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REVIEW ARTICLE

Phytochemistry, Nutritional Features and Therapeutic Potential of *Malus domestica* Borkh.: A Review

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Abstract

Fruit has been a mainstay of the human diet since the dawn of recorded history, and there is ample evidence to conclude that most of our ancestors were frugivorous. The apple, also called *Malus domestica* Borkh. (*Rosaceae*), is a well-known fruit that stands out for having a high concentration of polyphenols, which are bioactive compounds assumed to be in charge of metabolic activity. Due to its abundance of phytonutrients, this fruit is extremely valuable to human health and offers a variety of advantages. Fruit-derived bioactive chemicals have gained popularity as a treatment against a range of ailments since they are less likely to induce negative effects than chemical drugs. It is a versatile fruit and every part is packed with nutrients (carbohydrates, soluble proteins, fat, and dietary fibres), vitamins (A, B-complex, C, E, and K), minerals (iron, calcium, phosphate, magnesium, zinc, and cobalt), electrolytes (potassium, sodium, and chlorine), and essential phytochemicals (lutein-zeaxanthin, Cryptoxanthin-ß, and carotene-ß), and having different pharmacological activities, for example, antioxidant, anti-inflammatory, analgesics, wound healing, *etc*. However, quercetin, ursolic acid, kaempferol, and myricetin, as well as other catechins, powerful anthocyanins, phlorizin, and chlorogenic acid, are the main biologically active components of apple polyphenol. The objective is to give an overview of the nutritional health benefits, phytochemical properties and potential therapeutic uses of *Malus domestica* reported in traditional as well as modern literature to date.

Keywords: Antioxidant, Anti-inflammatory, Analgesic, Apple, *Malus domestica*, Wound Healing

1. Introduction

Apple (*Malus domestica* Borkh.) of the rose family (*Rosaceae*) is a delicious fruit and is the fourth most widely produced fruit worldwide[1]. *Malus* species and their fruit provide a wide range of nutritional, ecological, and aesthetic advantages, including human health benefits. The scientific classification of apples is mentioned in Table 1. There are 7,500 distinct apple types worldwide[2]. The apple-growing regions of India are the Himalayan ranges and high altitudes which provide a temperate atmosphere. For generations, this 'pome' fruit has been eaten with its peel, but there has been a shift in how it was previously enjoyed. The results of earlier studies demonstrated that the peel that is typically discarded as waste contains a significant amount of phenolic chemicals and has antioxidant and anti-proliferative properties. Phytochemically, apples are rich in polyphenols, flavonoids, phenolic acids, and triterpenoids, which possess antioxidant, anti-inflammatory, and anti-cancer properties[3]. These substances, along with essential nutrients and dietary fibre, support several physiological processes, which makes apples an important part of the human health promotion process.

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This review explores the bioactive compounds, health-promoting properties, and medicinal applications of apples, highlighting their role in preventing chronic diseases and supporting overall wellness.

Diet (or food) is one of the key elements that nature has supplied for a good existence. The promotion of good health and protection against a wide range of illnesses are two things that the ancient classics place more emphasis on using *Ahara*[4]. According to its diverse forms, Acharya Charka divided the *ahara dravya* (diet/food items) into twelve main *Varga* (classes), which is one of the classifications of the *ahara dravya*. It includes *Phala-varga*[5]. This *Varga* is enhanced with several fruit varieties and *M. domestica*. is one of them. It has long been used in *Ayurvedic* medicine in India. This fruit is commonly used in an old traditional Indian medical practice that dates to the *Vedic* era as mentioned in Figure 1. The *seb* was referenced by Acharya Charaka and Acharya Sushruta, within the *phalavarga* category as *Malus domestica* whereas Bhavprakash included it under the *aamradi varga* as *Pyrus malus*. The *Ayurvedic* principles of drug action like their taste (*rasa*), property (*guna*), potency (*veerya*), and post-digestion effect (*vipak*) with pharmacological activity (*doshakarma*) are mentioned in Table 2[4].

