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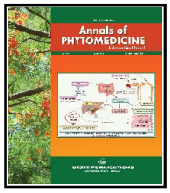

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Fruits that heal: A comprehensive review on bioactive compounds and therapeutic properties of fruits and their implications on human health

B. Somraj*, B. Kalpana*, J. Karunakar*, P. Saidaiah◆, B. Srinu* and A. Geetha*****

** Department of Horticulture, School of Agriculture, SR University, Warangal-506 371, Telangana State, India*

*** Department of Genetics and Plant Breeding, College of Horticulture, Sri Konda Laxman Telangana State Horticultural University, Mojerla-509 387, Wanaparthy Dist., Telangana State, India*

**** Department of Crop Physiology, College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad-500 030, Telangana State, India*

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Abstract

Fruits along with vegetables are known as protective foods as they are rich source of vitamins, minerals, dietary fibre and antioxidants. They are known to prevent health problems like obesity, diabetes, cardiovascular diseases and cancer. India is home for many indigenous fruit varieties whose growth is limited to particular region. These fruit crops have high nutritional and medicinal properties but commercial cultivation is lacking. In recent times, more emphasis is being given to the exotic fruits for their high nutritional value but most of the under-exploited fruit crops in India are rich in nutritional and medicinal value and they act as main source of many ayurvedic formulations. These fruits are abundantly grown by the local due to lack of scientific knowledge regarding their therapeutic value and may be due to difference in palate preference, as commercial cultivation of fruits is mainly focused on national and international demand. These fruits are rich in nutrient elements, vitamins and minerals and bioactive compounds, have nutraceutical value with therapeutic and antioxidant properties which improves human immune system. They are known to have great potential to cure several deficiency disorders and chronic diseases. Found in various fruits, flavonoids have antioxidant, anti-inflammatory, and cardiovascular benefits. Fruits contain phytochemicals such as stilbenes, tannins, coumarin, and saponins, which contribute to their therapeutic potential. Fruits are rich in antioxidants, which help to protect cells from oxidative damage and reduce the risk of chronic diseases. Certain fruits, like berries, cherries, and citrus fruits, have anti-inflammatory properties that may benefit conditions like arthritis and cardiovascular diseases. Some fruits, such as grapes (resveratrol) and citrus fruits (limonoids), have compounds with potential anticancer effects. Fruits with soluble fiber (*e.g.*, apples, pears) can help regulate blood sugar levels and improve gut health. Consuming fruits rich in potassium (*e.g.*, bananas, oranges) supports heart health.

1. Introduction

Indian sub-continent has a varied climate distribution and vast heritage of biodiversity of several temperate, tropical and subtropical underutilized and underexploited fruit crops. In India, major fruit crops, such as mango, banana, citrus, guava and apple, account for more than 72% of the total area under fruit crops, while indigenous (native) fruit crops contribute only 6.56% of the area (0.437 mha) with quite high productivity (11.47 tons/ha) (NHB, 2022). Some of the fruit crops are khirni (*Manilkara hexandra*), aonla (*Emblica officinalis*), bael (*Aegle marmelos*), chironji (*Buchanania lanzan),* jamun (*Syzygium cuminii*), pilu (*Salvadora oleoides*), kokum (*Garcinia indica*), ker (*Capparis decidua*), karonda (*Carissa carandas*), phalsa (*Grewia subinaequalis*), wood apple (*Feronia limonia*), tamaind (*Tamarindus indica*), ber (*Ziziphus mauritiana*), monkey jack *(Artocrapus lakoocha*), lasoda (*Cordia dichotoma*), ramphal (*Annona reticulata*), soursop (*Annona muricata*), fig (*Ficus carica*), loquat (*Eriobotrya japonica*), chalta (*Dillenia inclica*), manila tamarind (*Pithecellobium dulce*), timru (*Diospyrus melenoxylon*), tadi (*Phoenix sylvestris*), mahua (*Madhuca indica*), palmyra palm (*Borassus flabellifer),* bilimbi (*Averrhoa bilimbi*), star gooseberry*(* *Phyllanthus acidus*), governor's plum (*Flacortia indica*), durian *(Durio zibethinus*), wax apple (*Syzygium samarangense*), carambola (*Averrhoa Carambola*), egg fruit (*Pouteria campechiana*), bread fruit(*Artocarpus altilis*) and pulasan (*Nephelium mutabile*).

There is old saying that "prevention is better than cure" which still holds strong meaning in this modern era because nowaday's health sector is focusing more on steps towards prevention of diseases like obesity, diabetes, hypertension, cardio vascular diseases, neurodegenerative disorders and even cancer. Good diet comprising of fruits, vegetables, cereals, millets, pulses and probiotics *etc*., is crucial for sound health, rejuvenation and longevity of life. COVID -19 pandemic was an eye opener which increased awareness of the correlation between good diet and health with today's sedentary stressful life style, and ever-increasing health care costs encouraging making healthy eating choices.

India being a country of one of the greatest, oldest civilization and heritage existing in this world, blessed with wide range of biodiversity

Corresponding author: Dr. Pidigam Saidaiah

Associate Professor, Department of Genetics and Plant Breeding, College of Horticulture, Sri Konda Laxman Telangana State Horticultural University, Mojerla-509382, Telangana, India.

E-mail: saidu_genetics@yahoo.co.in

Tel.: +91-7780509322

and different climatic ones distributed throughout the country but still being counted as one of the countries with increasing hunger index is to be taken seriously. In the current Global Hunger Index (GHI) India landed at 111 places out of 125 countries. Malnutrition is a major problem affecting total of 159 million children under the age of five making them stunted in growth (Ashok *et al.,* 2020). Climate change interms of increased temperatures, floods, droughts and new pest and disease incidence in are posing great threat to sustainable production of major commercial fruits. Being indigenous these minor fruits show wide range of adaptability to various environmental conditions (Berwal, 2021). After the COVID-19 pandemic, a major shift has taken place in awareness regarding many health related aspects. Malnutrition, obesity, diabetes, cardiovascular diseases and cancer cases are alarmingly increasing irrespective of age group. Underutilized crops have important nutritional and functional values, presenting sustainable sources of proteins, carbohydrates, essential fatty acids, vitamins, minerals, phytochemicals, and dietary fibre. Antioxidant, anti-inflammatory, and anticarcinogenic properties additionally add to the importance of these crops.

Bioactive compounds in fruits are secondary metabolites that offer numerous health benefits by interacting with various physiological systems in the human body. These compounds include vitamins, minerals, phenolics, flavonoids, carotenoids, antioxidants, and fiber, which contribute to the prevention and management of chronic diseases such as diabetes, cardiac ailments, and cancer (Jatinder Bir Singh, 2023). Fruits like apples and pears are rich in polyphenols, which are powerful antioxidants that improve blood circulation and protect skin tissues. Citrus fruits, in particular, contain phenols, flavonoids, and carotenoids that exhibit anti-inflammatory, anti-cancer, and oxidative stress-reducing properties by modulating signaling pathways and interacting with molecules like P53 and P21(Tongling Shan 2022). Additionally, fruits such as date, jabuticaba, grape, and olive have shown significant antioxidant and antimicrobial activities, which can inhibit microbial growth and slow oxidative reactions in foods. The underutilized Brazilian fruit *Eugenia punicifolia* is noted for its high content of carotenoids and ascorbic acid, making it a potent source of bioactive compounds. Moreover, bioactive compounds in fruits are essential in delaying aging and improving the quality of life by reducing oxidative stress and preventing age-related disorders. The incorporation of these compounds in postharvest technologies can extend the shelf life of fruits and vegetables, preventing spoilage and enhancing nutritional content. Studies have also shown that dried fruits, such as apricots, apple rings, cranberries, and prunes, are rich in polyphenols and carotenoids, although the concentration of these compounds can vary significantly between organic and conventional products. Overall, the diverse bioactive compounds in fruits play a crucial role in promoting health and preventing various diseases, highlighting the importance of their inclusion in the diet.

