

From Fruit Waste to Functional Bioactive: A Comprehensive Review on Apple Peel Extract and its Therapeutic Relevance

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Abstract - Apples (*Malus domestica*) are consumed lavishly worldwide, while demand is increasing for the management of the huge apple-waste amounts that lead to significant disposal costs and ecological issues. Additionally, apple represent fruits with several bioactive constituents, which are key factors in a healthy, balanced diet. In the present study, an extensive review is presented regarding the bioactive compounds of an apple processing by-product, namely apple peel, mentioning their significance as viable ingredients/substances in foods and cosmetics aiming at chronic disease prevention and health promotion. In this paper, we review the recent studies about the chemical composition of apples, including carbohydrates, proteins, lipids, dietary fibers, minerals, vitamins, phenolics, and other compounds. Among the bioactive compounds in apple, the phenolic compounds, including hydroxybenzoic acids, hydroxycinnamic acids, flavanols and their oligo- and polymeric structure, flavonols, dihydrochalcones, and anthocyanins, majorly contribute to beneficial biological impacts. These bioactive compounds leads to its antioxidant, anti-inflammatory, anti-microbial, anti-cancer and skin-protective properties. Here, we also review studies on various extraction method of apple peel such as maceration, Soxhlet extraction, ultrasound-assisted extraction. All these characteristics make apple residues suitable as natural ingredients for the development of high-added-value products in food, cosmetic, and pharmaceutical industries. This review focuses on the phytochemical constituents, extraction methods, pharmacological activities, and future prospects of apple peel extract as a valuable natural therapeutic agent. It focus on evaluation of benefits, pharmacological effects of apple peel extract in various diseases.

Keywords - Apple Peel, Review, Bioactive Compounds, Phenolics, Anti-Oxidant, Extraction.

I. INTRODUCTION

“An apple a day keeps the doctor away” is a well-known phrase that highlights the significance of apple consumption in health promotion and well-being. Apples are among the most widely consumed fruits worldwide due to their adaptability and easy availability [1]. The consumption of apple fruit and its products are a rich source of natural antioxidants and contributes up to 22% of total dietary phenolics. Apple peel contains approximately 3- to 6-times higher flavonoid content compared to the apple flesh. It also contains unique flavonoids like quercetin glycosides, which are absent in the apple flesh. The extract obtained from apple peel possesses strong antioxidant ability. Various phenolic compounds present in apple peel and flesh include catechins, procyanidins, phloridzin, phloretin glycosides, caffeic acid, and chlorogenic acid. Besides these polyphenols, the apple peel also has some additional flavonoids. These polyphenols have protective effects against oxidation, tumoral formation, and cell signaling. Increased consumption of apples and their products in the diet, may lower the chance of chronic diseases like cancer, heart-related diseases, asthma, and Alzheimer's [2,3]. Overall, this review summarizes the health benefits of apple peel bioactives and their abilities to alleviate

and prevent chronic inflammation-linked diseases. It also discusses efficient extraction methods and utilization of apple peel in functional foods and cosmetic formulations. [4,5].

II. MATERIAL AND METHODS

A comprehensive literature search was carried out using electronic databases including PubMed, Springer, MDPI, ScienceDirect, RSC Publishing, Google Scholar, and International Journal of Research and Review. Published articles from 2004 to 2025 related to apple peel extract, phytochemicals, antioxidant activity, nutraceutical formulations, and marketed products were included.

III. BOTANICAL CHARACTERISTICS OF APPLE PLANT

Apple (*Malus domestica*) belongs to Rosaceae family. The botanical characteristics of apple have been described by Jackson & Palmer, 2011. Depending on the rootstock, the apple tree ranges from 1.5 to 7 m in height, with basal diameter of 1 to 4.5m. It is a hermaphrodite plant; some cultivars are partly self-fertile, although cross-pollination can also occur. Apple trees can grow in a wide range of soil types. The expected yield varies from 20 to 70 tons/ha, during 3–10 years of full production period, depending on the cultivar, rootstock and environmental conditions [6,7,8,9].

IV. REPORTED PHYTOCHEMICAL CONSTITUENTS OF APPLE PEEL EXTRACT

The major phytochemicals reported in apple peel include:

A. Carotenoid Content of Apple Peels

Carotenoids participate in light harvesting and are recognized as powerful antioxidants. In studies, total carotenoid content has been reported to be higher in peels compared with flesh, indicating the potentially higher bioactivity. The pigment profile typically includes neoxanthin, violaxanthin, lutein, luteoxanthin, β -cryptoxanthin, and β -carotene. However, the concentration of individual carotenoids varies among different apple cultivars [10,11].