Table 1. Scientific classification of *M. domestica*

Kingdom	Plantae
Division	*Magnoliophyte*
Class	*Magnoliopsida*
Order	*Rosales*
Family	*Rosaceae*
Sub-family	*Maloideae*
Genus	*Malus*
Species	*domestica*

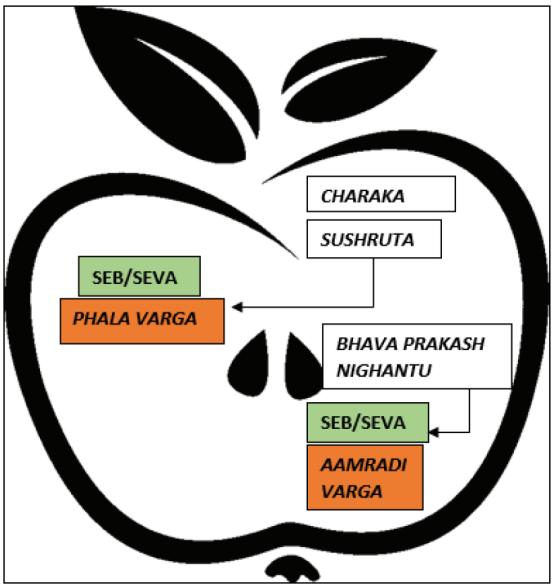


Figure 1. The ancient literature of *Malus domestica*.

2. Material and Methods

Databases like Scopus, Google Scholar, ScienceDirect, and PubMed were used to perform a thorough literature search. The following keywords were used: "*Malus domestica*", "bioactive compounds", "health benefits", "phytochemistry", "nutritional benefits", "therapeutic potential", and "antioxidant properties". Peer-reviewed journal articles, conference proceedings, and authoritative books were all taken into consideration for inclusion. Publications were selected based on their relevance to the topic, the quality of the study design, and their relevance to the topic.

3. Morphological Characters of *Malus domestica*

3.1 Root

The root has a lateral fibrous root system and a deep taproot system. Root systems developed quite quickly, with maximum depths of 8.8 feet and lateral spreads of 12 feet in the first year, and 14.8 feet and 21.2 feet in the second. The deepest depth achieved was 17 feet during the third year, while the largest lateral spread was 29.4 feet.

Table 2. *Rasa-panchak* of *M. domestica*

Rasa (Taste)	***Madhura*** (Sweet)
Guna (Property)	***Guru*** (Heavy)
Virya (Potency)	***Sheeta*** (Cold)
Vipaka (Post digestion effect)	***Madhura*** (Sweet)
Doshakarma (Pharmacological activity)	***Vata pitta shamak*** (Decrease dryness and heat)

Root types fall into three principal classes, that is, taproots, fibrous roots and feeder roots. Apple trees often have a few vertical, deep roots that reach a great depth in the earth. These deep roots can access the moisture stores buried deep in the earth to keep the tree alive through dry spells and nutritional shortages. The deep roots of apple trees send out radial, horizontal roots that spread out into the soil in all directions away from the plant in search of moisture and nutrients. Fibrous roots give way to feeder roots, which extend up to the top few millimetres of the soil layer. The apple tree's feeder roots typically fight with adjacent plants and grass for water and nutrients[6].

3.2 Bark

Bark has thin, scaly, peeling plates that are grey and brown[6]. The inner bark is composed of a secondary phloem, which normally has a one-year functional lifetime in transit. Some of the older phloem cells give rise to the cork cambium, a second kind of lateral (non-apical) meristem that produces cork cells. Old secondary phloem cells are pushed toward the stem's edges by the cork cells, where they are ripped, crushed, and shed off[6,7].

3.3 Leaf

Apple leaves are simple and alternately sized, measuring 2 to 5 inches long and 1.5 to 2.5 inches broad. Oval in form, the leaves are grouped alternately with the short branches. In the fall, the leaves become yellow. The undersides of the leaves are frequently coated with white pubescence, while the tops of the leaves have a vivid green colour that gradually intensifies. Its edge is curved and serrated. There are either unicostate or pinnate venations. The base of the leaf is irregular, and it has a stalk. Apple leaves curl and appears dried-out and burnt[8].

3.4 Flower

Mid-April sees the appearance of white blooms. In the early stages of bloom, it has tiny, fragrant angiosperm flowers with petals ranging from white to pink. Since the centre blossom has the potential to provide a bigger fruit than other blooms, it is also referred to as the "King bloom." On spurs or, to a lesser extent, on long stems, mixed buds develop flowers terminally[9-11].