2. Nutritional value of fruits

2.1 Carbohydrates

They are major food group which provides energy required for the body for physical activity, optimal organ function and brain function. It includes fibre, starches and sugar. Fruits like passion fruit, rambutan, mangosteen, *etc*., are great source of carbohydrates (Gopalan *et al.,* 2004, Pareek *et al*., 1998). Dietary fibre essential for good gut health is nothing but undigested complex carbohydrates. It acts as a laxative as undigested complex carbohydrates absorb water and become bulky and helps in regulating bowel movements and protects colon mucous membrane from cancer causing chemicals. Fruits like lasoda, jamun are rich source of dietary fibre (Table 1).

Table 1: Carbohydrate content of some fruits

Fruit	Carbohydrates (g/100 g edible part)
Bael (*Aegle marmelos*) pulp	28.1-31.0
Ker (*Capparis decidua*) ripe	71.0
Jherberi (*Ziziphus nummularia*)	93.0
Tamarind (*Tamarindus indica*)	67.4
Mahua (*Madhu caindia*)	22.7
Durian (*Durio zebithinus*)	28.3-34.1

Table 2: Protein content content of some fruits

Fruit	Protein (g/100 g edible part)
Wood apple (*Ferronia limmonia*) pulp	7.1-8.0
Brazil nut (*Bertholletia excelsa*)	14.3-14.4
Chronji (*Buchanania lanzan*) seed	21.6
Pilinut (*Canarium ovatum*)	19.6
Ker (*Capparis decidua*)	8.0

2.2 Proteins

Proteins are essential macronutrients which are essential for catalyzing metabolic reactions, providing structure to cells, DNA replication; they are the building material for our skin, bones, muscles and other tissues in the body. Certain fruits are rich in proteins (Table 2).

2.3 Fats

They are made up offatty acids and glycerol molecules. They are vital for proper brain function, cell membrane structure and overall growth and development. Fat content of certain fruits is furnished in Table 3.

Table 3: Fat content of some fruit crops

Fruit	Fat (g/100 g edible part)
Mahua (*Madhuca indica*) seeds	51.1
Pilu (*Salvadora oleoides*) seeds	40-50
Kokum (*Garcinia indica*) seeds	23-26
Shia butter tree (*Butyrospermum parkii*)	52.6

2.4 Vitamins

Vitamins are organic substances that are generally fat or water soluble. They are needed for normal cell function, growth and development.

2.4.1 Vitamin A

It is also known as retinol gives natural immunity to our body to fight against illness and infection, it is essential for healthy vision, healthy skin and mucus lining of bodyparts like nose. Its deficiency causes night blindness. Fruits like egg fruit and cape gooseberry are rich source of vitamin A (Table 4).

2.4.2 Vitamin C

Also known as ascorbic acid is a powerful antioxidant helps to fight against oxidative stress. It is essential for maintaining healthy skin, blood vessels, bones and cartilage. It helps in wound healing and repairing all the body parts. It is essential for collagen formation which is a main structural protein in human body required for maintaining healthy blood vessels, bones and organs. Deficiency of vitamin C causes scurvy. Fruits like barbados cherry and camu-camu are rich sources of vit. C (Table 5).

Table 4: Vitamin A content of some fruits

Fruit	Vitamin A (IU /100 g edible part)
Ker (*Capparis decidua*) ripe	3500 IU
Barbados gooseberry (*Pereskia aculeata*)	3215 IU
Eggfruit (*Pouteria campechiana*)	533-2000 IU
Cape gooseberry (*Physalis peruviana*)	1000-5000 IU
Khirani (*Manilkara hexandra*)	495 µg

Table 5: Vitamin C content of some fruits

Fruit	Vitamin C (mg/100 g edible part)
Barbados cherry (*Malpighia glabra*)	1550-5600
Aonla (*Emblica officinalis*)	500-625
Camu-camu (*Myrciaria dubia*)	2994-4000
Manila tamarind (*Pitheceloobium dulce*)	138
Indian jujube (*Ziziphus maritiana*)	39-166

2.4.3 B complex group of vitamins

They are vital for maintaining good health. They play important role in metabolism of carbohydrates and fats and convert food into energy, formation of red blood cells, DNA synthesis, cell signalling and act as neurotransmitters. Fruits like chironji, pine nut, bael, elephant apple and mahua are rich source of vitamin B, whose deficiency causes Beri-Beri (Tables 6, 7 and 8).

Table 6: Vitamin B1 content of some fruits

Fruit	Vitamin B1 (mg/100 g edible part)
Pichi (*Eugenia stipitata*)	9.84
Pine nut (*Pinus edulis*)	1.28
Pilinut (*Canarium ovatum*)	0.75-1.04
Durian (*Durio zibethinus*)	0.24-0.35
Indian almond (*Terminalia catappa*)	0.32-0.71

Table 7: Vitamin B2 content of some fruits

Fruit	Vitamin B2 (mg/100 g edible part)
Bael (*Aegle marmelos*)	1.19-1.20
Wood apple (*Ferronia limmonia*) pulp	1.70
Mahua (*Madhuca indica*) flower	0.87
Brazil nut (*Bertholletia excelsa*)	0.69
Soursop (*Annona reticulata*)	0.10-0.18

Table 8: Vitamin B3 content of some fruits

Fruit	Vitamin B3 (mg/100 g edible part)
Mahua (*Madhuca indica*) flower	5.2
Pine nut (*Pinus edulis*)	4.5
Egg fruit (*Pouteria campechiana*)	2.5-3.72
Ilama (*Annona diversifolia*)	2.18
Sycomore fig (*Ficus sycomous*)	2.2

2.5 Minerals

Minerals are inorganic elements that are essential for bodies to develop and function normally. Iron being a component of hemoglobin inside the red blood cells, determines the oxygen-carrying capacity of the blood. Iron is required for red blood cell formation as well for cellular oxidation. Potassium is an important component of cell and body fluids that helps regulating heart rate and blood pressure. It also reduces the risk of developing kidney stones and help to decrease bone loss. Calcium is essential constituent of bone, teeth, muscle contraction, blood clotting and nerve impulse conduction. Manganese is used by the body as a co-factor for the antioxidant enzyme. Copper is required for bone metabolism as well as in production of white and red blood cells.Magnesium is essential for bone growth and its strengthening. It has a cardiac-protective role as well. Fruits like mangosteen, wood apple, jack fruit, durian, *etc*., are rich sources of minerals like phosphorus, magnesium, zinc, *etc.* (Tables 8, 9, 10 and 11).

