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Manilkara zapota (Sapodilla or Chikko): A Review of the Phytochemical Composition, Traditional Uses, and Therapeutic Potential

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Abstract:

Manilkara zapota, also referred to as sapodilla, is the most prominent and widely grown fruit in the Sapotaceae family. It is distinguished as a nutrient-rich fruit, including sugars, acids, proteins, amino acids, and minerals. Chiku is rich in bioactive components such as ellagitannins, gallotannins, phenolic acids, depsides, and flavonoids, including anthocyanins and flavanols. This review seeks to systematically gather critical information and possibilities for extracting bioactive chemicals from the sapodilla for exploring its therapeutic potential.

In this review, we highlight the composition of sapodilla fruit and present current research findings on the principal pharmacological actions. The significant bioactive qualities indicate the potential to employ components from both the edible and inedible sections of the sapodilla in the development of innovative food and medicinal products. The nutritional value of sapodilla fruit, along with the phytochemical variety present in its by-products such peels, seeds, bark, and leaves, establishes them as potential sources of nutraceutical components for functional food development. From a pharmacological standpoint, both the consumable and non-consumable components of sapodilla demonstrate potential as antioxidants, anticancer agents, antimicrobials, analgesics, anti-inflammatories, and hepatoprotective agents.

Keywords: *Manilkara zapota*; sapodilla; phytochemicals; bioactive compounds.

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1. Introduction-

Manilkara zapota, commonly known as sapodilla or chikko, is an evergreen tree native to the Americas and the Caribbean, currently cultivated in numerous tropical and subtropical regions. It is a member of the Sapotaceae family and is celebrated for its sweet, delectable fruit, which has become popular both as fresh produce and as an ingredient in diverse culinary applications. The fruit of *Manilkara zapota* is rich in carbohydrates, primarily simple sugars such as sucrose, fructose, and glucose [1]. Furthermore, it possesses moderate amounts of dietary fibre, which aids digestion and enhances overall gut health. Regarding micronutrients, sapodilla is a commendable source of vitamin C, vitamin A, potassium, and calcium. Furthermore, the fruit is rich in phytochemicals such as tannins, flavonoids, and polyphenols, which are recognised for their antioxidant properties and enhance its health benefits [2].

The antioxidant effects of *Manilkara zapota* are due to its elevated levels of polyphenolic compounds, which help neutralise harmful free radicals in the body, thereby reducing oxidative stress. This is especially advantageous for averting cellular damage, ageing, and numerous chronic ailments, such as cancer and cardiovascular illnesses [3]. Initial research has suggested that extracts of *Manilkara zapota* have anti-inflammatory and antibacterial properties, potentially aiding the treatment of infections and alleviating inflammation associated with diverse health issues. Furthermore, the fruit's elevated fibre content may help control blood glucose levels, making it potentially advantageous for those with diabetes or at risk of the condition [4].

Numerous pharmacological investigations have been conducted to assess the therapeutic potential of *Manilkara zapota* extracts. For example, research on animals has shown that it has hypoglycemic and hypolipidemic effects, indicating that it may be useful in the treatment of diabetes and the improvement of lipid profiles[5]. Nevertheless, to validate these results, larger-scale clinical trials are necessary and ascertain the optimal dosage and treatment duration for therapeutic application. Sapodilla, is a versatile fruit with promising nutritional and therapeutic properties[6]. Its rich phytochemical profile, antioxidant capacity, and potential health benefits make it a valuable addition to a healthy diet and a subject of interest for further scientific research. To completely understand its modes of action, safety profile, and therapeutic potential in people, additional thorough research is necessary[7].

This comprehensive review offers detailed insights into the diverse applications of both the edible and non-edible parts of the sapodilla plant[8]. By highlighting its nutritional richness, bioactive compounds, and phytochemical diversity, the review underscores the potential for leveraging sapodilla in various industries. In the food sector, sapodilla can be explored for its functional and nutritional benefits, enhancing the quality and health-promoting properties of food products[9]. Within the pharmaceutical sector, the bioactive compounds found in the plant offer avenues for the development of novel therapeutic agents, encompassing antioxidants, anticancer medications, and anti-inflammatory treatments. Additionally, the cosmetic industry can tap into sapodilla's phytochemicals for formulating skincare and beauty products with potential skin health benefits[10]. This assessment is an essential resource for researchers, industry experts, and policymakers seeking to use the sapodilla plant's full potential across several sectors.

Historical and geographical distribution

*Manilkara zapota*has a rich historical background that traces its origins to Central America and the Caribbean. Indigenous communities in these regions have utilized sapodilla for centuries, both

as a food source and for its medicinal properties[11]. The ancient Mayans and Aztecs revered the sapodilla tree for its sweet and nutritious fruit and used its latex for variety of therapeutic benefits, including wound healing and digestive ailments.As trade routes expanded during the colonial era, sapodilla spread to other tropical and subtropical regions, including Southeast Asia, where it was introduced due to its delicious flavour and adaptability to local growing conditions[12]. Over time, it became integrated into the culinary traditions and folk medicine of these regions, further contributing to its global distribution and popularity.

Manilkara zapota, a fruit-bearing tree belonging to the Sapotaceae family, is extensively planted in tropical and subtropical countries owing to its suitability for warm and humid weather [13]. Indigenous to Central America and the Caribbean, it has been introduced and naturalised in several places throughout Asia, Africa, and Oceania. Renowned for its saccharine, malty-flavoured fruit, sapodilla is cultivated commercially in areas like the Philippines, Indonesia, Vietnam, Malaysia, and India, especially in the states of Gujarat, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, and Kerala. It is extensively cultivated in Thailand, Bangladesh, Cambodia, Sri Lanka, and Pakistan, where favourable climatic conditions and fertile soils facilitate its growth (fig.1) [7]. The chicozapote tree, esteemed for its superior lumber, medicinal uses, and latex yield, is a significant species within a family of around 1,250 flowering varieties. The tree reaches heights of 25–45 meters and has an average trunk diameter of 1.5 meters, flourishing in tropical conditions[9]. It yields unique white, bell-shaped blooms over several flowering intervals, including June–July, September–October, and March–April, contingent upon local climatic circumstances [14].

In Africa, sapodilla cultivation is prevalent in countries such as Nigeria, Kenya, and Tanzania. It is primarily grown for both local consumption and export markets[9]. Similarly, in Oceania, sapodilla can be found in countries like Australia and Fiji, although its cultivation is less widespread compared to other regions. Overall, the geographical distribution of *Manilkara zapota* reflects its adaptability to diverse climatic conditions and its significance as a valuable fruit tree with both nutritional and medicinal properties[15].

Manilkara zapota cultivated for commercial purposes in countries such as The Philippines, Indonesia, Vietnam, Malaysia, India, and Thailand. Additionally, it is grown abundantly in Bangladesh, Cambodia, Sri Lanka, and Pakistan.

