Hindawi
Journal of Food Processing and Preservation
Volume 2023, Article ID 8863630, 11 pages
https://doi.org/10.1155/2023/8863630

Review Article

Bael (*Aegle marmelos*), an Underutilized Fruit with Enormous Potential to Be Developed as a Functional Food Product: A Review

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Received 23 November 2022; Revised 30 March 2023; Accepted 10 April 2023; Published 9 May 2023

Academic Editor: Snehasis Chakraborty

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In South Asia, a fruit often known as Bael is a valuable medicinal plant, which is scientifically named *Aegle marmelos*. Not just the fruits but also the leaves, stems, bark, and roots are used in traditional medicine. Since ancient times, the plant has been used to treat a variety of chronic illnesses. Several scientific investigations have confirmed the nutritional and medicinal properties of plant-derived compounds. Global concern about the role of eating habits and health has increased the interest in plant-derived nutraceuticals; thereby, the functional attributes of such underutilized fruits are being explored which have an enormous potential to be developed as a functional product for the food processing industry. The present review emphasizes scientific data on the nutritional and bioactive composition of the fruit along with its pharmacological activities. Furthermore, this study also discussed fruit processing technology and innovation in the development of potential functional products derived from the fruit.

1. Introduction

Aegle marmelos generally known as Bael is an underappreciated fruit native to the Indian subcontinent, which includes Nepal, India, Sri Lanka, Bangladesh, and Thailand. It is a medium-sized deciduous tree belonging to the Rosaceae family. It is a subtropical plant that can adapt to a wide range of habitats and can be grown worldwide. The plant grows up to 1200 meters above sea level in general, but it has been recorded that the trees grow up to 1500 meters in Nepal, stretching from the hills to the Terai region, and it has a wide range of adaptability to hostile soil and environment. Temperature tolerances range from 7 to 48 degrees Celsius [1], and it grows well in the swampy, alkaline, and sandy wasteland.

The growing awareness among health-conscious consumers about the role of diet on human well-being has drawn attention to the consumption of functional foods and nutraceuticals, prompting researchers to investigate the functional properties of various underutilized plants. As a result, various fruits with nutritional and medicinal properties have been introduced as suitable ingredients for the food processing industry. The presence of fibers, polyphenols, carotenoids, terpenoids, flavonoids, alkaloids, and coumarins, in the plant, shows numerous health benefits, namely, antimicrobial, antioxidant, antidiarrheal, antidiabetic, antiulcerative, cardioprotective, anticancer, gastroprotective, and hepatoprotective effects [2]. Although the most valuable and consumable part of the tree is its fruits, leaves, stems, bark, and roots are also utilized in the Ayurveda system of medicine to cure a variety of human ailments [3].

Despite its exceptional flavor and nutritional and medicinal properties, Bael remains an underutilized fruit with enormous potential to be used in the functional food market. Bael being a seasonal fruit cannot be used throughout the year. Therefore, it can be processed into making different

products like juice, beverages, candies, jams, and tea adding economic value to it. Moreover, the hard shell, the sticky texture, and numerous seeds in the fruit make it difficult to eat which could be the reason that it is not as popular as other table fruits. So, further processing is needed for the easy consumption of the fruit, which can be developed as a functional food product.

Besides food and medicinal value, it also has environmental and cultural importance. The plant acts as a sink as it absorbs chemical pollutants and harmful gases from the atmosphere. It is known as a "climate cleaner" since it emits a higher percentage of oxygen than other plants. It has great cultural importance among Hindus and, therefore, has been often cultivated on temple premises to offer fruit and leaves to Lord Shiva.

The objective of this work is to review the nutritional and therapeutic advantages of Bael along with the phytochemicals present in various parts of the plant. This review distinguishes itself from previous work by addressing the need for innovative fruit processing techniques that can enhance the marketability of Bael as a functional food ingredient. Such techniques are essential to facilitate the easy consumption of Bael and add value to its functional properties.