Table 8: Potassium content of some fruits

Fruit	Potassium (mg/100 g edible part)
Bael (*Aegle marmelos*)	600
Durian (*Durio zibethinus*)	436
Carambola (*Averrhoa carambola*)	133
Governors plum (*Flacourtia indica*)	171
Java apple (*Syzygiumsa marangense*)	123

Table 9: Calcium content of some fruits

Fruit	Calcium (mg/100 g edible part)
Pilu (*Salvadora oleoides*)	630
Chronji (*Buchanania lanzan*) seed	279
Ker (*Capparis decidua*)	210
Kumquat (*Fortunela japonica*)	266
Mahua (*Madhuca indica*) flower	140

Table 10: Iron content of some fruits

Fruit	Iron (mg/100 g edible part)
Khejri (*Prosopis cineraria*)	19.0
Gular (*Ficus glomorta*)	19.0
Macadamia nut (*Macadamia integrifolia*)	20
Mahua (*Madhuca indica*) flower	15.0
Jherberi (*Ziziphus nummularia*)	7.0

Table 11: Magnesium content of some fruits

Fruit	Magnesium (mg/100 g of edible part)
Barbados cherry (*Malpighia glabra*)	18
Durian (*Durio zibethinus*)	10
Longan (*Dimocarpus longan*)	10
Carambola (*Averrhoa carambola*)	10

2.6 Nutraceutical value

The term "nutraceutical" was coined by Stephen Defelice, which refers to the natural whole food or part of food or product, extracted, purified and produced from plant or animal or marine source that have therapeutic and nutritional health benefit and help in prevention and curing of chronic diseases (Srivastava *et al*., 2015). According to ayurvedic literature frits play an important role in curing several diseases. They are useful in curing nutritional deficiency disorders. They act as connecting links between food and medicines. Apart from providing nutritional benefits they also provide therapeutic benefits by providing antioxidants which act as scavengers of free radicals (OH, OOR, singlet oxygen) which are harmful to our body by to DNA, proteins *and* natural defence enzymes.

2.7 Health benefits of fruit crops

These fruits in additional to various macronutrients are also a source of secondary metabolites which directly do not have any role growth and development but they act as antioxidants and independently or in combination demonstrate numerous health benefits such as having anti-inflammatory, antidiabetic, anticancerous properties and lesser the risk of CVD'S and stroke (Figures 2 and 3, Table 12).

Table 12: Health benefits of some fruits

Common name	Scientific name	Health benefits	Source
Aonla/Amalaki/ Amla	*Emblica officinalis*	It is used to cure insomnia, scurvy, constipation, haemorrahage and diabetes.	Diengngan *et al*. (2015)
Bael	*Aegle marmelos*	Helps to cure diarrhea, dryness of the eye, common cold. Gives cooling effect and arrests bleeding, good for digestive health.	Diengngan *et al*. (2015)
Chironji	*Buchana nialanzan*	It has potential capacity to cure various diseases, such as snakebite, dysentery, diarrhea, asthma, burning sensation of body, fever, ulcers, cold and Alzheimer's, and it has antidiabetic and antihyperlipidemic activity.	Patil *et al*. (2017)
Lasoda	*Cordia dichotoma*	It was reported that several bioactive compounds present in fruit showed antidiabetic activity, anthelmintic activity, gastroprotective and anti-ulcer effect.	Jamkhande *et al*. (2013)
Velvet apple	*Diospyros blancoi*	Traditionally used to treat diarrhea, dysentery, aphthous stomatitis, snakebites, heart problems, hypertension, spider bites, stomach aches, diabetes, and eczema.	Akter *et al*. (2015)
Manila tamarind	*Pithecellobium dulce*	Manila fruit is used to treat toothaches, mouth ulcers, sore gums, dysentery, chronic diarrhea, stress, aging symptoms and dark skin spots.	Arul *et al*. (2011)
Timroo	*Diospyros melanoxylon*	It is used as an indicator for high sulfur dioxide concentration. Timroo fresh fruit has high total phenolic content, flavonoids, scavenging activity, antioxidants. Its bark extracts are used to treat dyspepsia, diarrhea, and smallpox (burnt bark) by ethnomedicine practitioners.	Singh *et al*. (2007) Bhat and Karim (2009) Hmar *et al*. (2017)

3. Therapeutic value of fruits

Fruit species play a crucial role in enhancing nutritional and health well-being through the provision of vital micronutrients, antioxidants, and bioactive phytoconstituents (Figure 1). Consequently, products derived from fruits are progressively acknowledged as functional foods that offer possible health advantages through pharmacological properties (Figures 2, 3 and 4).

3.1 *Aegle marmelos* (Bael)

Abdominal pain, cholera, nocturnal fever, gastrointestinal disorder, and snakebite are traditionally treated with fruits and roots in certain tribes for gastric ailments. Additionally, the bite of a rabid dog can be remedied by these natural remedies. In Indian tribes, laxatives are prepared using various methods (Gupta, 2016). Furthermore, a paste made from leaves serves as an antidote to counteract the venom of poisonous creatures. In eastern Rajasthan, the powder derived from the fruit and bark is employed to alleviate stomach pain and dysentery (Joshi, 1986). Studies have shown that an extract of Bael, administered at a dosage of 250 mg/kg of body weight, exhibits superior efficacy compared to glycenamide, an antidiabetic medication. The aqueous extract of Bael fruits has been proven to possess anti-hyperlipidemic properties, using diabetic subjects induced with streptozotocin. Furthermore, a dosage of 250 mg/kg of body weight of the fruit extract showcases better outcomes than glibenclamide (36 µg/kg). The presence of flavonoids, alkaloids, sterols, tannins, phlobatannins, and flavonoid glycosides in Bael

may account for its antioxidant properties (Kamalakkannan and Prince, 2003). Various assays have been conducted to assess the cytotoxic effects of Bael extracts, including the brine shrimp lethality assay, sea urchin eggs assay, and MTT assay using tumor cell lines. Notably, the extract of *Aegle marmelos* displayed toxicity in all assays conducted. The ethanolic extract of dried Bael fruit pulp has exhibited efficacy against several intestinal pathogens, such as *Shigella boydii*, *S. sonnei*, and *S. Flexneri*, attributed to the presence of phenols, tannins, and flavonoids (Maheshwari *et al.,* 2009). Moreover, the leaf extract of Bael demonstrates anti-inflammatory, antipyretic, and analgesic properties, significantly reducing carrageenan-induced paw edema and cotton-pellet granuloma in rats (Arul *et al.,* 2005). The aqueous extract of Bael demonstrates anti-inflammatory effects, as shown by its ability to reduce rat paw edema, thus confirming its anti-inflammatory activity. Additionally, Shankharananth (2007) observed that the methanolic extract of Bael leaves at doses of 200 and 300 mg/kg body weight exhibits notable analgesic effects in acetic acid-induced writhing and tail flick tests in mice.