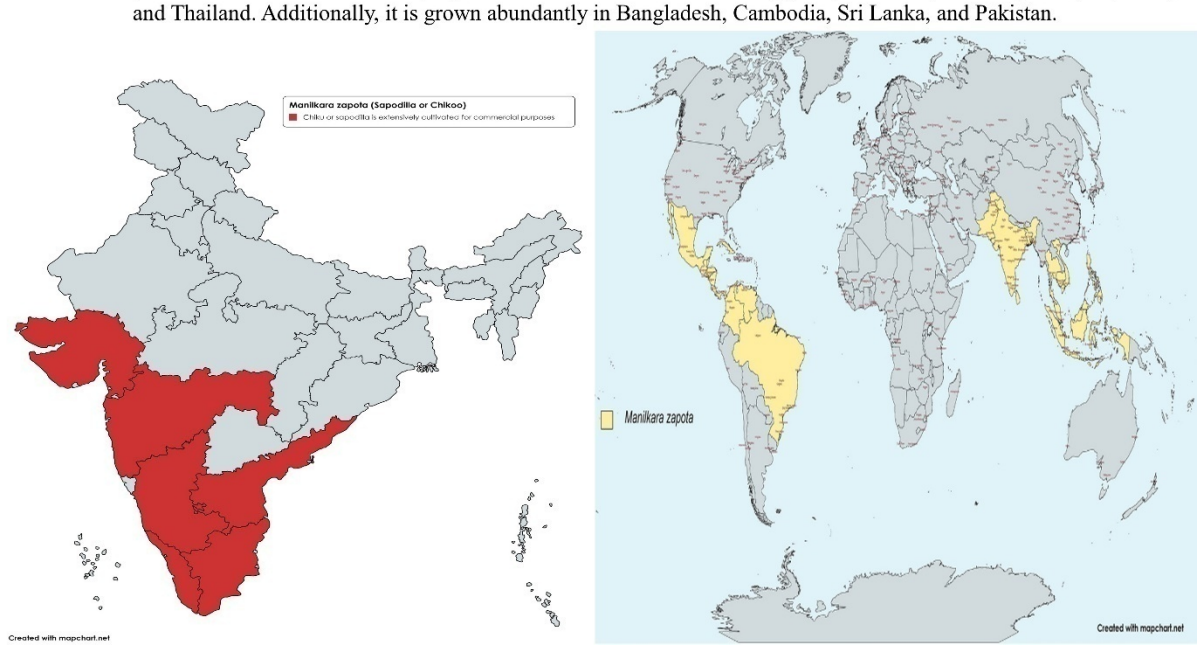

Figure 1: Worldwide distribution of *Manilkara zapota*[7,9].

2. Botanical Description

2.1 Taxonomy and Classification

Manilkara zapota belongs to the Sapotaceae family, a diverse group of flowering plants that includes approximately 1,250 species. Within this family, Manilkara is a genus comprising various species of trees and shrubs, among which *Manilkara zapota*, often referred to as sapodilla or chiku, is among the most recognized and widely cultivated species[16].

2.2 Morphological Characteristics

Tree:*Manilkara zapota*tree can grow to a height of 25–45 meters (80–150 feet) under favourable growing conditions. It has a straight trunk with a greyish-brown bark that is rough and fissured[1, 9].

Leaves: The leaves of the sapodilla tree are glossy, oval-shaped, and alternate in arrangement. They are leathery in texture and can vary in size, ranging from 5 to 15 centimetres in length. The leaves are characterized by prominent veins and possess a dark green hue[17].

Flowers: The sapodilla tree produces small, white to pale pink, bell-shaped flowers that are approximately 1–1.5 centimetres in diameter. These flowers are fragrant and usually appear in clusters during specific periods, including June–July, September–October, and March–April[4].

Fruits: The fruit of *Manilkara zapota*, referred to as sapodilla or chiku, is a round to oval berry with a rough, brownish exterior. When ripe, the fruit has a soft, grainy texture and contains 2–10 black seeds. The pulp of the fruit is sweet, with a flavour reminiscent of brown sugar or caramel[18].

Bark: The bark of the sapodilla tree is rough and deeply fissured, becoming more pronounced as the tree matures. Its colour varies from greyish-brown to reddish-brown, influenced by age and environmental factors. Serving as a protective layer for inner tissues, the bark is relatively thick[19]. Lenticels on its surface facilitate gas exchange. Sapodilla trees are known for latex production, with reservoirs in the bark that release milky white latex when injured, hardening upon exposure to air[8].

Seed: Sapodilla seeds typically measure 2 to 5 centimetres in length and have an oval or ellipsoidal shape. They exhibit varying shades of light to dark brown, often adorned with mottled patterns or speckles. The seeds' surfaces are typically smooth or lightly wrinkled, encasing a hard and woody exterior that safeguards the inner kernel. Within the seed, a white or cream-colored endosperm provides essential nutrients for germination when the seed sprouts[20].

2.3 Growth Requirements and Cultivation

Manilkara zapota flourishes in tropical and subtropical settings characterised by elevated temperatures and high humidity. It favours well-drained, sandy or loamy soils abundant in organic materials [21]. The sapodilla tree necessitates complete sunlight exposure for best growth and fruit yield. Propagation of sapodilla is primarily achieved by seeds, although grafting and budding techniques are utilised to preserve particular cultivars with preferred characteristics [22]. The tree exhibits considerable drought tolerance and can endure brief intervals of waterlogging. Regular pruning is advised to preserve the tree's shape and enhance fruit harvesting. The commercial cultivation of sapodilla is widespread in countries such as India, Thailand, Malaysia, Indonesia, and the Philippines, where the tree is cultivated for its delectable fruit, as well as its superior timber and latex [9].

The cultivation of *Manilkara zapota* is optimal in well-drained sandy or loamy soil with a pH range of 6.0 to 7.5. The soil must be neutral to slightly acidic to facilitate optimal development and fruit yield. Nitrogen (N) is crucial for leaf and stem development, with a recommended application rate of 50–100 kg/ha/year. Phosphorus (P) is essential for root development and fruit yield, with a suggested application rate of 30–50 kg/ha/year [23]. Potassium (K) is essential for plant vitality, fruit quality, and disease resistance, with a suggested application rate of 50–100 kg/ha/year. Furthermore, calcium (Ca) and magnesium (Mg) are essential for optimal root development and fruit quality, with suggested applications of 100–200 kg/ha/year for Ca and 20–40 kg/ha/year for Mg. Sulphur (S), essential for amino acid and protein synthesis, should be applied at a rate of 20–40 kg/ha annually. Micronutrients such as iron, zinc, copper, manganese, boron, and molybdenum, though needed in minimal amounts, are essential for growth, flowering, and fruiting [24]. The advised dosage for micronutrients depends on soil test outcomes and is typically administered as a blend or particular individual elements according to deficiency indicators. Integrating organic matter, such as compost or farmyard manure, into the soil enhances its structure, water retention, and nutrient accessibility [25]. Ensuring sufficient soil moisture, especially during blooming and fruit development phases, is crucial for maximum growth and fruit yield. Ensuring adequate soil drainage is essential to prevent water logging, which can result in root rot and other ailments. Periodic soil testing is advised to assess nutrient concentrations and pH, facilitating tailored fertilisation and soil management strategies appropriate to the needs of *Manilkara zapota* cultivation [26].

3. Nutritional Composition

3.1 Macronutrients

*Manilkara zapota*is a nutrient-dense fruit with a rich nutritional profile. The fruit is primarily composed of carbohydrates, predominantly in the form of simple sugars like sucrose, fructose, and glucose[27]. These sugars not only enhance its sweet flavour but also offer a rapid source of energy. In terms of proteins, while sapodilla is not a significant source, it does contain some amount of this macronutrient, which is essential for the growth and repair of body tissues[28]. Moreover, sapodilla is low in fat, rendering it a suitable fruit for individuals aiming to manage their fat intake. However, it still provides essential fatty acids in small amounts, contributing to overall health[29,90].

3.1.1 Carbohydrates: Sapodilla is chiefly constituted of carbohydrates, mainly as simple sugars such as sucrose, fructose, and glucose. The sugars impart sweetness and supply energy. Carbohydrates constitute around 83-85% of the total weight of sapodilla, predominantly as simple sugars [30].

3.1.2 Proteins: Although sapodilla is not a substantial source of protein, it does contain a little quantity of this macronutrient, which is vital for the growth and repair of bodily tissues. Sapodilla comprises around 0.5-1% protein by weight [31].

3.1.3 Fats: Sapodilla is low in fat, making it a suitable fruit for individuals mindful of their fat intake, while still offering essential fatty acids in modest quantities.The fat content in sapodilla is negligible, comprising less than 1% of its total weight[32].