3.5 Fruit

Fruit is juicy, sweet, and medium to large. Between mid-September and mid-October is the time when it is in its ripest stage. *M. domestica* belongs to the pome fruit category. The endocarp is a stiff, thin coat covering the seeds, the mesocarp, the flesh of the core, and the exocarp comprise the pericarp in pomes (the outer layer of the core, which is fused to the edible flesh of the apple)[11].

3.6 Apple Peel

It is referred to as the fruit's rind outer skin. The combination of several pigments in varying concentrations gives apple skin its colour. Chlorophyll and carotenoids, two phytochemical pigments, are responsible for the background's yellow-green hue. In contrast, anthocyanins and flavones are responsible for the red colour of apple skin[10,12,13].

3.7 Apple seed (Pip)

The seeds are tiny and range in colour from dark brown to black. It has a smooth texture, a pointed tip, a circular base, and a bitter taste. The endosperm and embryo are covered by a layer of maternal tissue called the seed coat, often referred to as the Testa, which hardens to protect them. The apple seed is incredibly thin as it grows because the two cotyledons almost entirely consume the endosperm for sustenance[14].

The various plant parts of *M. domestica* are shown in Figure 2 and the dried and fresh apple peel is demonstrated in Figure 3.

4. Microscopical Characters of *Malus domestica*

Fruit peel structure, particularly the epidermis and cuticle that serve as a barrier between the fruit's internal and exterior surroundings, is directly connected to fruit quality.

4.1 Epicuticular wax

The apple fruit has two distinct types of epicuticular waxes: crystalline wax platelets with a range of sizes and shapes, and amorphous wax that forms a continuous film. The epicuticular wax's primary purpose is to reduce surface wetness and moisture loss. By limiting water evaporation, and pathogen penetration, and keeping fruit firmness, epicuticular wax, which is generated on the fruit surface, is essential for sustaining the fruit's life[15].