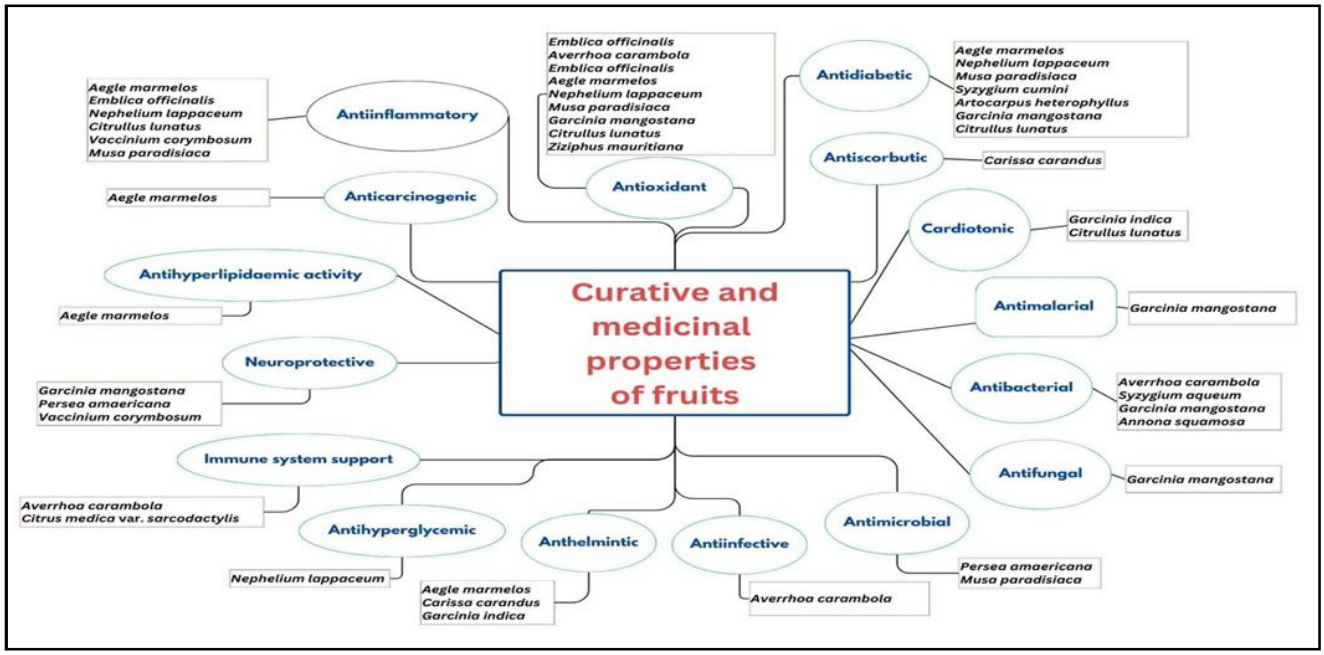

Figure 1: Curative and medicinal properties of fruits.

3.2 *Emblica officinalis* (Aonla)

The ethanolic extract of aonla (100 mg/kg BW) exhibited a significant reduction in lipid peroxidation parameters (MDA, carbonyl, total DNA, SOD, and CAT), ulcer index (3.8), and DNA damage induced by indomethacin (85.73% protection) in rats. Emblica fruit extract also demonstrated inhibition of the growth of *Staphylococcus aureus, Bacillus subtilis, Salmonella paratyphi, Shigella dysenteriae,* and *Candida albicans* (Ahmad and Beg, 2001). The aqueous extract of aonla showed inhibition of human lung carcinoma and (A549) and human hepatocellular carcinoma (HepG2) cell lines. In an *in vitro* model of cartilage degradation in explant cultures of articular knee cartilages obtained from osteoarthritis patients, fruit powder exhibited a significant chondroprotective effect (Sumantran *et al.,* 2008). The antioxidant properties in aonla fruit are attributed to the presence of phenolic compounds (Anila and Vijayalakshmi, 2002; Sabu and Khuttan, 2002; Kumar *et al.,* 2006). Anthocyanins demonstrate anticarcinogenic properties such as inducing cell-cycle arrest and apoptosis, as well as inhibiting tumor formation and growth in animals (Sabu and Khuttan, 2002). Known as Indian gooseberry, aonla fruit showcases a diverse range of healing properties due to its rich nutritional content and bioactive elements. Research has indicated the beneficial effects of Amla in managing various conditions like diabetes, cancer, inflammation, and liver-related ailments. Its antioxidant, antimicrobial, gastroprotective, cardioprotective, radioprotective, anti-inflammatory, and immunomodulatory properties make it a valuable natural remedy for a variety of health issues. Amla is renowned for its hepatoprotective effects, promoting liver health, as well as enhancing skin, hair growth, and memory function. Traditionally, the fruit has been used to address anemia, anxiety, jaundice, and digestive issues, highlighting its versatility in supporting overall well-being and providing a comprehensive approach to health maintenance. Studies have demonstrated that amla supplementation can lead to significant enhancements in metabolic parameters like lipid profile, glucose levels, and C-reactive protein concentrations, suggesting its potential in managing chronic diseases. Additionally, amla is acknowledged for its anti-inflammatory, antioxidant, hypoglycemic, and hypolipidemic effects, along with therapeutic properties such as analgesic, anti-diabetic, antimicrobial, and hepatoprotective activities. In conclusion, the varied medicinal attributes of amla position it as a valuable natural remedy capable of effectively addressing a range of health concerns.

3.3 *Pithecellobium dulce* (Manila tamarind)

Pithecellobium dulce, a plant from the Fabaceae family, exhibits a wide range of curative properties attributed to its various bioactive compounds. The plant's extracts have demonstrated significant antibacterial activity against multi-drug-resistant bacteria, with compounds like D-turanose and inositol showing promising interactions with bacterial receptors (Abdu *et al.,* 2023). Additionally, *P. dulce* has been found to possess antihyperlipidemic properties, effectively reducing cholesterol and triglyceride levels in

hyperlipidemic rats. Its fruit extract has shown anti-metastatic efficacy by downregulating key signaling pathways involved in cancer progression, such as EGFR/STAT/NFκB/AKT, and enhancing the expression of anti-metastatic genes. The plant is also rich in antioxidants, which contribute to its anti-inflammatory, anti-diabetic, cardio-protective, and anti-ulcerogenic activities. Furthermore, *P. dulce* leaves exhibit potent anthelmintic activity, effectively inhibiting the hatching of Haemonchus contortus eggs, which is beneficial for controlling gastrointestinal nematodes in livestock. The fruit peel extract is notable for its high phenolic and flavonoid content, providing strong antioxidant and potential anticancer activities. The lipophilic fractions of the bark and leaves also show moderate antioxidant and antibacterial activities, with no observed cytotoxicity, making them suitable for food and pharmaceutical applications. Moreover, *P. dulce* fruit extract has been shown to mitigate the toxic side effects of the chemotherapeutic drug cyclophosphamide, reducing immuno-suppression, urotoxicity, hepatotoxicity, and nephrotoxicity in treated animals. Lastly, the fruit extract has demonstrated significant anti-inflammatory effects by regulating pro-inflammatory mediators and enhancing antioxidant enzyme expression, suggesting its potential as a natural alternative to non-steroidal anti-inflammatory drugs. Overall, *P. dulce* is a versatile medicinal plant with numerous therapeutic applications.

3.4 *Averrhoa carambola* (Star fruit)

The display of a wide range of healing properties is delineated in the scholarly publications. Abundant in antioxidants such as L-ascorbic acid, epicatechin, and gallic acid, it delivers anti-inflammatory, anti-infective, antitumor, and immune-enhancing impacts. Moreover, star fruit harbors bioactive elements like polyphenols and flavonoids which impede bacterial functions. In addition, star fruit extract along with its flavonoid constituents have demonstrated notable inhibitory effects against skin inflammation and premature ageing triggered by airborne pollutants, exhibiting efficacy in safeguarding the skin from harm (Ping Wu *et al.,* 2022). The therapeutic attributes of the fruit also encompass hypotensive, hypoglycemic, hypocholesterolemic, and hypolipidemic effects, rendering it advantageous for ailments like diabetes and cardiovascular conditions.