3.2 Micronutrients

Manilkara zapota is a significant source of macronutrients and offers a range of vital micronutrients for general wellness. Sapodilla is notably abundant in vitamin C, vitamin A, and

other B vitamins, such as thiamine (B_1), riboflavin (B_2), and niacin (B_3)[33]. These vitamins are essential for immunological function, energy metabolism, and general health. Sapodilla provides vital minerals including potassium, calcium, magnesium, phosphorus, and iron. These minerals are essential for regulating fluid balance, enhancing bone health, aiding muscular function, and enabling oxygen delivery in the bloodstream [34].

3.2.1 Vitamins: Sapodilla is rich in various vitamins, including vitamin C, vitamin A, and several B vitamins like thiamine, riboflavin, and niacin [1,35]. These vitamins are essential for immunological function, energy metabolism, and general health.

- Vitamin C: Approximately 14-20 mg /100 grams of sapodilla
- Vitamin A: Around 20-50 IU (International Units) /100 grams
- Thiamine (B1): Approximately 0.02-0.04 mg /100 grams
- Riboflavin (B2): Around 0.02-0.05 mg /100 grams
- Niacin (B3): Approximately 0.2-0.5 mg /100 grams

3.2.2 Minerals: The fruit supplies vital minerals including potassium, calcium, magnesium, phosphorus, and iron [9]. These minerals are essential for regulating fluid balance, supporting bone health, facilitating muscular function, and enabling oxygen transfer in the bloodstream [36].

- Potassium: Approximately 193-200 mg / 100 grams
- Calcium: Around 21-30 mg / 100 grams
- Magnesium: Approximately 12-20 mg / 100 grams
- Phosphorus: Around 8-12 mg / 100 grams
- Iron: Approximately 0.2-0.6 mg / 100 grams

3.3 Phytochemicals and Antioxidants

3.3.1 Phytochemicals

Sapodilla comprises several phytochemicals, such as ellagitannins, gallotannins, phenolic acids, depsides, and flavonoids, including anthocyanins and flavanols. These bioactive chemicals provide significant health benefits, encompassing antioxidant, anti-inflammatory, and anticancer capabilities [37]. Throughout the entire fruit, including the pulp, seeds, and leaves, these bioactive compounds are dispersed. The fruit contains ellagitannins and gallotannins, polyphenolic and hydrolyzable tannins respectively, which are present in the pulp, seeds, and leaves. Ellagitannins make up approximately 0.5-1% of the pulp and 1-2% of the seeds, while gallotannins account for about 0.3-0.8% in the pulp, 1-2% in the seeds, and 0.5-1% in the leaves[38].

Alongside tannins, sapodilla contains phenolic acids such as gallic acid and ellagic acid. These phenolic acids contribute antioxidant and anti-inflammatory effects and comprise approximately 0.1-0.5% (pulp), 1-2% (seeds), and 0.5-1% (leaves). Depsides, which are esters of phenolic acids, are also present in the leaves and peel of sapodilla, with a composition of approximately 0.2-0.4% in the leaves and 0.1-0.3% in the peel[39].

Moreover, flavonoids such as anthocyanins and flavanols, which contribute to the color and antioxidant properties of sapodilla, are present in compositions of approximately 0.5-1.5 mg per 100 grams in the pulp and 1-2 mg per 100 grams in the peel[40]. Sapodilla also contains saponins, terpenoids, and alkaloids, which have various pharmacological activities, including cholesterol-lowering, immune-boosting, anti-inflammatory, antimicrobial, and anticancer effects. Saponins make up approximately 0.5-1% in the seeds and 0.3-0.7% in the leaves, terpenoids account for

about 0.2-0.5% in the leaves and 0.1-0.3% in the peel, and alkaloids are present in trace amounts, with compositions of approximately 0.01-0.03% in the seeds and 0.005-0.02% in the leaves[41]. The numeric compositions presented are approximate and may fluctuate based on factors like as ripeness, cultivation circumstances, and processing techniques. These phytochemicals function synergistically to confer several therapeutic effects, including antioxidant, anti-inflammatory, and anticancer capabilities, rendering sapodilla a significant enhancement to a nutritious diet [42, 89].

3.3.2 Antioxidants

The rich concentration of phytochemicals in sapodilla contributes to its antioxidant properties, assisting in reducing oxidative stress by neutralizing harmful free radicals in the body and improvehealth.*Manilkara zapota* or sapodilla is a nutrient-rich fruit containing carbohydrates, proteins, and fats as macronutrients, along with vitamins and minerals as micronutrients. Additionally, its phytochemical and antioxidant content further enhances its nutritional value[4,9].

4. Traditional and Culinary Uses

4.1 Traditional medicinal uses across different cultures

Manilkara zapota, has been cultivated and utilized by diverse cultures for both medicinal and commercial purposes for centuries. In traditional Mexican medicine, the fruit and its seeds were employed to treat gastrointestinal issues like diarrhoea and constipation, while in the Caribbean, it was used to alleviate stomachaches and indigestion[43]. Additionally, sapodilla leaves were utilized to address coughs, colds, and respiratory conditions. The tree's latex was applied topically to wounds and cuts to promote healing and prevent infections, and both the bark and latex were used in various traditional medicines as anti-inflammatory agents[44]. Some cultures even used sapodilla extracts to regulate blood sugar levels and manage diabetes.On the commercial front, the sapodilla fruit is widely enjoyed fresh due to its sweet, malty flavour and is used in various desserts, jams, and beverages[16]. It also serves as a natural sweetener and flavouring agent in the food industry. The sapodilla tree yields a durable and hard wood that finds its way into construction and furniture making. Additionally, the latex extracted from the tree is used in the production of chicle, a natural chewing gum base. Sapodilla extracts are sought after in cosmetics and skincare products for their moisturizing and antioxidant properties, and they are also incorporated into pharmaceutical formulations[45].

Across different cultures, the uses of sapodilla vary but are equally significant. In Latin America, particularly Mexico and Central America, sapodilla is a popular fruit consumed fresh and used in various traditional dishes and beverages[46-48]. The latex from the tree has been historically used in the production of chicle-based chewing gums. In the Caribbean islands, sapodilla is cherished as a beloved fruit enjoyed fresh and used in desserts and beverages, with its leaves and bark finding use in traditional medicine[17]. In India and Southeast Asia, where it is known as "chikko" sapodilla is consumed fresh, juiced, or used in desserts and ice creams and is also utilized in traditional Ayurvedic medicine. Lastly, in West Africa, sapodilla is cultivated and consumed as a fruit, and its latex is sometimes used in local traditional medicines[49]. Overall, *Manilkara zapota* has a rich history of traditional medicinal uses and is widely valued for its commercial applications across various cultures worldwide.

4.2 Culinary uses and recipes

Chikko is a versatile fruit enjoyed in various culinary preparations both in India and around the world[50]. In India, chikko is commonly consumed fresh by peeling and slicing the fruit. It is also

a key ingredient in the popular chikko milkshake, a creamy beverage made by blending ripe chikkos with chilled milk, sugar, and sometimes a pinch of cardamom[51-53]. Additionally, chikko is used in various Indian desserts like ice creams, puddings, and halwas. Internationally, sapodilla is enjoyed fresh by peeling and slicing the fruit, much like in India. It is also used in desserts such as pies, tarts, and ice creams, and in beverages like juices and smoothies[54-56]. One popular international recipe is sapodilla pie, a delicious dessert made by combining sliced sapodillas with sugar, flour, cinnamon, salt, and lemon juice. In conclusion, whether enjoyed as a refreshing milkshake in India or as a delectable pie internationally, chikko's sweet and malty flavour makes it a favourite ingredient in many kitchens across the globe[57-59].

5. Phytochemical / bioactive compounds of *Manilkara zapota*

Various plant components, including fruits, leaves, seeds, and bark, contain a varied range of phytoconstituents. The medicinal activities of the plants are attributed to these inherent bioactive substances [60]. The chicozapote fruit is celebrated for its abundant nutritional composition, containing vital nutrients, minerals, and advantageous phytochemicals (Fig 2). According to the USDA, 100 grammes of chicozapote fruit has around 83 calories, 0.4 grammes of protein, 1.1 grammes of fat, 20 grammes of carbs, and 5.3 grammes of dietary fibre[61]. The mineral composition is significant, featuring elevated potassium levels (193 mg), succeeded by calcium (21 mg), magnesium (12 mg), and phosphorus (12 mg) [62,85].