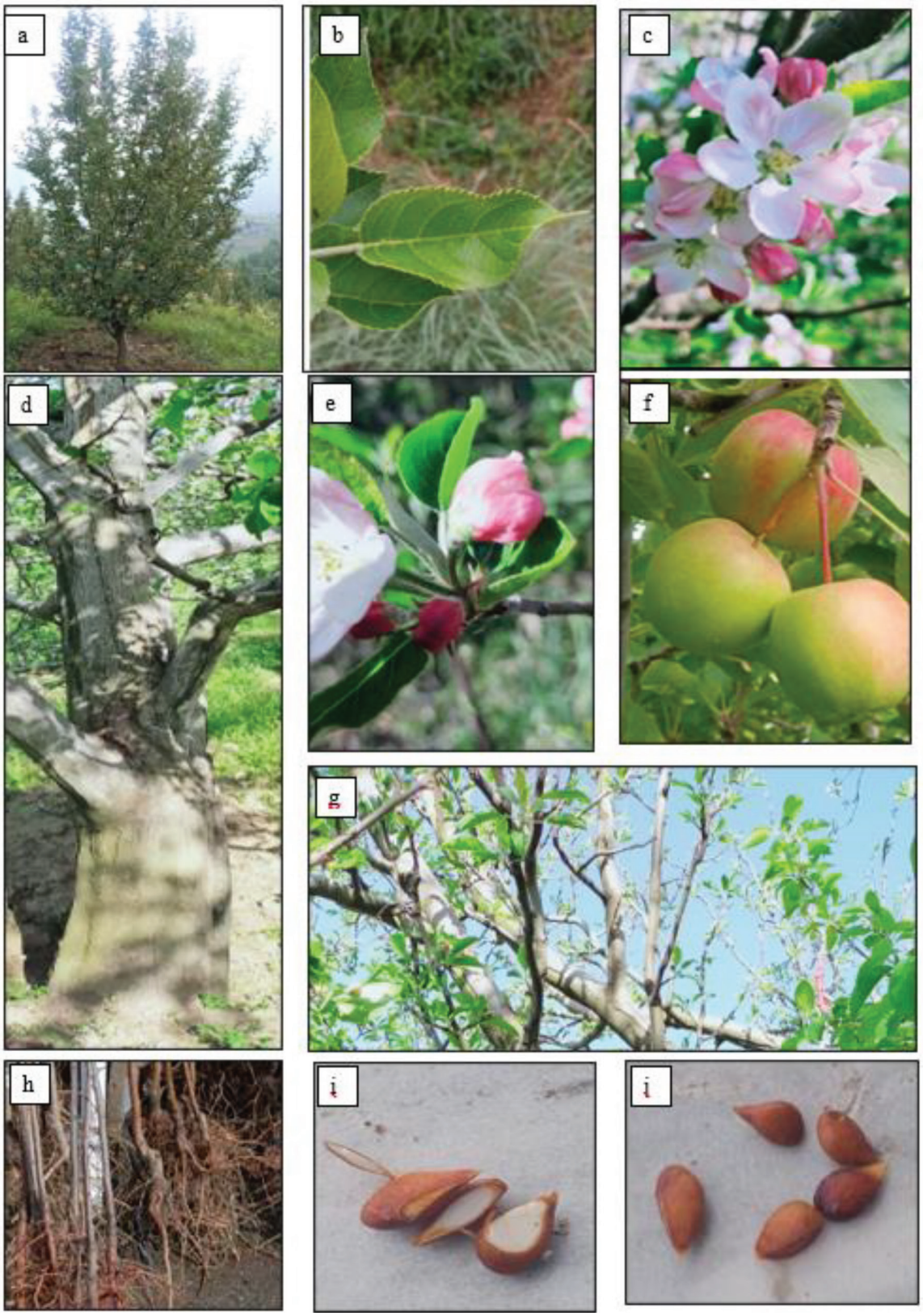


Figure 2. *Malus domestica* Borkh. plant parts **(a).** Tree; **(b).** Leaves; **(c).** Flower; **(d).** Bark; **(e).** Inflorescence; **(f).** Fruit; **(g).** Twig; **(h).** Roots; **(i).** Seeds.

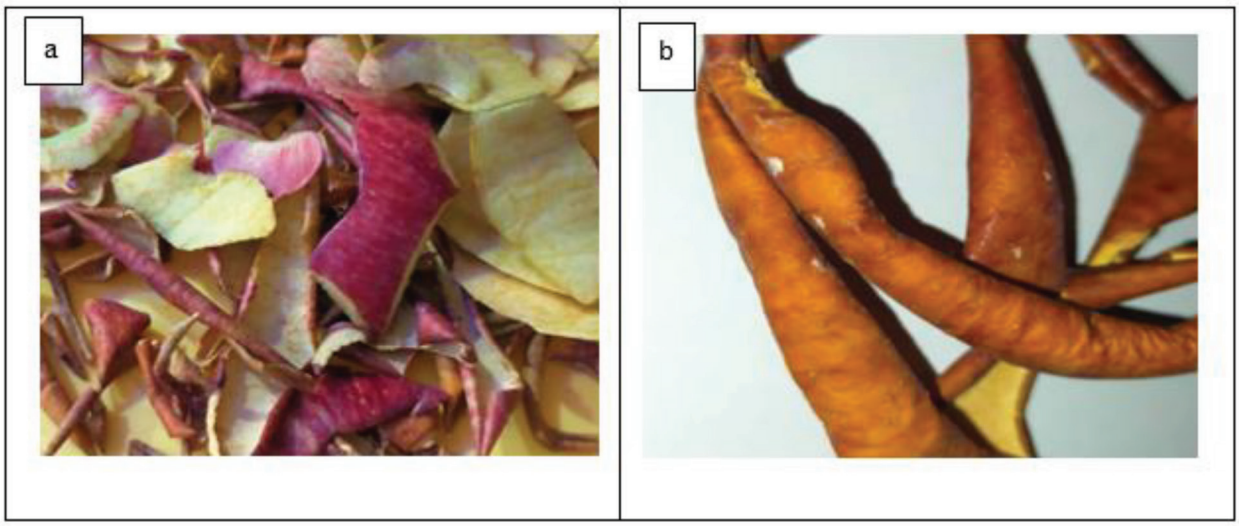


Figure 3. Sample of apple peel: **(a).** Fresh peel; **(b).** Dried peel.