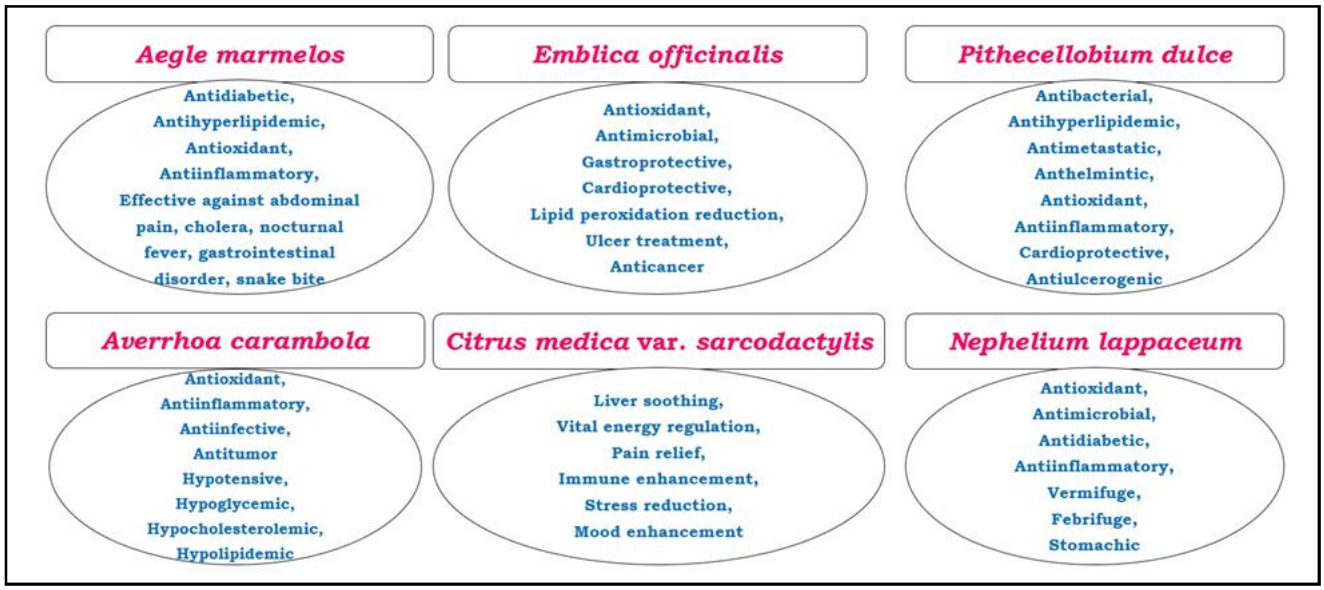

Figure 2: Pharmacological properties of some fruits.

3.5 *Citrus medica* var. *sarcodactylis* (Fingered citron)

The diverse therapeutic benefits of fingered citron in traditional medicine and wellness applications are well-documented in various research papers. Its efficacy in soothing the liver, regulating vital energy, and relieving pains has been emphasized The utilization of fingered citron in medicinal liquor formulations is attributed to its capacity in bodybuilding, blood activation, intestines and stomach tonification, and immunity enhancement. Within brown sugar substitutional tea, fingered citron plays a crucial role, renowned for its capability to regulate vital energy and address symptoms like rib-side distention and anxiety in women. Inhalation of fingered citron peel oil has demonstrated an increase in positive emotions, such as well-being and activeness, alongside a decrease in negative emotions like drowsiness, underscoring its stimulating properties. Overall, these properties collectively showcase the varied curative properties of fingered citron in the realm of traditional medicine and well-being practices.

3.6 *Nephelium lappaceum* (Rambutan)

Unripe fruit is astringent, stomachic; acts as a vermifuge, febrifuge, and is taken to relieve diarrhoea and dysentery. The leaves are poulticed on the temples to alleviate headache. In Malaya, the dried fruit rind is sold in drugstores and employed in local medicine. The astringent bark decoction is a remedy for thrush. A decoction of the roots is taken as a febrifuge. Ethanolic extract of rind act as an anti hyperglycaemic agent in addition to its extremely high anti oxidant activity and low pro oxidant capability. Geraniin has the potential to be developed into an antihyperglycemic agent (Uma *et al.,* 2011). Ethanol extract of rambutan fruit peels contains ethyl gallate (Muhtadi *et al.,* 2016), which has the strong antioxidant activity. Ethanol extract of rambutan fruit peels is known to have a greater ability as an antioxidant to capture DPPH free radicals than vitamin E (Tamimy, 2006). Rambutan is reported to have many biological activities (Suganthi and Josephine, 2016; Nethaji *et al.,* 2015). The study of anti-inflammatory activities of the aqueous extract of the peel of

Rambutan cv. Malwana special revealed that total phenolic content and the total flavonoid content of AEPR were 463.5 ± 5.2 mg (PGE)/g and 375.0 ± 13.2 mg (QE)/g, respectively. AEPR prepared from peel waste has a potential to be used as an antioxidant and also it possesses anti-inflammatory activity (Uduwela *et al.,* 2019). Rambutan is a tropical fruit rich in bioactive compounds, exhibits various therapeutic properties making it a valuable source for medicinal and functional food applications. Studies have highlighted the curative potential of different parts of the rambutan fruit, including the peel, pulp, and seed. The fruit is known for its antioxidant, antimicrobial, antidiabetic, and anti-inflammatory properties, while the peel specifically contains high levels of antioxidants with applications in the food, cosmetic, and pharmaceutical industries (Muhammad *et al*., 2023). Rambutan peels have been found to possess bioactive compounds that demonstrate antibacterial and antioxidant activities, along with cytotoxicity against certain cell lines, showcasing their potential for various applications (José *et al*., 2021). Furthermore, the rambutan seed, a major co-product of the fruit industry, is rich in premium-grade fat, protein, fiber, antioxidants, and phenolic content, offering opportunities for use in the food, pharmaceutical, and cosmetic sectors (Cristian *et al.,* 2019).

3.7 *Syzygium cumini* (Jamun)

An infusion made from fruit or a combination of powdered bark and fruit is utilized for the management of diabetes in the northeastern region of India (Sharma *et al.,* 2001). The oral administration of juice extracted from the bark is employed in the treatment of women with a background of recurrent abortions in Lakher and Pawi, located in the north eastern part of India. In Maharashtra, the employment of fruit and stem bark is observed in the treatment of diabetes, dysentery, enhancement of appetite, and alleviation of headache (Jain *et al.,* 2005). To address diabetes, a decoction of the stem bark is ingested thrice daily for 2-3 weeks (Chhetri *et al.,* 2005). The combination of leaf juice with honey or cow's milk is applied for the treatment of diabetes. The consumption of fresh fruits is practiced by the Kani tribals in Southern India to alleviate stomach ache and manage diabetes (Ayyanar, 2008; Udayan *et al.,* 2006). In Madagascar, seeds are orally administered for diabetes management (Ratsimamanga, 1998). The ingestion of dried seed powder thrice daily is part of the therapeutic approach for diabetes in Andhra Pradesh (Nagaraju *et al.,* 2006). The early morning consumption of a mixture of leaf juice and milk is a method utilized by Siddis in Karnataka for diabetes management (Bhandary *et al.,* 1995). The combination of stem bark juice with buttermilk is employed for addressing constipation. In Brazil, the oral intake of leaves is practiced to manage diabetes (Braga *et al.,* 2007). Tender leaves are orally consumed to tackle jaundice in Maharashtra (Natarajan and Paulsen, 2000). The methanolic extracts from jamun leaves exhibit inhibitory effects on the growth of certain Gram-positive and Gram-negative bacteria (Mohanty and Cock, 2010). The administration of an aqueous seed extract of Jamun at a dose of 1 g/kg body weight in diabetic rats has been shown to induce a hypoglycemic effect in the bloodstream of rats (Kedar and Chakrabarti, 1983). Treatment of streptozotocin-induced diabetic rats with 100 mg/kg body weight seed kernel ethanol extract resulted in a reduction of blood sugar levels, urea, and cholesterol, along with an improvement in glucose tolerance, and a decrease in glutamate oxaloacetate transaminase and glutamate pyruvate transaminase activities (Ravi *et al.,* 2004).