Research indicates that chicozapote fruit comprises primary organic acids, including malic, lactic, and succinic acids, which contribute to its unique flavour throughout all stages of ripeness [63]. Moreover, the fruit is rich in numerous vitamins, such as vitamin A, B complex, C, folate, niacin, and pantothenic acid [64]. A further study revealed that among seven chicozapote fruit varieties, the total soluble solids (TSS) varied from 17 to 23.40 °Brix, signifying a greater sugar content relative to numerous other fruits. The increased calorie content is mostly due to its carbohydrate composition, as well as tannins [65,87].

5.1 Fruit

The fruit is abundant in polyphenols, encompassing flavonoids, phenolic acids, and tannins, including ellagitannins and gallotannins, as well as vitamins such as vitamin C, vitamin A, various B vitamins, minerals, and advantageous phytochemicals [66]. Furthermore, it contains carotenoids like beta-carotene, lycopene, and lutein, in addition to both soluble and insoluble dietary fibre, which supports digestive health and regulates blood sugar levels. Moreover, the fruit comprises terpenes, alkaloids, saponins, steroids, and glycosides. Research by Bashir et al. indicates that chicozapote fruit is rich in phenolic compounds. Coumaric acid and ferulic acid are significant ingredients, accompanied by fatty acids, carotenoids, triterpenes, sterols, hydrocarbons, and phenylethanoid substances. Chicozapote contains other polyphenolic chemicals such as methyl chlorogenate, myricitrin, (+)-catechin, (−)-epicatechin, (+)-gallocatechin, kaempferol, and dihydromyricetin. Novel antioxidant chemicals, methyl-4-O-galloylchlorogenate and 4-O-galloylchlorogenic acid, have been identified in chicozapote[10]. Various studies have reported differing values for the total phenolic content and total flavonoid content in chicozapote fruit. Salleh et al. documented a total phenolic content (TPC) of 99 mg of gallic acid per 100 grammes of fresh pulp, but Pravin and Shashikant observed a TPC of 1151.40 mg GAE per 100 grammes and a total flavonoid content (TFC) of 564.50 mg quercetin per 100 grammes in the peel, respectively [36].

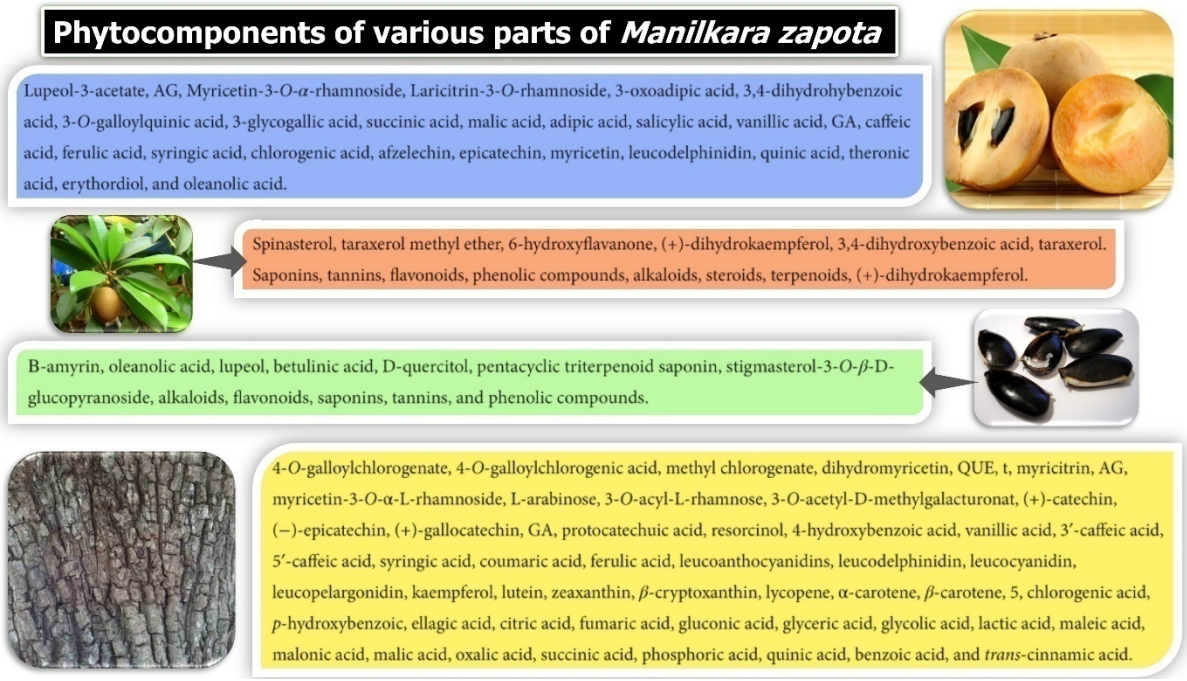

Figure 2: Various phytocomponents of *Manilkara zapota*[9]

Fresh and dried chicozapote fruits exhibit distinct olfactory properties. Essential components in fresh variants comprise ethyl, methyl, and hexyl benzoate, imparting a minty, woody aroma. Dried fruits, however, display citrussy and balsamic fragrances, predominantly characterised by hexyl benzoate, 3-Methyl-1-butanol, and ethyl benzoate [67-69]. Dehydration enhances scent stability, yielding 19 fragrant components in dried fruit compared to 13 in fresh fruit. In summary, chicozapote fruit provides numerous health advantages and therapeutic potential owing to its nutrient-rich composition, antioxidant characteristics, and varied phytochemical profile[70].

5.2 Leaves

Leaves of plants contain a variety of phytoconstituents with specific numerical values, enhancing their therapeutic properties[71]. There are notable concentrations of nitrogenous chemicals called alkaloids, which have a variety of medicinal actions. Flavonoids like quercetin, kaempferol, and catechins are found in concentrations ranging from 5-20 mg/g, exhibiting antioxidant, anti-inflammatory, and anticancer properties[72]. Terpenoids, including essential oils and saponins, are present with concentrations typically ranging from 1-5 mg/g. Phenolic acids, such as caffeic acid and chlorogenic acid, are also present, contributing to their antioxidant and anti-inflammatory effects, with concentrations varying from 2-10 mg/g[73]. Additionally, vitamins like vitamin C, A, and B, along with minerals such as calcium, magnesium, phosphorus, and iron, are present in the leaves in concentrations similar to those found in fruits, contributing to overall health[9].

5.3 Seeds

Seeds of plants are nutrient-dense, containing proteins in concentrations typically ranging from 15-25%, which are important for repair and maintenance. They are also rich in fatty acids, including omega-3 and omega-6, with concentrations ranging from 5-15%, beneficial for cardiovascular health[74,82]. Phytosterols are present in concentrations of approximately 2-5%, aiding in lowering cholesterol levels. Additionally, seeds contain flavonoids and phenolic compounds, with concentrations typically ranging from 1-10 mg/g, contributing to their antioxidant properties. Minerals such as calcium (200-800 mg/100g), magnesium (100-300

mg/100g), phosphorus (400-800 mg/100g), and iron (2-10 mg/100g) are also found in seeds, enhancing their nutritional and medicinal value[75,84].

5.4 Bark

Lastly, the bark of plants is rich in phytoconstituents with specific numerical values that enhance its therapeutic properties. Tannins, polyphenolic compounds with astringent properties, are present in concentrations typically ranging from 10-20% [15]. Alkaloids, nitrogenous compounds are found in concentrations of approximately 2-8%. Flavonoids and phenolic compounds are present in concentrations ranging from 5-15 mg/g, contributing to their antioxidant and anti-inflammatory effects. Terpenoids, including triterpenes and steroids, are found in concentrations typically ranging from 1-5 mg/g[13]. Additionally, the bark contains complex mixtures of resins and gums with various medicinal properties, with concentrations varying from 3-10%[22,86].