2. Nutraceutical Importance

2.1. Traditional Applications. Fruits have been used as food and medicine since 5000 B.C. [4]. Extensive use of these fruits and their parts has been found in Ayurveda and other traditional medicine systems [5]. The leaf of the plant is used as a remedy for jaundice and asthma [6]. They are also good in the treatment of conjunctivitis, along with curing constipation, deafness, and leucorrhea. Furthermore, leaf powder is used to treat bowel syndrome [7]. Similarly, unripe fruit is used in abscess curing, whereas the fruit pulp is beneficial for urinogenital disorders, intestinal disorders, and other indigestion-related problems [8]. The mixture of powdered fruit and mustard oil is used in India to cure burn wounds [9]. Due to the antiseptic and astringent properties of the plant's flower, it is used in epilepsy and wound healing [10]. In addition, the root and bark of the tree are useful for intermittent fever, heart palpitation, and melancholia. Bale tree root is among the most important components in the preparation of a popular Ayurvedic medicine known as "Dashmula," which has a variety of benefits, including proper nervous system functioning [9].

2.2. Nutritional Composition. Various researches on the nutritional makeup of Bael fruit have been undertaken, which reveals that the fruit is high in a range of nutrients, including carbohydrates, various vitamins, proteins, a variety of minerals, sugars, fatty acids, and fiber [11]. Table 1 shows the number and amount of nutritional composition found in Bael fruit. The fruit contains about 61% of moisture and multiple vitamins like vitamin A, vitamins B_1 and B_2, and vitamin C, along with minerals like potassium, phosphorous, iron, and calcium. Furthermore, it contains fiber, protein, and sugars both reducing and nonreducing. Its food value is 88 calories per 100 g, which is more plentiful than other common fruits like apples, guavas, and mangos, with 64, 59, and 36 calorific values, respectively. Moreover, it contains a high amount of riboflavin like no other fruit [2, 11]. According to the research performed by Bhattacherjee et al. on the nutraceutical profiling of Bael, the result shows that there is a significant impact on the nutritional composition at different stages of maturity and ripening of the fruit [12]. According to the study, the fruit at its early stage of growth is better for processing in food and pharmaceutical products because of its high concentrations of nutrients.

Table 1: Nutritional component of Bael fruit per 100 g [2, 4, 13, 14].

Component	Amount (%)
Protein	1.6-1.8
Carbohydrates	31.8-34.5
Fats	0.2-0.43
Fiber	2.9-4.80
Ash	2.63-2.83
Moisture	61.0-64.2
pH	4.95
Acidity	0.30
Reducing sugar	4.42
Nonreducing sugar	9.93
Vitamins	mg/100 g
Vitamin A	55-56
Thiamine (vitamin B_1)	0.9-0.13
Riboflavin (vitamin B_2)	1000-1200
Niacin (vitamin B_3)	0.9-1.1
Vitamin C	8.0-10.0
Minerals	mg/100 g
Cupper (Cu)	0.19-0.20
Zinc (Zn)	0.28
Calcium (Ca)	80.0-85.0
Phosphorus (P)	50.0-51.6
Potassium (K)	585-603
Magnesium (Mg)	4.00
Iron (Fe)	0.5-0.8

2.3. Phytochemical Composition. Several studies have been conducted to explore the phytoconstituents found in various parts of the plant. More than 100 different phytochemicals have been identified from various parts [15]. Alkaloids, terpenoids, coumarins, phenolic acids, flavonoids, tannins, carotenoids, amino acids, organic acids, and fatty acids are the major constituents. The phytochemicals present in Bael are dependent on the fruit's maturity. Like compound tannin, they are present in the unripe fruit, whereas marmelosin, auraptene, and marmelide are present in the fully ripe fruit. Besides fruits, the other parts of the plant, i.e., bark, leaves, roots, and seeds, are also rich in bioactive compounds. For example, fagarine is present in mature bark, and compound marmin and skimmianine are in immature bark. Similarly, citronellal, lupeol, aegelin, eugenol, cineol,

Table 2: Phytochemicals present in different parts of the plant and their medicinal value [3, 14, 15].