4.2 Cuticle

The apple's cuticle shields it from environmental hazards such as wind, temperature changes, pollutants, and dehydration. The complex lipid-based bio composites known as plant cuticles are filled with non-polymerized cuticular lipids known as "waxes" and are formed of cutin polymer. The cutin polymers serve as a pathogen barrier in the hydrophobic scaffolding, enable wax buildup, and maintain the integrity of the cuticle. The cuticle was found to have two distinct layers: an interior layer that bordered the epidermal cell wall and was about 1 mm thick and reticulate, making up the cuticular layer, and an exterior layer that was between 0.7 and 0.9 mm thick and had a lamellate structure, *i.e.*, cuticle proper[15,16].

4.3 Lenticels

Open lenticels found in the apple skin allow water molecules to diffuse through them. These are the small lens-shaped natural openings in the cuticle. At the maturity stage of fruit, a handful of the lenticels were larger and occupied more space over the peel surface. Convex or, less usually, flattened cells filled them. There were sometimes mycelium hyphae visible inside the lenticels. The cuticle layers closing the lenticels were stained with Sudan III or phellogen[13].

4.4 Epidermal Layer

The cuticle adheres to the epidermis outer cell wall, impregnating the inner epidermal and maybe hypodermal cell walls as well[16]. Cuticles and crystalline wax platelets coated the single-layered epidermis. Different levels of vacuolization were present in epidermal cells. The fruit surface contained many 1-2 mm long non-glandular unicellular trichomes, stomata, and micro-cracks that were up to 3.9-7.8 um broad. The plastid, mitochondria, and vacuole of an epidermal cell may be observed in TEM pictures[16,17].

4.5 Hypodermal layer

Stratified hypodermis layer present beneath the epidermis[17].

5. Bioactive Substance in *Malus domestica*

Malus domestica is rich in a variety of bioactive substances that contribute to its medicinal and nutritional benefits. The major bioactive compounds include polyphenols, and flavanols, which are known for their potent antioxidant, anti-inflammatory, anti-microbial and anti-tumor properties. The polyphenols are ferulic acid, ellagic acid, gallic acid and flavonols including quercetin, ursolic acid, phytosterols, *etc*. It also contains significant amounts of dietary fibre, particularly pectin, which has been linked to improved digestive health and cholesterol regulation. Additionally, it consists of pectin, carbohydrates, amino acids and endogenous hormones. These bioactive substances make apples a valuable food for promoting overall health and supporting therapeutic interventions in traditional and modern medicine. The

Table 3. Distribution of bioactive substance in different parts of *Malus domestica*

	Chemical Constituents	Pharmacological Activity	Section entails	References
Polyphenols				
1	2- hydroxy cinnamic acid	Antioxidant and Chemoprotective effect	Leaf, pulp, peel	19,32
2	p-coumaric acid	Antioxidant and Anti-inflammatory property	Pulp	33,34
3	Ferulic acid	Anti-microbial and anti-diabetic	Leaf, pulp	34–36
4	Ellagic acid	Anti-proliferative	Pulp	37,38
5	Gallic acid	Anti-neoplastic property	Peel	39,40
Flavanols				
1	Quercetin	Anti-allergic, anti-inflammatory, anti-viral, anti-protozoal	Peel	41,42
2	Ursolic acid	Anti-oxidant, anti-inflammatory, anti-fungal	Peel	43
3	Oleanolic acid	Hepatoprotective, anti-tumor	Peel	44,45
4	Corosolic acid	Anti-hyperlipidemic	Peel	45,46
5	Betunilic acid	Anti-HIV and Anti-malarial	Peel	47
6	Anthocyanins	Neuroprotective and Cardiovascular protective	Peel	48
7	Phytosterols	Cholesterol metabolism	Peel	49,50
8	Phlorizin	Anti-hyperglycemic	Peel, Seed	34
9	Phloretin	Anti-thrombotic	Peel	25
10	Chlorogenic acid	Lipid and glucose metabolism	Peel, pulp, kernel, leaf	51
11	Caffeic acid	Anti-carcinogenic activity	Peel, pulp	34
12	Caffeoylquinic acid	Weight reduction	Pulp and skin	51
13	P-coumaroylquinic acid	Anti-bacterial	Pulp and skin	52,53
14	(+)-Catechin	Memory enhancer	Peel, pulp, kernel	34,53
15	(-)-Epicatechin	Anti-carcinogenic and cytoprotective	Peel, pulp, kernel	34
16	Proanthocyanidins	Free radical scavenging activity	Peel, pulp, leaf	54,55
General class				
1	Pectin	Anti-bacterial activity	Peel, pulp, root, stem, leaf	56
2	Carbohydrates	Anti-inflammatory activity	Seed, Pulp, leaf	57
3	Amino acid, peptide, and protein ingredients	Anti-viral activity	Seed, Pulp	58
4	Oil composition	Pesticide activity	Seed, Pulp	2
5	Amygdalin	Anti-arthrosclerosis, anti-tumor	Seed	59
6	Endogenous hormone	Antioxidant	Plant	60