6. Therapeutic Potential or pharmacological activities of *Manilkara zapota*

Manilkara zapota, is not only a delicious tropical fruit but also offers a range of health benefits due to its rich phytochemical composition.

6.1 Antioxidant Properties

Antioxidants, including ellagitannins, gallotannins, and flavonoids, prevalent in sapodilla, support the body's defence against harmful free radicals. These antioxidants are crucial for alleviating oxidative stress, preventing cellular damage, and reducing the risk of chronic diseases such as cancer, heart disease, and neurological disorders [24].

Research by Ma J et al. indicated that chicozapote fruit extract produced two novel antioxidants and eight recognised polyphenols, exhibiting significant antioxidant and cytotoxic properties. As the fruit ripens, the levels of total antioxidant capacity (TAC), total phenolic content (TPC), gallocatechin, and catechin diminish. Among the extracted antioxidants, methyl-4-O-galloylchlorogenate demonstrated the highest efficacy in the DPPH assay, with an IC50 of 12.9 µM, while 4-O-galloylchlorogenic acid exhibited an IC50 of 23.5 µM [54]. In a separate investigation, the leaf extract revealed substantial reducing capacity, with AEAC values of 40.09 ± 3.61 µM (CUPRAC) and 53.3 ± 2.85 µM (FRAP). The bark extract exhibited antioxidant ability in the DPPH assay, with an IC50 of 16.83 µg/ml, while ascorbic acid showed an IC50 of 4.87 µg/ml [55].

The methanolic extracts of Chicozapote flowers exhibited the highest DPPH and ABTS activity, with IC50 values of 22.74± 0.67 µg/ml and 20.89± 0.17 µg/ml, respectively. Aqueous extracts of fruit and root exhibited IC50 values in DPPH of 33.08 ± 0.26 and 44.24 ± 0.49 µg/ml, respectively, and in ABTS of 35.29 ± 0.58 and 41.34 ± 0.65 µg/ml. The DPPH potential of fresh pulp extract was shown to exceed that of dried fruit, indicating that the drying process may affect antioxidant capacity [56].

Chicozapote comprises flavonoids with potent antioxidant capabilities, achieved via free radical scavenging and metal ion chelation, including quercetin, myricetin, and myricitrin. Due to its hydrophilic nature, myricitrin exhibits significant inhibition of lipid peroxidation in membranes. In a liposome model, chicozapote juice demonstrated antioxidant properties, perhaps inhibiting free-radical lipid peroxidation. Among flavonoids, catechins and flavones provided the most effective protection against reactive oxygen species [57].

6.2 Anti-inflammatory Effects

Sapodilla contains phenolic acids and flavonoids that provide anti-inflammatory effects. These bioactive compounds facilitate the alleviation of inflammation in the body, potentially mitigating symptoms related to inflammatory conditions such as asthma, inflammatory bowel disease, and arthritis [9].

Tumour necrosis factor α is synthesised in response to chronic inflammation and binds to its receptor cyclically to prolong inflammation[58].Chicozapote leaf extract has time-dependent anti-inflammatory action, according to Ganguly et al., outperforming diclofenac sodium with 92.75% inhibition at 6 hours. It works by preventing the formation of prostaglandins and the enzymes that cause inflammation in the cyclooxygenase pathway[59].

According to Konuku et al. the extract of chicozapote leaves has anti-inflammatory properties since it inhibits enzymes such as COX-2, 5-LOX, and PLA-2. QE was effective against 5-LOX (IC50 = 4.851 µg/ml), which suggests that QE is responsible for this action. This substance decreases the synthesis of pro-inflammatory cytokines, COX-2, and iNOS, and controls the expression of TLR4. It also inhibits the translocation of NF-κB[60].*Manilkara zapota* bark extract have antihistamine effect. This activity is probably attributed to the high flavonoid concentration of the extract, specifically QE, which inhibits inflammatory mediators. The function of polymorphonuclear leukocytes may be hampered by GA, another prominent component in chicozapote [61].

A separate study indicated that *manilkara zapota* fruit extract significantly reduced nitric oxide production in murine macrophage cells (IC50 = 7.65 ± 0.12 µg/ml). Chicozapote exhibits AG's anti-inflammatory characteristics, which inhibit PG synthesis, suggesting a mechanism that obstructs PGE2 production [62]. Additionally, the catechins in chicozapote have been shown to improve cholinergic dysfunction by modulating acetylcholine (ACh) and acetylcholinesterase (AChE) in hippocampus tissues. Acetylcholine reduces the synthesis of pro-inflammatory cytokines and suppresses the expression of NF-κB [58].

6.3 Antimicrobial and Antiviral Activities

Sapodilla contains saponins and terpenoids, which have antimicrobial and antiviral properties. These compounds can help inhibit the growth of bacteria, fungi, and viruses, making sapodilla beneficial for boosting the immune system and combating infections.

Because of the structure of their cell walls, phytochemicals frequently have greater efficiency against Gram-positive bacteria[76]. Broad-spectrum antibacterial and antifungal activities of chicozapote have been demonstrated. The ethyl acetate extract from the bark and leaves of chicozapote was discovered by Osman et al.to have moderate to strong action against pathogens such as Bacillus and Candida species, inhibiting a variety of bacteria and fungus. Additionally, seeds shown efficacy. Against Micrococcus luteus, the acetone seed extract displayed a maximal inhibition zone [77].

Chicozapote substances have distinct methods of action against germs, such as myricetin and QE. They break down cell membranes, stop ATPase from working, and interfere with resistance systems such efflux pumps. As putative efflux pump inhibitors, myricetin, QE, and kaempferol increase the action of antibiotics. Chicozapote extracts and antibiotics such as isoniazid and tetracycline combined demonstrated synergistic benefits against microorganisms resistant to multiple drugs [78].

Synergistic interactions between chicozapote and other plants like Cassia fistula enhanced antimicrobial activity[79]. Additionally, nanoparticles (NPs) synthesized from chicozapote extracts, such as Cu and silver NPs, exhibited antibacterial and antifungal properties[4,22]. Other applications include acaricidal and feeding deterrent activities against pests like Musca domestica and lethal effects on parasites like Strongyloidesvenezuelensis using chlorogenic acid [9].

Numerous phytochemicals present in chikko, such as polyphenols, tannins, and flavonoids, are acknowledged for their antiviral properties. These chemicals disrupt various phases of the viral life cycle, hence inhibiting viral propagation. In vitro, chikko extracts shown significant inhibitory activity against herpes simplex virus types 1 (HSV-1) and 2 (HSV-2). The flavonoid and tannin content of chikko extract was associated with its antiviral activities. A separate study investigated the antiviral efficacy of chikko against the dengue virus. Findings indicate that chikko leaf extracts may inhibit the replication of the dengue virus, potentially due to the presence of bioactive compounds such as alkaloids and flavonoids.

6.4 Cholesterol-lowering Potential and antidiabetic activities

Saponins discovered in sapodilla seeds exhibit properties that can lower cholesterol levels. Regularly consuming sapodilla may assist in sustaining healthy cholesterol levels, thereby diminishing the risk of heart diseases[45].

Research has explored the potential health advantages of chikko, including its antilipidemic and antidiabetic properties. Rats administered these extracts showed cholesterol levels comparable to those treated with atorvastatin, a cholesterol-lowering drug[27]. Furthermore, studies have shown that chicozapote leaf and pulp juice can enhance the metabolic profile in rats, leading to reductions in glycemic index, insulin levels, total cholesterol, and triglyceride levels.Chikko polyphenols, including epicatechin, GA, and catechin, have been shown to inhibit pancreatic cholesterol esterases and decrease the absorption of cholesterol by altering the solubility of cholesterol in the intestinal lumen[57].