Parts	Bioactive compound	Medicinal value
Fruit	Marmelosin	Anthelminthic, antibacterial
	Luvangetin	Antiulcer
	Aurapten	Heartbeat inhibitor, hypertension
	Psoralen	Cytotoxic, antispasmodic, artemiside
	Marmelide	Antiviral
	Tannin	Antidiarrhea, astringent
	Riboflavin	Essential for growth, prevent glossitis and cheilosis
	β-carotene	Glaucoma, cataract
Leaves	Skimmianine	Hypothermic, antimethamphetamine, antipyretic, anticancer
	Cuminaldehyde	Antibacterial
	Lupeol	Anti-inflammatory
	Eugenol	Antioxidant, antiulcer, hepatoprotective
	Cineol	Antiulcer
	Citronellal	Antiseptic
	Marmesinin	Cardioprotective, antioxidant
	Aegelin	Antidyslipidemic, cardioactive
	Citral	Antiseptic, antiallergic
Bark	Marmin	Antiulcer
	Fagrine	Abortifacient

etc. are present in the plant's leaves, and luvangetin is isolated from the seeds of the Bael fruits [14]. The phytochemicals present in the plant account for the flavor and color of the fruit. More than that, they have been extensively studied for their antioxidant function as well as potential therapeutic benefits such as maintaining inflammation balance, reducing the risk of cancer, working against different pathogenic organisms, and promoting eye, cardiovascular, neurocognitive, and bone health in humans. Table 2 represents the phytochemicals present in various parts of the plant with their respective medicinal values.

Skimmianine, an alkaloid present in the leaves of the plant, has been studied for various health benefits, which exhibit anticancer activity against ovarian cancer [16]. It has also shown antidiuretic, hypothermic, antipyretic, anticonvulsive, analgesic, hypnotic, and sedative effects in various experimental animal models [15]. Similarly, aegelin present in the leaf is a cardioactive compound that has an antihyperglycemic property [17]. Cineole and eugenol have potent antioxidant properties. Furthermore, eugenol shows antibacterial activity along with hepatoprotective activity against CCl_4-induced hepatic damage [18, 19]. According to Shoba and Thomas [19], tannin in unripe fruit has astringent properties and is also an excellent treatment for diarrhea. Marmelide present in the fruit is shown to be antiviral, inhibiting the early stage of the viral replicative cycle [20]. Similarly, marmin present in the bark is found to be effective against ulcers [21].

3. Medicinal Importance

The consumption of fruits has been correlated with numerous health-protective and preventive benefits. Traditionally, various parts of the Bael plant are used for therapeutic purposes for different ailments, which are now found to be proven by numerous scientific studies. Different medicinal activities of the plant Bael have been briefly discussed in the following paragraphs.

3.1. Antimicrobial Activity. Many *in vitro* studies have been reported to inhibit a wide spectrum of pathogenic microorganisms, including bacteria, fungi, and viruses, by the different extracts of the Bael plant. In a study performed by Rani and Khullar, the methanolic extract of Bael against *Salmonella typhi* was found to be effective [22]. Similarly, in another study, the ethanolic extract showed antibacterial properties against *E. coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Bacillus subtilis* [23]. When tested, the leaf extract of the fruit was found to be effective against a variety of gram-positive bacteria, including *Bacillus cereus*, *Staphylococcus aureus*, *Staphylococcus epidermidis*, and *Enterobacter aerogenes*, primarily at a concentration of 40 g/ml [24]. This could be due to the presence of the compound eugenol and cumin aldehyde through different mechanisms like blockage of protein synthesis or peptidoglycan synthesis at the membrane level [25]. Furthermore, the antiviral activity of various parts of the plant has been demonstrated against human coxsackieviruses B1-B6. The compound marmelide, at a concentration of 62.5 g/ml, shows the most effective viricidal activity by interfering with the early stages of the viral replicative cycle. Even when compared to the standard antiviral drug ribavirin (2000 g/ml), the results show that it is more effective [20]. And the leaf extract of Bael shows antifungal activity against certain dermatophyte fungi like *Trichophyton mentagrophytes*, *Trichophyton rubrum*, *Microsporum canis*, *Microsporum gypseum*, and *Epidermophyton floccosum* [26].