details of bioactive substances in different parts of the plant are mentioned in Table 3 and the structure of a few bioactive compounds are shown in Figure 4.

6. Result

6.1 Pharmacological Activity

6.1.1 Antioxidant Property

Depending on the phenolic composition, the fruit's antioxidant activity varies widely. Apples, especially their peels, have been proven to contain strong antioxidant properties that can significantly slow the progression of liver cancer and colon cancer[18]. The overall antioxidant activity of apples with the peel was around 83 mol Vitamin C equivalents, therefore 100 g of apples have about 1500 mg of antioxidant activity. Apple polyphenols have a radiation protective effect through dose-dependently lowering the radiation-mediated destruction of 2-deoxyribose (2-DR). Apple polyphenols also decrease radiation damage by scavenging hydroxyl free radicals,

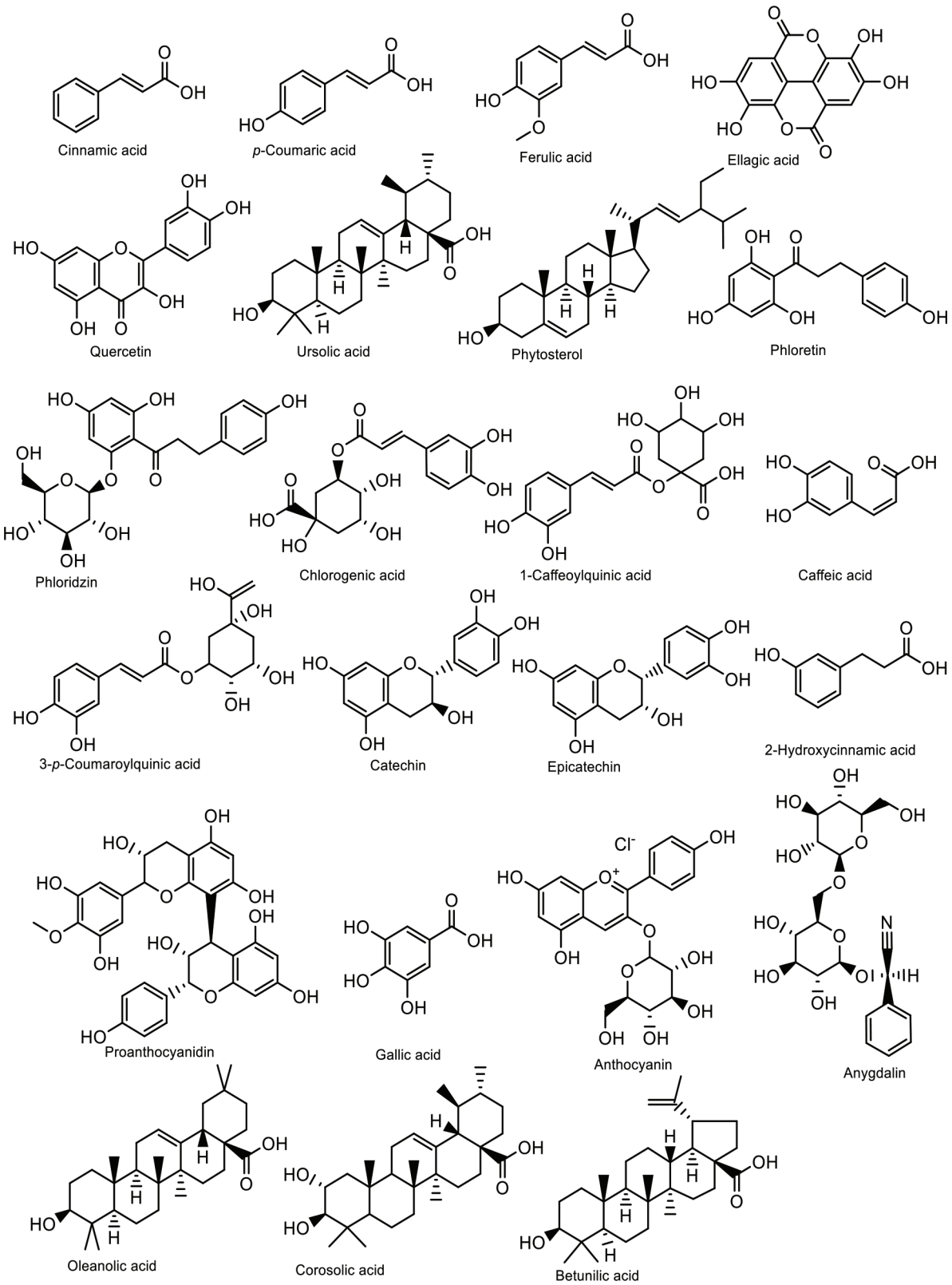


Figure 4. Chemical constituents of *Malus domestica* Borkh.

which can stop single and double-strand breaks brought on by radiation in rat thymocytes. The flavonoids and phenolic compounds contained in apples demonstrate biological roles as antioxidants, antimicrobials, and enzyme inhibitors regarding cholinesterase, tyrosinase, amylase, and glucosidase. The polyphenolic extract of *M. domestica* is effective against gramme +ve and gramme -ve bacteria[3].

6.1.2 Anti-microbial Property

The phenolic compounds might affect the antibacterial action, and their polyphenol extracts showed more potent bacterial inhibitory effects. It has been discovered that apples have potent antibacterial capabilities[19]. Apple extracts from organic orchards have an antimicrobial effect on *Bacillus cereus* and *E. coli*. In this instance, it was discovered that their peel exhibited distinct activity, with inhibitory zones expanding from 6 mm to 13 mm in diameter. Apple extracts that are high in phenols are used as a source of antimicrobials to fight against different infectious diseases such as urinary tract infections, *etc*[50].

6.1.3 Anti-inflammatory Property