Ethanolic leaf extracts of chicozapote have shown significant inhibitory activity against α-glucosidase, an enzyme that hydrolyses carbohydrates into glucose, leading to increased blood glucose levels. The fruit extract also exhibited α-glucosidase inhibition, although less potent than the leaf extract. Phytochemicals like proanthocyanidins, caffeic acid, chlorogenic acid, ferulic acid, epicatechin, and myricetin present in chicozapote contribute to its antidiabetic properties[12,92].

Additionally, vitamins found in chicozapote, such as thiamine and riboflavin, associated with preventing hyperglycaemia, reducing oxidative stress, minimizing vascular damage, and decreasing leptin and insulin levels. In summary, chicozapote exhibits potential antilipidemic and antidiabetic effects through its phytochemical and vitamin content. To confirm these results and comprehend the underlying mechanisms underlying these health benefits, more research is required[32].

6.5 Gastroprotective activity

The gastroprotective properties of sapodilla are believed to originate from many bioactive components present in the plant extract. These comprise tannins, flavonoids, saponins, alkaloids, and phenolic chemicals. Tannins, recognised for their astringent characteristics, may provide a protective barrier on the gastrointestinal mucosa, hence diminishing the likelihood of ulcer development and potentially mitigating diarrhoea [24]. Flavonoids, with their antioxidant and anti-

inflammatory characteristics, protect the gastric mucosa against oxidative stress and inflammation. Saponins, due to their varied biological properties, may augment gastric mucus formation and mucosal blood flow, hence enhancing mucosal integrity and suppressing stomach acid release. Alkaloids, a distinct category of chemicals, may regulate gastric acid secretion and facilitate mucosal repair [6]. Phenolic substances, such as phenolic acids and lignans, provide gastroprotection by neutralising free radicals and reducing inflammation in the gastrointestinal mucosa. The bioactive components in sapodilla are essential for its gastroprotective benefits; nevertheless, additional study is required to comprehensively elucidate their mechanisms of action and therapeutic potential in treating stomach ulcers and associated gastrointestinal disorders [51,91]. The dietary fibre in sapodilla promotes digestive health by ensuring regular bowel movements and mitigating constipation. Chicozapote extracts have antidiarrheal, antiulcer, and antisecretory effects via several pathways [21]. The antidiarrheal properties of the leaf are ascribed to the inhibition of PG production, whilst the fruit mitigates induced diarrhoea by promoting relaxation and decreasing fluid secretion, potentially via the blockade of PDE enzymes and Ca2+ channels [9]. Phytochemicals such as flavonoids, alkaloids, polyphenols, and saponins in chicozapote influence gut microbiota and metabolites. Research involving chloroform and aqueous chicozapote extracts in mice demonstrated efficacy in preventing diarrhoea and minimising ulceration, corroborated by proteome analysis. Furthermore, the bark extract exhibited antidiarrheal characteristics by reducing faecal production and enhancing intestinal transit [8].

The antiulcer potential of Chicozapote may derive from its ability to inhibit Ca2+ channels, its antioxidant properties, and its capacity to scavenge free radicals, thereby diminishing oxidative stress in the gastrointestinal tract [42]. Furthermore, it demonstrates anti-inflammatory properties by reducing levels of TNF-α, p-NFκB, and COX-2. Catechins in chicozapote modulate gut microbial balance, functioning as prebiotics to enhance beneficial bacteria proliferation and inhibit pathogenic strains [16]. Furthermore, chicozapote extracts are efficacious in addressing gastrointestinal illnesses such as gastritis, constipation, and ulcerative colitis, demonstrating significant antioxidant properties and normalising oxidative parameters [21].

6.6 Anti-Arthritic Potential

Extracts from sapodilla plants have shown promise as anti-arthritic pharmaceuticals. Ethanolic extracts significantly reduced protein denaturation in an in vitro model that mimicked rheumatoid arthritis. The extracts demonstrated their anti-arthritic potential by reducing protein denaturation to 58.89% and 75.84%, respectively, at doses of 100 and 250 µg/ml.Additionally, studies have shown that chikko extracts have anti-arthritic properties against RA. At a dosage of 250 µg/ml, the ethanolic leaf extract showed a 75.84% suppression of protein denaturation[73].

Furthermore, some researchers investigated the anti-arthritic characteristics of gold- and extract-based nanoparticles (NPs). In experimental model, the extract significantly prevented paw edoema and, at 400 mg/kg, decreased it by 61.19%. It's interesting to note that gold NPs inhibited sub-acute arthritis by 83.34%, showing even more effective effects than the aqueous extract. Alkaline phosphatase, aspartate transferase, and alanine transaminaseactivities were also found to be reduced, suggesting a possible alteration of physiologically active chemical mediators[74].

6.7 Anti-Aging Properties

Skin ageing is caused by a combination of inherent and extrinsic causes, with ultraviolet exposure and the passage of time being the main culprits. Key skin proteins like collagen and elastin

maintain skin structure, but their depletion due to factors like collagenase and elastase can lead to wrinkles and aging signs [80].

Chaianuchittrakul et al.,numerousdemonstrated that ethanolic extracts of chikko pulp can impede crucial enzymes linked to skin aging. At a concentration of 140 µg/ml, they exhibited collagenase inhibition rates of 66.42% and 64.66%, respectively, albeit less potent compared to the standard EGCG at 20 µg/mL, which achieved 98.43% inhibition. Conversely, only the 95% extract significantly inhibited elastase, demonstrating a 47.74% inhibition at 80 µg/ml, surpassing the standard's 45.51% inhibition[81]. Similarly,Pientaweeratch et al. further characterized the 100% ethanolic pulp extract, finding dose-dependent antioxidant activity with IC50 values of 37.65 ± 1.18 µg/ml in DPPH and 73.14 ± 2.84 µg/ml in ABTS assays. Collagenase and elastase inhibition were also dose-dependent, though less potent than the EGCG standard. The chicozapote extract showed effective elastase inhibition ($IC50 = 35.73 \pm 0.61$ µg/ml), potentially due to flavonoids like QE, myricetin, epicatechin, and catechin[80].

Chunhakant and Chaicharoenpong identified anti-tyrosinase components in chicozapote bark extracts as a treatment for hyperpigmentation, a consequence of photoaging. The ethyl acetate extract had the most significant anti-tyrosinase activity ($IC50 = 191.69 \pm 6.05$ µg/ml), indicating its promise as an anti-aging and skin cancer prophylactic medication. A further investigation into different chicozapote structures determined that the methanolic bark extract exhibited the highest efficacy against tyrosinase, which correlated with the presence of (+)-dihydrokaempferol [33].

Lastly, Kashif and Akhtar developed a chicozapote fruit extract-based emulgel sunscreen with promising UV A and UV B radiation quenching effects. Notably, chicozapote leaves demonstrated superior elastase inhibitory activity compared to the fruits[63].

6.8 Analgesic and Antinociceptive Effects

Pain arises from various conditions, including tissue damage and inflammation. Chicozapote extracts have shown analgesic properties in studies. Research investigated leaf extracts for a non-inflammatory pain model. At a dosage of 200 mg/kg, both extracts demonstrated significant analgesic effects, increasing reaction time and reducing acetic acid-induced pain response by 94.27% and 96.82%[9].

Leaf extracts including ethanol, PE, and EA were evaluated by study [48]. At 400 mg/kg doses, there were notable reductions in abdominal contractions; the extracts showed 59.89% and 58.24% inhibition, respectively. Thirty minutes after injection, the radiant heat tail-flick method showed enhanced reaction times of 88.22% and 52.05%, individually, with central antinociceptive effects lasting for ninety minutes evaluated leaf extracts of ethanol, petroleum ether, and ethyl acetate. At 400 mg/kg doses, there were notable reductions in abdominal contractions; the ethanolic and petroleum ether extracts showed 59.89% and 58.24% inhibition, respectively. Thirty minutes after injection, the radiant heat tail-flick method showed enhanced reaction times of 88.22% and 52.05%, respectively, with central antinociceptive effects lasting for ninety minutes.The analgesic mechanisms may involve non-selective COX inhibition, nociceptor activity, and opioid µ-receptor binding in the CNS. Other opioid receptors like k and δ may also contribute to chicozapote's pain-relieving effects [75].