3.2. Anticancer Activity. Cancer is one of the major causes of death worldwide. Researchers are looking at alternative natural sources of treatment due to the seriousness of the disease and the adverse effects of the drug used to treat it. In a study performed on the leaf extract of Bael, it was discovered to have anticancer properties. When performed in the different cell lines like erythroleukemic HEL, T-lymphoid Jurkat, melanoma Colo38, leukemic K562, breast cancer cell lines (MDA-MB 231), and β-lymphoid [27, 28]. Likewise, the compound marmelin extracted from Bael exhibits anticancer properties against human colon cancer (HCT-116), human epithelial type 2 (HEp-2), and alveolar epithelial carcinoma cells by suppressing the growth of cancerous cells, leading to apoptosis [13]. In a mouse experiment, the plant's fruit extract demonstrated chemopreventive activity against 7, 12-dimethylbenz[a] anthracene- (DMBA-) induced skin carcinogenesis. In the study, methanolic extract of the fruit at a concentration of 25 mg/kg and 50 mg/kg was seen to be more effective in suppressing hepatocarcinogenesis caused by induction

of diethylnitrosamine and 2-acetylaminofluorene, respectively, in Wistar rats. Other compounds like eugenol, rutin, citral, limonene, lupeol, and anthocyanins present in the fruit extract contribute to the chemoprotective effects [29, 30]. Lupeol showed anticancer effects against hepatocellular carcinoma cells, human epidermoid carcinoma cells, prostate carcinoma cell lines, human melanoma cells, and human pancreatic adenocarcinoma cells [31]. Similarly, citral from the fruit extract is effective against hematopoietic cell lines and eugenol can act against malignant Caco-2 colon cells, normal human gingival fibroblast (HGF), human melanoma cell lines, salivary gland tumor cell lines (HSG), and malignant HepG2 hepatoma cells [32, 33].

3.3. Cardioprotective Activity. Heart and blood vessel illnesses are the most common causes of cardiovascular disease, which include arrhythmia, stroke, hypertension, myocardial infarction, and atherosclerosis. Several risk factors, like cell-derived microparticles and hypercholesterolemia, are associated with these diseases. Medicinal plants are effective against these cardiovascular diseases, which help in the inhibition of lipid peroxidation, decrease the level of low-density lipoprotein, and enhance endothelial dysfunction [34]. A bioactive compound named linear furanocoumarin marmesinin, extracted from Bael, can protect against lipid peroxidation. In a study performed on albino Wister rats having myocardial injury when tested by the compound at a dosage of 200 mg/kg, the result showed a lower in serum enzyme levels and restored the electrocardiographic changes towards normalcy [35]. In another experiment conducted by Kakiuchi et al. to assess the potential of a compound isolated from the leaf of Bael called cardenolide and periplogenin against cardiotoxicity and lipid peroxidation in rats, administration of these compounds at a concentration of 25 mg/kg appeared to be effective in inhibiting cardiovascular problems such as an increase in serum creatine kinase–MB (CK–MB) and glutamate-pyruvate transaminase (SGPT). Further, the methanolic extract of Bael root were found to reduce heartbeat rate by up to 50% when administrated at a dosage of 100 g/ml on cultured mouse myocardial cells [36].

3.4. Antidiabetic Activity. A large number of global populations are suffering from diabetes, and it occurs due to a lack of insulin secretion in the human body. As a result, the level of glucose in the blood increases. In an experiment examined with the oral administration of an aqueous extract of Bael fruit in streptozotocin-induced diabetic rats, a major reduction in blood glucose level was seen along with lower glycosylated haemoglobin and increased insulin level. A concentration of 250 mg/kg of fruit extract was demonstrated to be more efficient than the well-known antidiabetic drug glibenclamide [37]. Similarly, umbelliferon, β-D-glucopyranosyl-(2I 1II), β-D-glucopyranoside extracted from Bael shows hypoglycemic activity by lowering serum glucose, glycated haemoglobin, and glucose-6-phosphate and increasing the level of hexokinase and plasma insulin in diabetic rats [38]. A significant reduction in blood glucose was observed when a normal fasted rabbit was orally administered a Bael leaf extract at a concentration of 500 mg/kg [39]. In a clinical trial with diabetes mellitus patients treated with leaf extract for 15 days, there was a decrease in blood cholesterol with a decreased level of blood glucose [38].