It has been found that various triterpene acids such as chlorogenic acid and maslinic acid have the potential for anti-inflammatory activity. Maslinic and pomolic acids show anti-inflammatory and anti-arthritic effects through NF-κB inactivation. Some researchers found that many significant sources of such compounds show potential in anti-inflammatories and glycemic control effects[51]. It has been demonstrated that eating apples helps to reduce the symptoms of intestinal inflammation. Phloretin and phlorizin, its glycoside, are two (poly) phenols that have been linked to these positive benefits. Polyphenol extracts from apples prevent damage to human gastric epithelial cells *in vitro* and rat gastric mucosa *in vivo* also anti-oxidant polyphenolic compounds significantly reduce inflammation and skin ageing[52].

6.1.4 Anti-cancer

In cancer patients who have had chemotherapy, *M. domestica* syrup can lessen the intensity and length of their nausea[53]. Eating fruit lowers the risk of cancer, especially colon and lung cancer[54]. Phloretin, in a dose-dependent way, suppressed proliferation and brought about death in lung cancer cells A549, Calu-1, H838, and H520. Phloretin also prevented these cells from migrating and invading[39]. By consuming at least one part of *M. pumila* daily, women can reduce their risk of developing lung cancer, but this association was not shown in males.

6.1.5 Anti-diabetic Property

Malus domestica has a high water and fibre content, which may lower the risk of developing diabetes. It reduces the degree of glycation in circumstances with effectiveness and efficiency. Consuming apples may reduce the risk of diabetes because they contain a larger quantity of quercetin and eating apple peels was also linked to a lower risk of type II diabetes. Apples don't elicit a sugar rise because of their low glycemic index of 36. It can maintain blood levels and even include additional nutrients that support the creation of insulin and the breakdown of glucose[51].

6.1.6 Obesity

Obesity has been particularly difficult for healthcare professionals to control and reduce. Apples include bioactive substances that might support healthy gut flora and improve the health of obese persons[51]. Additionally, fibre might make someone feel fuller longer and decrease their tendency to overeat. In recent years, doctors, dietitians, and nutritionists have frequently advised eating an apple every day to prevent chronic ailments[55].