3.8 *Carissa carandus* (Karonda)

The roots are utilized for their stomachic, anthelmintic, and antiscorbutic properties, treating various stomach disorders like flatulence and acidity, as well as conditions such as intestinal worm infestation, diabetic ulcer, scabies, and pyrexia. They are also known to act as an insect repellent. Furthermore, they are employed in the management of remittent fever, diarrhoea, earache, mouth and throat soreness, and syphilitic pains (Kumar *et al.,* 2013). The unripe fruit serves as an appetiser, astringent, antiscorbutic, stomachic, anthelmintic, laxative, and antipyretic, effectively treating anorexia, diarrhoea, and haematemesis. In contrast, ripe fruits function as an appetiser, antiscorbutic, and expectorant, aiding in the treatment of anorexia, burning sensation, pruritus, skin disorders, anaemia, and as an antidote for poisons and carminative. They are also used to enhance female libido and combat worm infestation, microbial and fungal infections, as well as in the treatment of insanity (Khare, 2007).

The total antioxidant activity and phenolic content of karonda fruit are comparable to vincristine sulfate, exhibiting IC values of 3.43 and 2.66 for ethanolic and n-hexane extracts, respectively. The fruit extract was found to be effective against breast cancer, with an IC_{50} concentration of 86.7308 (µg/ml) against MCF-7 cell lines (Kiruthika *et al.,* 2019). Scientifically known as *Carissa carandas*, karonda possesses a diverse range of medicinal properties due to its rich phytochemical composition. It is a good source of iron, vitamins A, C, B complex, and minerals like calcium, phosphorous, and potassium (Nilesh Bhowmick *et al.,* 2023). Traditionally used in Ayurveda, Unani, and Homoeopathy, karonda has been employed to treat ailments such as pruritus, anorexia, rheumatism, and rabies (Sawanit Aichayawanich *et al.,* 2021). The plant is rich in bioactive compounds like alkaloids, flavonoids, saponins, cardiac glycosides, and tannins, which contribute to its medicinal value (Suneeta Singh *et al.,* 2019). Various parts of the plant, including the fruit, leaves, root, and shoot, contain chemical constituents like carissol, ascorbic acid, and lupeol, which have therapeutic uses in conditions such as anemia, biliousness, and as antimicrobial agents (Virmani *et al.,* 2017). In conclusion, the diverse phytochemical profile of karonda supports its well-established reputation as a beneficial medicinal plant with a wide range of healing properties.

3.9 *Garcinia indica* (Kokum)

Kokum fruit has been utilized for treating various conditions such as diarrhoea, inflammatory disorders, dermatitis, bowel issues, and rheumatic pains, as well as for the prevention of excessive perspiration. The fruits are employed for their antihelmintic and cardiotonic properties. Extracts from the kokum rind, particularly the juice, have been historically used to address ailments like piles, colic issues, dysentery, and diarrhoea (Baliga *et al.,* 2011). Traditional medicine also involves the use of decoctions made from the fruit rinds to manage diabetes. Furthermore, kokum butter has been traditionally applied to promote wound healing, treat fissures on the hands, and purportedly restore skin elasticity, serving as a moisturizer (Jeyarani and Reddy, 1999). Research indicates that the anthocyanin cyanidin-3-glucoside found in kokum fruits has demonstrated potential in reducing the occurrence of both benign and malignant skin tumors in a two-stage skin carcinogenesis model. Additionally, it has exhibited a dose-dependent inhibitory effect on the migration and invasion of metastatic A549 human lung carcinoma cells (Ding *et al.,* 2006).

3.10 *Artocarpus heterophyllus* (Jack fruit)

The utility of leaves extends to treating fever, boils, wounds, and skin ailments. The immature fruits possess acrid, astringent, and carminative properties. On the other hand, the mature fruits offer sweetness, cooling effects, laxative qualities, aphrodisiac properties, and serve as a brain tonic. The seeds act as diuretics and are also known for causing constipation. The wood exhibits nervine characteristics, acts as an antidiabetic agent, possesses sedative properties, and proves beneficial in cases of convulsions (Hemborn, 1996). The latex is effective in treating dysopia, ophthalmic issues, pharyngitis, and serves as an antibacterial agent (Sato *et al.,* 1996). Ash derived from Jackfruit leaves finds application in ulcer treatment. The dried latex contains artostenone, which can be converted to artosterone, a compound with significant androgenic effects. When combined with vinegar, the latex aids in healing abscesses, snakebites, and glandular swellings (Vaidya Gogte, 2000). The root serves as a remedy for skin disorders and asthma, while an extract of the root is administered in cases of fever and diarrhoea. Bark is utilized in making poultices, and heated leaves are applied on wounds. According to Fernando *et al.* (1991), the hot water extract of jackfruit leaves led to a notable enhancement in glucose tolerance among both normal individuals and diabetic patients, when administered orally at doses equivalent to 20 g/kg. It also displayed hemagglutination activity against human and rabbit erythrocytes.

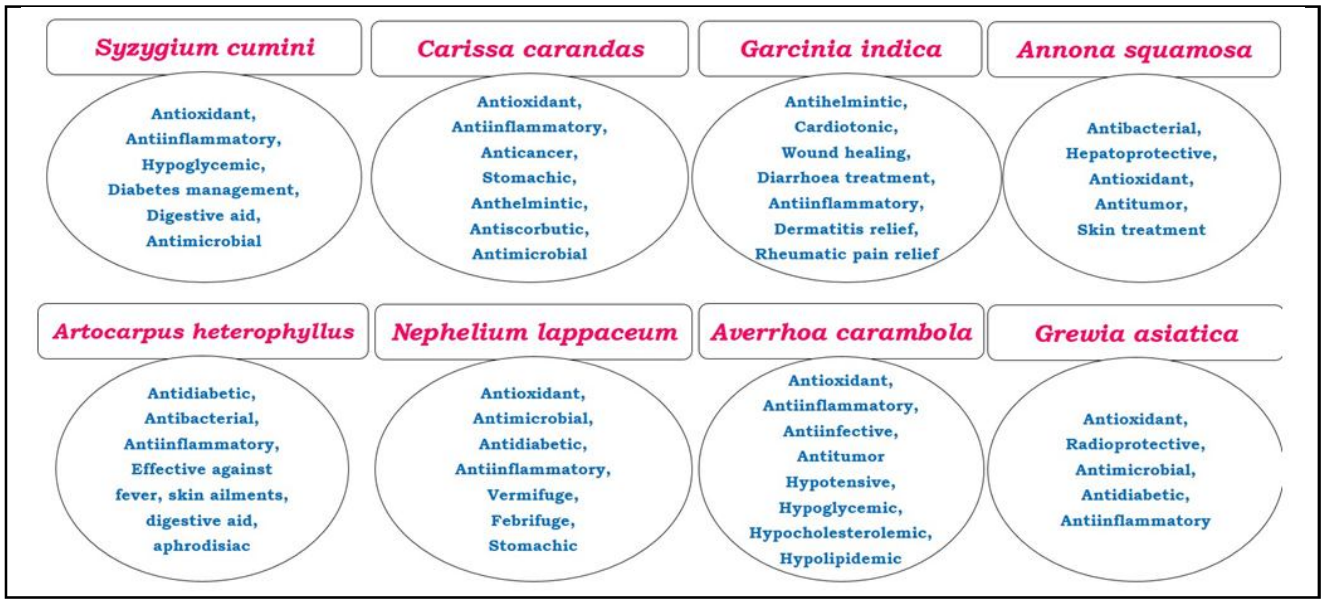

Figure 3: Pharmacological properties of some fruits.