B. Total Phenolics Content of Apple Peels

Studies have shown that many heritage cultivars contains higher phenolic levels compared to modern commercial cultivars. In a study by Duda-Chodak et al., the polyphenol content of Idared" and "Champion" peels decreased during ripening from 84.7 to 30.0 mg/100 g FW and from 69.0 to 31.8 mg/100 g FW, respectively, suggesting that unripe apple are more valuable for polyphenol extraction. Subsequently, polyphenolic content increased to 38.4 mg/100 g FW ("Idared") and 46.8 mg/100 g FW ("Champion") during long-term storage (112 days) in cold stores. This indicates that long-term-stored apples are still precious materials [12,13,14].

C. Anthocyanin Content of Apple Peels

The concentration of anthocyanins in red-skinned apple varieties has been analyzed using HPLC-PDA. Three types of glycosylated cyanidins, cyanidin-3-O-galactoside, cyanidin-3-O-glucoside, and cyanidin-3-O-arabinoside, were detected. Cyanidin-3-O-galactoside was the predominant anthocyanin in all four varieties, covering >83% of the total anthocyanins [14].

Other phytoconstituents found in apple peel are :

- Flavonoids
- Triterpenoids
- Polysaccharides and
- Pectin

Table 1: Phytoconstituents of Apple Peel and their Function

Phytoconstituent	Function	Mechanism of Action
Carotenoids	Antioxidant, provitamin A activity, eye and skin protection	Scavenges free radicals and reduces oxidative stress
Phenolics	Antimicrobial, antioxidant	Prevents lipid oxidation and protects cells from oxidative injury

Anthocyanins	Anti-inflammatory, antioxidant, gives red colour to the apple	Neutralizes ROS and inhibits inflammatory mediators
Flavonoids	Antioxidant, anticancer, cardioprotective	Donates hydrogen/electrons to free radicals and blocks cell damage pathways
Triterpenoids	Anticancer, anti-inflammatory	Induces apoptosis and inhibits tumor cell growth and inflammatory pathways
Polysaccharides	Immune support, gut health	Acts as dietary fibres and prebiotic, improves intestinal microflora
Pectin	Digestive health, cholesterol lowering	Forms gel in intestine, slows sugar and fat absorption, supports gut bacteria

V. APPLE PHENOLICS EXTRACTION

Phenolics are the important metabolites of apple as they could show health-promoting effects when ingested. The phenolic extraction procedure should be accurate and precise to maximize the yield of targeted compounds and their antioxidant activity. Therefore, extraction might be the most critical step in the analysis of apple's metabolites, as the ideal extraction should recover all the targeted metabolites without any chemical addition. Various apple products (juice, peel, mash, pomace, whole fruit) were extracted using various extraction methods, such as liquid–liquid extraction (LLE) and solid–liquid extraction (SLE), as well as advanced methods such as microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), supercritical fluid extraction (SFE), pulsed electric field (PEF)-assisted extraction, and pressurized liquid extraction (PLE). Several factors influence the extraction process, including solvent type and concentration, temperature, sample-to-solvent ratio, particle size, and sample preparation methods such as grinding or milling [15,16,17].

A. Conventional Extraction

Solid–liquid extraction (SLE) was conducted by most of the previous studies to extract the phenolics from the solid parts of apple (peel, pomace, and whole fruit) using acetone, methanol, ethanol, or water. Although most studies reported that using methanol resulted in higher phenolic yield, but the usage of acetone, ethanol, and water were reported to be safer and more environmentally friendly than methanol [18].

VI. PHARMACOLOGICAL ACTIVITIES OF APPLE PEEL EXTRACT

A. Antioxidant

Apple phytochemicals such as flavonoids (catechins, flavonols, and quercetin) and phenolic acids (glycosides of quercetin, catechin, epicatechins, and procyanidins), along with vitamins and fiber, provide significant antioxidant benefits. These compounds help in reducing oxidative stress and protecting cells from damage [19,20].

B. Antiobesity

Studies conducted on adult male Wistar rats have shown that supplementation with apple pectin exhibits an inhibitory effect on obesity. Apple phytochemicals help reduce oxidative stress caused by a high-fat diet and improve metabolic functions [21,22].