6.1.7 Asthma and Pulmonary Function

Consuming apples has been positively correlated with overall lung health as well as negatively correlated with asthma. It has been discovered that eating apples and pears reduces the likelihood of developing asthma and reduces bronchial hypersensitivity because they are high in antioxidants, vitamins, phenolic acid, and flavonoids, all of which aid in reducing airway inflammation[56].

6.1.8 Heart Disorder

There are several factors for why apples are good for the heart. Pectin, a soluble fibre abundant in apples, prevents cholesterol from being absorbed in the stomach and urges the body to utilize the waxy substance rather than storing it. Polyphenols, which are antioxidants that protect cells from free radical damage, are also

abundant in apple peels. Patients with higher TC and LDL levels benefited more from apple consumption. It's interesting to see those apples dramatically somewhat decreased HDL levels[57].

6.1.9 Brain Function

Apples may enhance cognitive function and promote the development of new brain cells. Apples include organic compounds that might promote the development of new brain cells, which might impact memory and learning. You might be able to temporarily avoid seeing a psychiatrist by eating an apple every day. Apples like berries both include a lot of antioxidants that can lower inflammation and guard against oxidative cell damage. The important neurotransmitter acetylcholine is produced in the brain at a higher rate when apple juice is consumed. According to research, frequently eating apples may shield neuronal cells from the neurotoxicity brought on by oxidative stress. The loss of the essential neurotransmitter acetylcholine, which is halted by eating an apple every day, may help to prevent the onset of Alzheimer's disease[58].

6.2 Traditional Uses

Since antiquity, entire fruit has been used except for the seeds. Nevertheless, apples were at least partially responsible for the saying "An apple a day keeps the doctor away". People in Himachal Pradesh and Kashmir, two mountainous areas in India, peel apples and dry the skins before consuming them as dried fruit that may be kept for up to 1.5 to 2 years. It is rich in vitamins, minerals, and fibre, all of which are extremely good for human health. Apples, have been a traditional plant since the Middle Ages and have several uses. In addition to pharmacological studies of *M. domestica*, apples' supposedly having therapeutic edible qualities include:

6.2.1 Antacid

Because it includes pectin and is affected by glycine, it is ideally suited to reducing stomach acidity[59].

6.2.2 Anti-diarrheal and Laxative

An apple's high pectin content makes it an excellent intestinal tract regulator while also making it a great case for colitis, diarrhoea, gastroenteritis, and any other condition where an excessive amount of soft faeces is produced[60].

6.2.3 Diuretic and Depurative

Malic acid, cysteine, and arginine, two nutrients found in apples, are excellent for removing toxins from the body as well as for treating or preventing disease. It is advised for the treatment of kidney-related illnesses, gout, urticarial, and uric acid intoxication.

6.2.4 Hearing Loss

Apple vinegar's high potassium, magnesium, zinc, and manganese content makes it particularly useful for the health of the ear. Deafness may result from one of these mineral deficiencies[6].

7. Discussion

The phytochemical profile of *M. domestica* reveals a variety of bioactive substances with noteworthy health advantages. Particularly important are the antioxidant, anti-inflammatory, and antibacterial qualities of polyphenols and flavanols, which may help prevent chronic illnesses including diabetes and cardiovascular disease. Dietary fibre enhances digestive health and aids in cholesterol regulation. These results highlight apples' diverse therapeutic potential as a natural remedy and functional food.

Even though apples' nutritional and medicinal qualities have been extensively studied, there is a need for more in-depth clinical studies to fully validate and understand the mechanisms underlying these benefits. The majority of research has been done *in vitro* or in animal models and few extensive human trials have been carried out to date to provide precise therapeutic guidelines. Future research should focus on the bioavailability of these bioactive compounds in humans and their long-term effects on health outcomes.

Furthermore, by utilizing the fruit's bioactive potential, functional foods and supplements made from apples may open up new avenues for preventative healthcare. Advances in biotechnology, such as genetically modified apples with enhanced bioactive content, may also open doors for optimizing their therapeutic applications. Apples may become an even more effective tool in the fight against chronic

illnesses if they can bridge the gap between traditional applications and modern research.

8. Author Contribution

AK conceptualized, supervised and reviewed the study. SS and KC collected the data. SS performed the experiment and wrote the manuscript. SoS and PN revised the manuscript. All the authors read and approved the manuscript.

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