3.11 *Syzygium aqueum* (Water apple)

Water apple showcases a variety of therapeutic attributes as indicated by research outcomes. Research indicates that water apple fruits are rich in antioxidants, total phenolic compounds, total flavonoids, and vitamin C, contributing to their medicinal advantages (Ganguli *et al.,* 2021). Moreover, the foliage of water apple demonstrates antibacterial effects, particularly against *Escherichia coli* and *Staphylococcus aureus*, due to the presence of bioactive elements such as tannin (Hamidah *et al.,* 2017). Additionally, water apple displays notable antioxidant properties, surpassing fragrant mango in levels, thus establishing itself as a beneficial natural treatment for combating free radicals and oxidative stress (Saptarini and Herawati, 2017). These cumulative characteristics position water apple as a promising fruit with potential health benefits, underscoring its significance in traditional medicine and prospective pharmaceutical uses.

3.12 *Garcinia mangostana* (Mangosteen)

The fruit is commonly referred to as the "queen of fruits" due to its abundance of healing properties stemming from its complex chemical structure. Specifically, the bioactive components in the fruit, such as xanthones like α-mangostin and γ-mangostin, play a crucial role in its varied health advantages. Recent studies have shown that mangosteen showcases a wide array of benefits including antioxidant, anti-inflammatory, antibacterial, antifungal, antimalarial, antidiabetic, anticancer, and neuroprotective effects. These characteristics position mangosteen as a promising candidate for phytotherapy, offering support in combatting toxicity by mechanisms like the inhibition of oxidative stress, modulation of inflammatory agents, and control over apoptosis and signaling pathways (Chenchen *et al.,* 2023). Moreover, the pericarp of the fruit, often overlooked in industrial processes, has been identified as a rich source of beneficial substances with antioxidant, anti-inflammatory, antiproliferative, and antibacterial properties, underscoring its importance in providing bioactive compounds (Maciej Kluz*et al.,* 2023).

3.13 *Persea amaericana* (Avocado)

The Lorena cultivars, in particular, are abundant in bioactive compounds possessing significant therapeutic attributes. Research has emphasized the detection of antioxidants such as flavonoids, condensed tannins, and phenols in the pulp, seed, and peel of avocados, demonstrating potent antioxidant and antimicrobial properties (Adriana*et al.,* 2022). These components play a vital role in averting neuronal damage associated with oxidative stress, thus indicating the potential efficacy of avocados in diminishing the susceptibility to neurodegenerative disorders like Alzheimer's and

Parkinson's. Moreover, the distinctive nutritional composition and bioactive profile of avocados have positioned them as a favorable candidate for innovative drug exploration in the management and prevention of various ailments, encompassing cancer, microbial infections, inflammatory conditions, diabetes, and cardiovascular ailments (Deep, 2019). The historical medicinal applications of avocados, such as lipid level reduction, enhancement of libido, and stimulation of menstrual flow, further accentuate their multifaceted therapeutic characteristics.

3.14 *Citrullus lunatus* (Watermelon)

It is a member of the Cucurbitaceae family, possesses various curative properties attributed to its rich nutritional profile and bioactive compounds. It is a natural source of antioxidants, including lycopene, citrulline, and phenolic compounds, which contribute to its medicinal value (Hujatullah Mukhlis *et al.,* 2022). Watermelon is known for its anti-inflammatory properties due to the presence of cucurbitacin E, aiding in treating ailments like cardiovascular diseases and obesity (Adedeji, 2018). Additionally, watermelon seeds are highly nutritious and used traditionally to treat urinary tract infections, bedwetting, and renal stones. The fruit's high water content, essential nutrients, vitamins (such as A, B, and C), and powerful antioxidants make it beneficial for overall health, including promoting bowel relaxation, saliva secretion, and lung moisture (Yang, 2007). These combined properties make watermelon a valuable functional food with potential therapeutic benefits for various health conditions.

3.15 *Ziziphus mauritiana* Lamk (Ber)

Ber fruit is characterized by its high antioxidant and nutrient content, particularly vitamin C, rendering it a valuable dietary inclusion (Sanjiv Kumar *et al*., 2022). Research indicates that Ber fruit demonstrates notable antioxidant properties, showing significant levels of DPPH radical scavenging, reducing power, superoxide anion radical activity, as well as substantial phenolic and flavonoid content (Lydia, 2012). Moreover, Ber fruit is associated with potential health advantages owing to its ability to thrive in unfavorable climatic conditions and provide good returns for cultivators (Prashant and Ananad, 2016). Furthermore, processing techniques such as blanching can enhance the antioxidant properties of Ber fruit by increasing total flavonoid content and superoxide anion radical activity, albeit potentially reducing other antioxidant activities to a minor extent (Kavitha, 2013). In essence, Ber fruit's remedial attributes stem from its antioxidant-rich composition and potential health benefits, positioning it as a promising fruit for consumption and further investigation (Tomasz and Janusz, 2005).

3.16 *Vaccinium corymbosum* (Blueberries)

These fruits demonstrate a broad range of therapeutic properties owing to their abundant concentration of bioactive compounds. Recent studies have indicated that blueberry extracts exhibit antibacterial and anti-inflammatory effects against Helicobacter pylori infections, suggesting a possible alternative for regulating bacterial proliferation and modulating gastric inflammation (José *et al.,* 2022). Additionally, the antioxidant characteristics of polyphenols found in blueberries have the potential to counteract oxidative stress and neuroinflammation in neurodegenerative disorders, thereby providing defense against neuronal cell degeneration and harm caused by glutamate-induced excitotoxicity or protein clumps. Moreover, blueberries have been correlated with ameliorating depressive symptoms, reducing gastrointestinal infections, and bolstering autoimmunity by upregulating brain-derived neurotrophic factor (BDNF) and miR-155 expression (Ning Xu *et al.,* 2017). Furthermore, the intake of blueberries has been linked to alleviating pain, stiffness, and challenges in daily tasks, while enhancing walking performance in individuals suffering from symptomatic knee osteoarthritis, potentially enriching their quality of life (Carmen, 2016).

3.17 *Musa paradisiaca* L. (Banana)

Bananas exhibit a broad spectrum of healing attributes owing to their abundant nutritional composition and bioactive elements. Recent studies indicate that bananas harbor essential bioactive components such as polyphenols, vitamins, phytosterols, and minerals, which contribute to their therapeutic advantages (Partha *et al.,* 2021). The bioactive compounds present in bananas have been linked to a variety of health-promoting functions, including antioxidative, anti-inflammatory, antidiabetic, antimicrobial, and anticancer characteristics (Ana Elisa *et al.,* 2022). Moreover, the chemical makeup of banana pulp and peel, specifically glycosylated polyphenols and resistant starch, has been associated with protective effects against intestinal inflammation processes, regulation of immune responses, oxidative stress, and intestinal microbiota (Nia Aprilla *et al.,* 2022). Furthermore, the nutritional assessment of different banana cultivars like Robusta has revealed elevated levels of protein, fat, carbohydrates, minerals, and energy content, rendering them advantageous for therapeutic purposes and preferable for specific applications such as baking. These outcomes collectively underscore the varied healing properties of bananas, spanning from gastrointestinal well-being to the management of chronic illnesses.

3.18 *Pyrus malus* (Apple)

These fruits possess a high concentration of bioactive compounds like phenolic acids, flavonoids, and triterpenes, which play a role in their therapeutic characteristics. The presence of these compounds results in antioxidant, anti-inflammatory, and anticancer properties, positioning apples as a promising chemopreventive substance against a range of illnesses, including cancer (Flávia Andressa *et al.,* 2014). Moreover, apples are a source of crucial nutrients like Vitamin C, thiamine, potassium, and dietary fiber, which offer advantages for cardiovascular well-being, weight regulation, and management of cholesterol levels (Özdemýr *et al.,* 2009). Investigations have indicated that apples have the potential to diminish the likelihood of prostate and lung cancer, cardiovascular ailments, and DNA harm, underscoring their healing capabilities (Nunuk *et al.,* 2018). Furthermore, extracts derived from both locally grown and imported apples have exhibited protective effects on cells, cell regeneration, and properties that combat aging, suggesting their plausibility as agents for rejuvenating impaired cells and counteracting cell ageing induced by oxidative stress.