6.9 Antineoplastic Properties:

Certain studies indicate that the phytochemicals in sapodilla, including flavonoids and phenolic acids, may possess anticancer qualities by impeding the proliferation and dissemination of cancer cells. Nevertheless, further investigation is required to validate these prospective advantages.

Plant extracts from chicozapote have been demonstrated to be harmless for regular cells but to exhibit potential cytotoxic effects on a variety of cancer cell lines. At doses >416.22 µM, the (+)-dihydrokaempferol in the bark extract did not cause any harm to human lung fibroblast WI-38 [1]. According to certain research, Vero and BALB/c 3T3 cells were not harmed by methanolic leaf extracts or by ethyl acetate seed coat [11].Extracts from *Manilkara zapota* also showed cytotoxicity in a range of cancer cell lines. Methyl-4-O-galloylchrologenate *manilkara zapota* extract was cytotoxic to HCT-116 and SW-480 colon cancer cells, and it impacted mouse myoblasts C2C12 cells[55]. Aq. leaf extracts were shown to have cytotoxic effects on a range of cancer cells, triggering CD- pathways and apoptosis [49]. Additionally, Ehrlich ascites carcinoma (EAC) cell proliferation was inhibited by a fruit preparation containing ethyl acetate. Moreover, the aq. leaf extracts demonstrated selective cytotoxicity against HepG2 cells, resulting in apoptosis and cell cycle arrest [55].HeLa cells were particularly susceptible to the effects of leaf extracts [52]. Certain compounds found in chicozapote bark, such as spinasterol and (+)-dihydrokaempferol, were shown to be cytotoxic to several types of cancer cell lines[33].

These compounds also showed potential anti-tyrosinase activity, suggesting skin cancer preventive properties.Synthesized Cu NPs from chikkoextracts demonstrated anticancer activity for breast cancer MCF7 cells (70). The IC50 value was 53.89 µg/ml, while its toxicity to normal Vero cells was much lower at 883.69 µg/ml, suggesting selectivity towards cancer cells[35]. The method includes kinase inhibition and the triggering of apoptosis through the translocation of Bax. Although sapodilla provides several health advantages and therapeutic potential, it is crucial to consume it as part of a balanced diet and in moderation. Individual responses to any food or supplement may differ, and it is prudent to seek personalised medical advice from a healthcare professional, particularly if you have underlying health concerns or are on medication[36].

7. Recent studies investigating the therapeutic potential

Manilkara zapota, a plant valued for its adaptability, exhibits a variety of biological activity in each of its many structures. They include cytotoxic, antibacterial, anti-inflammatory, gastroprotective, anti-arthritic, analgesic, and antinociceptive properties. It also demonstrates anti-hypercholesterolemic, hepatoprotective, anti-aging, neuro-depressant, and anti-HIV characteristics, indicating its importance in pharmaceutical and medical research as well as its potential in a variety of therapeutic applications (Table 1).

Table 1: Biological activities and applications of different *Manilkara zapota* extracts

S. no.	Plant Part	Extraction Method	Solvent	Pharmacological Investigation	Key Findings and Results	References
1	Bark	Soxhlet Extraction	Ethanol	Cytotoxicity	(+)-dihydrokaempferol showed potent cytotoxicity against multiple carcinoma cell lines	[49]

		Soxhlet Extraction	Methanol	Anti-tyrosinase Activity	Compounds isolated exhibited anti-tyrosinase activity	[32]
		Maceration	Hexane	Analgesic Activity	Reduced reaction time in hot-plate method	[54]
		Soxhlet Extraction	Ethyl Acetate	Antioxidant Activity	High ORAC value indicating strong antioxidant capacity	[12]
		Cold Maceration	Water	Anti-inflammatory	Reduced inflammatory cytokine levels	[76]
		Cold Maceration	Ethanol	Analgesic Activity	Effective in reducing pain in neuropathic models	[65]
2	Seed	Maceration	Ethyl Acetate	Cytotoxicity	Non-toxic to Vero cells at 50 µg/ml concentration	[32]
		Cold Maceration	Water	Anti-inflammatory	Significant reduction in inflammatory markers	[41]
		Maceration	Methanol	Cytotoxicity	Inhibition of cell growth in breast cancer cell lines	[53]
		Soxhlet Extraction	Methanol	Antioxidant Activity	High DPPH scavenging activity	[44]
3	Leaf	Cold Maceration	Methanol	Analgesic Activity	Significant analgesic effects were observed using hot-plate and pain response methods	[67]
		Soxhlet Extraction	Ethanol	Cytotoxicity	Moderate to high cytotoxic effect on C2C12 cells	[52]
		Soxhlet Extraction	Chloroform	Antioxidant Activity	Supraspinal pathway activation in hot-plate test	[80]
		Cold Maceration	Water	Anti-inflammatory	Significant reduction in COX-2 levels	[71]
		Soxhlet Extraction	Hexane	Anti-tyrosinase Activity	Effective inhibition of tyrosinase enzyme	[57]
		Maceration	Ethyl Acetate	Cytotoxicity	Selective cytotoxicity against specific cancer cell lines	[36]
4	Fruit	Soxhlet Extraction	Ethanol	Antioxidant Activity	Methyl-4-O-galloylchrologenate	[32]

					identified as a potent antioxidant	
		Maceration	Ethyl Acetate	Antiproliferative Activity	Synthesized Cu NPs showed anticancer activity against MCF7 cells	[62]
		Maceration	Ethanol	Analgesic Activity	Effective pain relief in animal models	[78]
		Soxhlet Extraction	Chloroform	Anti-tyrosinase Activity	Effective inhibition of melanin production	[27]

8. Optimal Extraction Parameters

Optimising extraction parameters is crucial for attaining the desired bioactive compound profile and enhancing the extract's potential health benefits. Several factors affect the extraction process, including solvent selection, extraction method, temperature, duration, pH, particle size of the raw material, and solid-liquid ratio (SLR) [5]. Extraction techniques including maceration, Soxhlet extraction, ultrasound-assisted extraction (UAE), and supercritical fluid extraction (SFE) can be utilised to enhance the extraction process. Every approach possesses distinct advantages and disadvantages regarding extraction efficiency, duration, and energy usage [2].Solvent selection is a critical consideration, as different solvents have varying polarities and extraction efficiencies for different compounds. Commonly used solvents for chikko extraction include water, ethanol, methanol, and their mixtures. The choice of solvent depends on the polarity of the target compounds and the desired extract properties. Parameters such as temperature, extraction time, pH, particle size of the raw material, and SLR also significantly impact the extraction efficiency of chikko extract. Higher temperatures generally increase the solubility of compounds but may also lead to thermal degradation. Similarly, longer extraction times may enhance yield but could also result in the extraction of undesirable compounds or degradation of heat-sensitive components[9].

The phrase "green" or alternative approach denotes a range of procedures, some of which have been applied to chicozapote extraction models. The methods examined include supercritical fluid extraction, high hydrostatic pressure, ultrasound-assisted extraction, and microwave-assisted extraction. A study by Ma et al. [73] investigated various extraction techniques to optimise the total flavonoid and total phenolic content of *Manilkara zapota* leaves. A separate study examined the potential for improved chemical isolation via extract fractionation. Fresh chicozapote pulp was extracted twice with methanol at ambient temperature and subsequently subjected to chromatographic partitioning. The resultant fractions produced various compounds, such as gallocatechin, gallic acid, catechin, epicatechin, methyl 4-O-galloylchlorogenate, galloyl chlorogenic acid, myricitrin, quercitrin, and methyl chlorogenate [45]. A separate study explored the potential for enhanced chemical isolation through extract fractionation. Methanol was utilised twice to extract fresh chicozapote pulp at ambient temperature, after which the pulp was isolated by chromatography. A variety of compounds, including gallocatechin, gallic acid, catechin, epicatechin, methyl 4-O-galloyl chlorogenate, galloyl chlorogenic acid, myricitrin, quercitrin, and methyl chlorogenate, were isolated from the resulting fractions [71].