C. Anticancer

Studies have been conducted to assess the effects of apple polyphenols, particularly anthocyanins, in reducing the development of precancerous markers. Colorectal cancer is one of the most commonly reported cancers worldwide. Apple peel contains flavonoids and anthocyanins, especially cyanidin-3-O-galactoside, which contribute to anticancer activity [23,24,25].

D. Antimicrobial

Studies have shown that apple peel extracts exhibit antimicrobial activity against various food-borne bacteria such as *Escherichia coli* and *Bacillus cereus*. Organically grown apples have been reported to contain higher levels of polyphenols, contributing to stronger antimicrobial effects [26,27,28].

E. Cholesterol-lowering effects

Apple consumption has shown protective effects against cardiovascular diseases due to its cholesterol-lowering ability. Studies indicate that supplementation with apple products leads to a reduction in plasma and liver cholesterol levels and an increase in high-density lipoproteins (HDL)[29,30].

Table 2: Marketed Herbal Anti-Acne Creams

S.no	Key Ingredients	Brand Name	Company Name
1.	Neem, Silk Cotton Tree, Alum	Himalaya Acne-n-Pimple Cream	Himalaya Wellness
2.	Wintergreen, Neem	Biotique Bio Winter Green Cream	Biotique
3.	Tea tree, Cinnamon	Lotus Herbals Tea Tree Cream	Lotus Herbals
4.	Neem, Clove	Jovees Anti Acne Cream	Jovees Herbal
5.	Neem, Basil, Aloe vera	Khadi Natural Anti Acne Cream	Khadi Natural

Source:

1. Himalaya Wellness Company. Acne-n-Pimple Cream: Neem-based herbal anti-acne formulation. Bengaluru, India: Himalaya Wellness; Available from: official company website.
2. Biotique. Bio Winter Green Spot Correcting Anti-Acne Cream, New Delhi, India: Biotique; Available from: official product catalogue.
3. Lotus Herbals Pvt Ltd. Tea Tree and Cinnamon Anti-Blemish Mattifying Day Crème, Noida, India: Lotus Herbals; Available from: official brand website.
4. Jovees Herbal Care India Ltd. Anti Acne and Pimple Cream with Neem and Clove, New Delhi, India: Jovees; Available from: official company website.
5. Khadi Natural Healthcare. Herbal Anti Acne Cream with Neem, Basil and Aloe Vera New Delhi, India: Khadi Natural; Available from: official product website.

VII. SAFETY AND TOXICOLOGICAL CONSIDERATIONS

Apple peel extract is generally considered safe; however, concentration optimization is necessary before topical or oral use. Data on acute toxicity, repeated dose toxicity, skin irritation, reproductive toxicity, genotoxicity, and carcinogenicity of apple peel extract are limited or not sufficiently reported in the available literature. However, studies on *Pyrus malus*-derived ingredients used in cosmetic formulations suggest that they are safe under normal conditions of use [31,32]. Further research is required to establish a comprehensive toxicological profile.

VIII. FUTURE PERSPECTIVES

Future studies should focus on:

- Nanoformulations
- Transdermal delivery
- Clinical anti-acne studies
- Sustainable extraction
- Scale-up technology
- Commercial herbal skincare products [33,34]

IX. CONCLUSION

Apple has been known as one of the most consumed fruits in the world and has been investigated by previous studies to be the source of functional ingredients, such as carbohydrates, fibers, minerals, vitamin C, vitamin B complex, and phenolics. The growing location, cultivars, and environmental factors affect the chemical composition of the fruit. Consuming unpeeled apple is recommended to increase daily intake of phenolics. The antioxidant activity of apple's phenolics majorly contributes to the health promoting impacts. Thus, the phenolic

extraction should be conducted correctly to maximize its benefits. In choosing the apple, it is also necessary to consider the bioaccessibility of antioxidants after the digestion.

Additionally, the use of apple peel, among other by-products, except for its contribution in producing novel products with functional properties, significantly eliminates the waste by-product amounts produced by the food industry, while the disposal and transport costs are also minimized, and thus, apple peel commercialization provides important economic benefits. According to the studies summarized in the present review, using apple peel as a functional ingredient or substrate is a rather viable approach which represents an ideal alternative to synthetic nutrients, not only able to improve human health, but also promoting well-being, both inward via food and outward via cosmetics.

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