenation products. In haircare, apple antioxidants protect against UV-induced damage and improve scalp nourishment and shine [43].

4.5 Agricultural and Environmental Applications

Apple pomace and leaves support sustainable agricultural uses, including compost, biofertilizers, and livestock feed. Pomace also serves as a raw material for producing bioethanol, biogas, biodegradable films, and industrial pectin, contributing to environmental sustainability and circular economy models [44]

5. SCOPE FOR NOVEL DRUG DEVELOPMENT

The diverse phytochemicals found in *Malus domestica* make it a promising source for developing new therapeutic agents. Both the fruit and the leaves contain an array of biologically active compounds—such as flavonoids (including quercetin and kaempferol), phenolic acids (like chlorogenic and gallic acid), triterpenoids (especially ursolic acid), and various polysaccharides. These constituents are known for their strong antioxidant, antiinflammatory, antimicrobial, anticancer, cardioprotective, and neuroprotective effects, creating a solid scientific basis for drug discovery [45–47].

Recent studies indicate that several apple-derived molecules may serve as effective lead compounds in different therapeutic areas:

5.1 Cancet Treatment:

Compounds such as ursolic acid and quercetin have demonstrated the ability to inhibit tumor cell proliferation and promote apoptosis, highlighting their potential in developing plant-based anticancer therapies [46,48].

5.2 Metabolic Disorders:

Apple polyphenols and pectin show promise in regulating glucose and lipid metabolism, suggesting potential applications in formulating anti-diabetic, anti-obesity, and lipid-lowering medications [45,47].

5.3 Neurodegenerative Diseases:

Antioxidant-rich apple extracts may help reduce oxidative stress and neuroinflammation, offering new opportunities for drugs aimed at Alzheimer's and Parkinson's disease [45,49].

5.4 Antimicrobial Therapies:

Bioactive compounds from apple leaves have shown antibacterial and antifungal activity, making them attractive candidates for natural antimicrobial formulations [47].

5.5 Dermatological Applications:

Triterpenoids and phenolic compounds support skin repair and exhibit antiaging and anti-inflammatory benefits, positioning them as promising ingredients for next-generation dermatological products [46].

Emerging technologies—including nanocarrier systems, green and efficient extraction techniques, and computational drug design—may further enhance the stability, bioavailability, and targeted delivery of appledderived bioactives. Additionally, the therapeutic potential of apple leaves, often overlooked as agricultural waste, presents new possibilities for sustainable and cost-effective drug development [47].

6. FUTURE DIRECTIONS AND CHALLENGES

Despite the encouraging preclinical and epidemiological evidence for the health benefits of apples (both fruit and leaves), several key areas require further investigation:

6.1 Human Clinical Trials:

We desperately need more rigorous, large-scale, randomized controlled human trials. These are essential to confirm the effectiveness and determine the best dosages of whole apples or apple-derived products (from either fruit or leaves) for specific health outcomes.

6.2 Bioavailability and Metabolism:

Understanding precisely how various apple phytochemicals (from both fruit and leaves) are absorbed, metabolized, and reach their target sites in the human body is crucial for translating laboratory findings into practical clinical applications.

6.3 Synergistic Effects:

Future research should focus on the synergistic interactions between the diverse compounds present in whole apples (fruit and leaf extracts), rather than just studying isolated constituents. It's likely that these compounds work better together.

6.4 Cultivar and Processing Effects:

Different apple varieties have varying phytochemical profiles, which could lead to different health effects. Also, we need to thoroughly investigate how processing methods (like drying or extracting for leaves, or juicing and cooking for fruit) impact the bioavailability and bioactivity of these apple compounds.

6.5 Standardization of Extracts:

For any potential therapeutic use, it's crucial to standardize apple leaf extracts based on their active compound profiles to ensure consistent and reliable effects.

6.6 Safety and Toxicity:

While whole apples are generally safe, thorough toxicological studies, especially for concentrated leaf extracts, are necessary before they can be widely recommended.

CONCLUSION

Malus domestica, commonly known as the apple, is not only one of the world's most popular fruits but also one of the most therapeutically valuable. Both the fruit and the leaves contain a rich variety of natural compounds that contribute to their health-promoting properties. The fruit is packed with polyphenols, dietary fiber, essential vitamins, minerals, and triterpenoids. Meanwhile, the leaves—often overlooked—are especially abundant in flavonoids like phloridzin, as well as several phenolic acids and other powerful antioxidant molecules which highlight their significant antioxidant and anti-inflammatory potential, alongside promising anti-diabetic and preliminary anti-cancer properties, primarily due to their high phenolic content.

Together, these bioactive constituents support a wide range of health benefits, including antioxidant, antiinflammatory, antidiabetic, antimicrobial, cardioprotective, neuroprotective, anticancer, and hepatoprotective effects.

Over the years, research has increasingly highlighted how apple-derived compounds can play a meaningful role in preventing or managing chronic diseases, particularly those linked to oxidative stress, metabolic imbalances, and inflammation. While the fruit has long been recognized for its nutritional value, scientists are now paying more attention to the leaves, which show great promise as a source of natural therapeutic agents. This growing interest positions apple-based products as valuable ingredients for the nutraceutical, pharmaceutical, and functional food industries.

Despite these promising findings, several research gaps remain. Many studies still lack standardized extraction methods, detailed mechanisms of action, and large-scale clinical evidence to fully confirm the therapeutic potential observed in laboratory and animal studies. Moving forward, researchers need to focus on refining extraction techniques, developing new value-added formulations, exploring lesser-used parts of the plant, and investigating how different apple phytochemicals work together synergistically.

In summary, *Malus domestica* is a remarkably versatile plant with significant nutritional and medicinal potential. Both its fruit and leaves offer exciting opportunities for health promotion and drug development. As traditional knowledge aligns increasingly with modern scientific insights, the apple continues to stand out as a multifunctional and highly valuable species in human health and wellness.

The accumulating scientific evidences also strongly support incorporating apples and potentially apple leafderived products into our daily diets for disease prevention and overall

health promotion. However, continued research, particularly well-designed human clinical trials, is essential to validate these promising preclinical and epidemiological findings. This will help us fully understand the precise mechanisms in humans and unlock the complete therapeutic potential of all parts of the *Malus domestica* plant for better health.

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