3.19 *Annona squamosa* L. (Custard apple)

The research papers have underscored a wide range of therapeutic properties possessed by custard apple. Traditionally, the fruit and its constituents have been employed for diverse medicinal purposes. Custard apple seeds harbor various bioactive compounds like alkaloids, flavonoids, phenolic compounds, acetogenins, and cyclopeptides, contributing to their antibacterial, hepatoprotective, antioxidant, and antitumor properties (Oltinoy, 2022). Moreover, custard apple seeds and peel serve as abundant reservoirs of

antioxidants, encompassing phenolic acids and flavonoids, which exhibit anti-inflammatory, anti-thrombotic, and antiaggregatory effects (Neeraj Kumari *et al.,* 2022). Additionally, the medicinal value of the plant is manifested through the utilization of its leaves in the treatment of skin conditions, abscesses, insect bites, and malignant tumors (Alejandro *et al.,* 2022). In conclusion, custard apple emerges as a potent natural remedy with substantial potential for therapeutic interventions.

3.20 *Grewia asiatica* L. (Phalsa)

The diverse therapeutic properties of the phalsa plant have been extensively documented in various scholarly publications. This botanical specimen is widely recognized for its antioxidant, radioprotective, antimicrobial, antidiabetic, anti-inflammatory, anticancer, and cardio-protective attributes, thus establishing it as a valuable asset in the field of medicine (Arshad, Mehmood *et al.,* 2020). Throughout history, the utilization of different components of the phalsa plant in traditional medicinal practices has been prevalent, with the fruit serving as an astringent, stomachic, and refrigerant, while the root and bark are specifically recommended for treating rheumatism (Dharam *et al.,* 2021). Furthermore, investigations into the therapeutic potential of this plant have shed light on its antihyperglycemic, hepatoprotective, antifertility, antifungal, analgesic, antipyretic, and antiviral properties, thus emphasizing its multifaceted healing capabilities (Jyoti*et al.,* 2015). The intricate phytochemical composition of phalsa plays a pivotal role in its medicinal efficacy, positioning it as a promising subject for further research in the domain of natural remedies and functional foods.

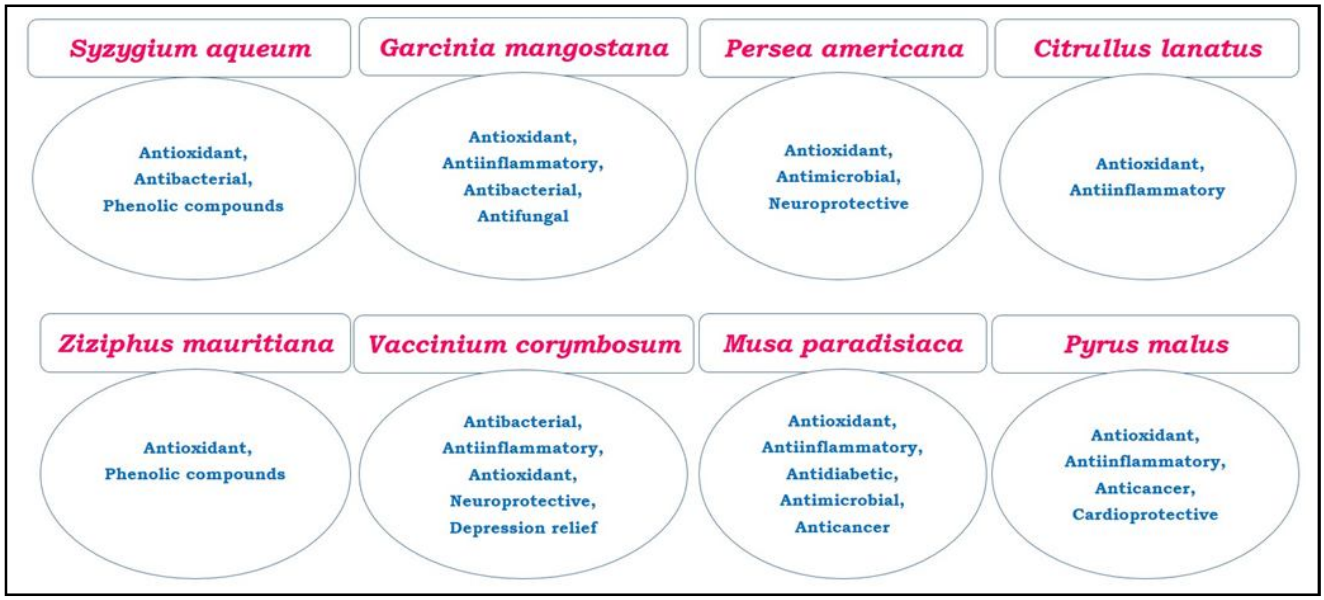

Figure 4: Pharmacological properties of some fruits.

4. Future prospects

As the worldwide population continues to expand, there is an anticipation of a substantial rise in the demand for food crops, particularly fruits. Scholars and experts in the field of agriculture are actively investigating novel approaches to augment fruit production and its quality. Progressions in biotechnology, encompassing genetic alteration and genome editing, present auspicious pathways for the amelioration of fruit crops. Techniques like CRISPR-Cas9 enable meticulous alterations to be made to fruit plant genomes, resulting in disease-resistant cultivars, heightened yield, and enriched nutritional value. The utilization of nanofertilizers has the capacity to boost nutrient absorption and enhance the quality of fruits. These minute particles facilitate a more effective delivery of nutrients to plants, thereby fostering superior yields and healthier fruits. Investigational efforts are being directed towards gene overexpression, promoter engineering, and other biotechnological strategies to cultivate fruit variants with prolonged shelf-life, enhanced postharvest resilience, and improved nutritional compositions. The exploration of disregarded and underutilized fruit species has the potential to broaden our dietary resources and contribute to global health and nutritional stability. These varieties often harbor distinct phytochemicals and antioxidants that confer therapeutic advantages.

5. Conclusion

The fruits are like a major boon to the food and nutraceutical industry. Increasing population and hunger index are posing a major threat to the national food security. Providing healthy and nutritious food for future generations in a sustainable way can only be achieved by increasing the area under cultivation of this fruits. These fruit crops are capable to adapt to wide challenging climatic conditions caused due to various biotic and abiotic stress. Though there is a lot of research going on in this sector, still there is scope for development of new high yielding varieties and more value-added products. Some research has been done on the characterisation and documentation of the phytochemical activity of these fruits but still substantial work is to be done to validate the ability of these fruits to treat diabetes, liver toxicity, fungal infection, microbial infection, inflammation, pyrexia and to relieve pain. Notably, fruits such as citrus, grape, blueberry, pomegranate, mango, orange, pineapple, strawberry, sweet cherry, lychee, apple, hawthorn, and avocado have been extensively studied and shown to possess preeminent antioxidant properties, contributing to their therapeutic effects in alleviating various disease conditions. Global recognition is required for increasing the demand of these fruits which are a major alternative in-terms of providing nutritional food, efficient usage of wastelands, production of fruits

even in abiotic stress conditions, extraction of various nutraceuticals as an alternative of pharmaceuticals and increasing the economy of the country.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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