9. Conservation Status and Sustainable Harvesting

Conservation of chikko (*Manilkara zapota*), commonly known as sapodilla, is becoming increasingly important due to its rising demand and the potential threats to its natural habitats. While the IUCN has not yet evaluated the conservation status of chikko, it is at risk due to habitat destruction caused by deforestation for agriculture, urbanization, and logging. Climate change further exacerbates these threats by altering the natural habitats of the chikko tree, affecting its growth and reproductive patterns.To ensure the sustainable harvesting of chikko, several measures need to be implemented[52, 83]. Selective harvesting, where only mature fruits are harvested, allows younger fruits to ripen and ensures the tree's reproductive cycle remains intact. Regulations on the quantity and frequency of harvesting can prevent overexploitation of chikko trees. Replanting chikko trees in deforested areas and involving local communities in sustainable harvesting practices are also crucial steps. Additionally, educating farmers and communities about the importance of sustainable practices and conservation can lead to better conservation efforts[37]. Continuous research and monitoring of chikko populations are essential to understand its ecological requirements and develop effective conservation strategies[40].

Chikko flourishes on well-drained sandy loam to clayey loam soils with a pH range of 6.0 to 8.0. The tree loves soil conditions that are slightly acidic to neutral. Proper water drainage is crucial to avert root rot, and consistent irrigation is necessary throughout the dry season to ensure optimal growth [9]. Chikko trees thrive in full sun exposure for a portion of the day and are susceptible to frost and low temperatures, rendering them most appropriate for tropical and subtropical climates. In summary, the adoption of sustainable harvesting practices, engagement with local communities, research initiatives, and comprehension of specific cultivation needs are essential for the conservation of chikko and its long-term viability [17].

10. Threats to *Manilkara zapota* due to deforestation and overharvesting

Manilkara zapota faces significant threats primarily due to deforestation and overharvesting. Deforestation, driven by agricultural expansion, urbanization, and logging, has led to the loss and fragmentation of the natural habitats where chikko trees thrive. This destruction not only diminishes the available habitat for the trees but also disrupts the intricate ecological balance that supports their growth and reproduction. Overharvesting poses another critical threat to the chikko population[9]. The increasing demand for chikko fruits has led to unsustainable harvesting practices, where trees are harvested beyond their capacity to regenerate. Harvesting immature fruits and not allowing trees enough time to recover can severely impact their reproductive health and overall growth. Such practices can lead to a decline in the chikko population, reducing its genetic diversity and making it more susceptible to diseases and pest[70].

These threats are further exacerbated by climate change, which alters the natural habitats of chikko trees, affecting their growth, flowering, and fruiting patterns. Changes in temperature, rainfall patterns, and extreme weather events can stress the trees and make them more vulnerable to diseases, pests, and other environmental stresses[67]. To mitigate these threats, it is crucial to implement sustainable forestry and agricultural practices. Selective harvesting, where only mature fruits are harvested, and regulations on the quantity and frequency of harvesting can prevent overexploitation of chikko trees[63]. Replanting chikko trees in deforested areas, involving local communities in conservation efforts, and raising awareness about the importance of sustainable

practices are essential steps to ensure the long-term survival of *Manilkara zapota*[56]. Additionally, conducting research and monitoring chikko populations to understand their ecological requirements and develop effective conservation strategies are vital for conserving this valuable tree species[81].

11. Prospects for Future Research and potential applications

Manilkara zapota, often known as chikko, has a rich phytochemical profile and interesting prospective uses in medicine, therefore future research routes seem promising[1]. Researchers are increasingly focusing on understanding the bioactive compounds present in chikko extracts and their pharmacological properties, aiming to develop innovative therapeutic agents for various ailments. One significant area of interest is the exploration of *Manilkara zapota*, often known as chikko, has a rich phytochemical profile and interesting prospective uses in medicine, therefore future research routes seem promising[9].

cytotoxic effects on different carcinoma cell lines. Studies have identified several compounds, such as (+)-dihydrokaempferol and methyl-4-O-galloylchrologenate, which exhibit potent cytotoxic activity against various cancer cell lines, including colon, liver, and breast cancers. Future research could delve deeper into the mechanisms underlying these cytotoxic effects and explore their potential in developing novel anticancer drugs[51].

Another promising area is the investigation of chikko's anti-inflammatory, antioxidant, and analgesic properties. Preliminary studies have indicated that chikko extracts possess significant anti-inflammatory and antioxidant activities, which could be beneficial in treating inflammatory conditions, oxidative stress-related diseases, and pain management. Future research could focus on isolating and characterizing the active compounds responsible for these activities and evaluating their efficacy and safety in clinical trials[72]. Moreover, chikko's potential as an anti-diabetic and anti-obesity agent has garnered interest among researchers. Studies have shown that chikko extracts can inhibit α-glucosidase and pancreatic cholesterol esterases, regulate glucose and lipid metabolism, and suppress adipogenesis[65]. Future research could explore the molecular mechanisms underlying these effects and assess the efficacy of chikko extracts in managing diabetes and obesity-related complications.Additionally, the skin-protective and anti-aging properties of chikko extracts have opened avenues for its application in cosmeceuticals. Research could focus on developing chikkobased formulations for skincare products, exploring its potential in preventing UV-induced skin damage, reducing hyperpigmentation, and promoting skin health and rejuvenation[66].In conclusion, the multifaceted pharmacological properties of *Manilkara zapota* offer promising avenues for future research and potential applications in the pharmaceutical, cosmeceutical, and nutraceutical industries[22]. Collaborative efforts among researchers, industry stakeholders, and policymakers are essential to harness the full therapeutic potential of chikko and translate research findings into innovative and sustainable healthcare solutions[9].

12. Conclusion

Manilkara zapota, widely referred to as chicozapote, has surpassed its conventional function as a dietary fruit. Chicozapote, celebrated for its unusual flavour and unique attributes, has achieved global recognition, resulting in extensive distribution and consumption over the years. Nevertheless, its significant perishability presents obstacles for commercialisation and the creation

of value-added products. To mitigate this constraint, chicozapote is frequently transformed into jams, syrups, ice creams, and fruit bars as techniques of preservation. In addition to its nutritional benefits, chicozapote is abundant in phytochemicals that provide the fruit with a variety of health-enhancing substances with extensive bioactivity. The phytochemical composition of chicozapote establishes it as a significant raw material for developing functional foods and products aimed at improving health and well-being.

The extraction method is crucial for maintaining the phytochemicals and their bioactivity. Consequently, it is imperative to utilise suitable extraction techniques to optimise the preservation of these advantageous chemicals. Studies have shown that chicozapote extracts possess numerous pharmacological properties, including antioxidant, anti-inflammatory, cytotoxic, antidiabetic, antimicrobial, analgesic, anti-aging, gastroprotective, hepatoprotective, anti-arthritic, neuro-depressant, and anti-HIV effects. The adaptability and low toxicity of chicozapote render it a good option for phytotherapeutics, providing numerous medicinal applications. Notwithstanding the encouraging initial results, further investigation is required to clarify the precise mechanisms of action that underpin these pharmacological effects and to fully exploit the medicinal potential of chicozapote. *Manilkara zapota* offers promising prospects for the advancement of novel and sustainable healthcare solutions via the creation of functional meals and goods enhanced with its bioactive ingredients. Cooperative initiatives among academics, industry participants, and policymakers are crucial to enhance our comprehension of chicozapote and convert these study outcomes into concrete health advantages for consumers.

Conflict of Interest: - No

Reference

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