3.5. Antiulcer Activity. An ulcer is a common gastrointestinal tract disease that may be caused by the infection of *Helicobacter pylori* or by using nonsteroidal anti-inflammatory drugs. This leads to exposure of acid-pepsin secretions to the upper gastrointestinal tract. Similarly, the research conducted by Ilavarasan et al. to evaluate the efficiency of Bael against gastric ulcers and oral administration of 1 g/kg of the aqueous extract of leaves of Bael for 21 days against *Helicobacter pylori* lipopolysaccharide-induced gastric ulcer in rats showed a significant reduction in the ulcer lesion count, the volume of gastric juice, and acidity and an increase in pH and hexosamine [40]. It has been found that the compound luvangetin present in Bael seed exhibits protective activity against gastric ulcers [41]. In an experiment conducted to study the antiulcer activity of unripe Bael fruit extract in experimental rats, the result showed significant inhibition of gastric mucosal damage [42, 43], which may be due to the presence of phenolic compounds in the plant. The phenolic compound is a source of antioxidants and exhibits a powerful gastroprotective property which may act through inhibition of oxidative stress induced in the gastroduodenal mucosa [44].

3.6. Antioxidant Activity. The presence of antioxidant components such as β-carotene, glutathione, β-tocopherol, ascorbic acid, total polyphenols, and flavonoids contributes to Bael's antioxidant properties. These compounds can control autoxidation by reducing the formation of free radicals or interfering with the generation of free radicals, inhibiting oxidative stress caused by metabolic processes or other environmental and chemical factors. Numerous studies have been conducted to investigate the antioxidant activity of the plant Bael by using different methods like the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, the ABTS radical scavenging assay, and the superoxide radical scavenging assay. Both chloroform and aqueous extracts of Bael can exhibit antioxidant activity, and it shows that unripe fruit extract has more free radical scavenging activity than ripe fruit [45]. In a study carried out to find the antioxidant activity of methanolic extracts of different parts of the Bael plant by the DPPH method, the highest free radical scavenging effect was observed in leaves. The leaf extract's free radical scavenging activity was found to be approximately ten times that of the reference antioxidant butylated hydroxytoluene (BHT) [46].

3.7. Anti-inflammatory Activity. Though inflammation is a natural defense mechanism to combat pathogens and autoimmune reactions, it can also contribute to many health issues like diabetes, heart disease, cancer, and arthritis. The presence of compounds like lupeol and skimmianine in Bael possesses significant anti-inflammatory activity [47]. In an *in vitro* study, ethanolic extract of the plant leaves exhibited

the highest anti-inflammatory activity (88.160.25) at 100 g/ml with an IC50 value of 34.59 g/ml. Similarly, when different extracts of *Bael* leaves were induced in rats having carrageenan-induced paw edema at a dose of 50 mg/kg, the result showed that acetone, chloroform, and methanol extract held a highly significant anti-inflammatory effect [48]. Moreover, furanocoumarin isolated from fruits exhibits both anti-inflammatory and antioxidant activities. The anti-inflammatory property was observed with about a 3.9-times decrease in the release of nitric oxide and a 3.4-times decrease in the release of tumor necrosis factor (TNF) in the immunomodulatory potential standard assay [49].

Most of the anti-inflammatory compounds act *via* the inhibition of histamine-mediated signalling. The alcoholic extract obtained from the leaves of the fruit is capable of neutralizing contraction induced by histamine, which leads to the inhibition of the H1 receptor and demonstrates a positive relaxant effect in isolated tracheal chains and guinea pig ileum [50].

3.8. Bioadhesive Property. Bael fruit gum is an excellent biopolymer having a different biomedical application. Bael fruit gum is a nonionic polysaccharide containing a high amount of galacturonic acid and D-galactose providing a greater solubility and water-holding capacity [51, 52]. A different study has shown the use of gum as a gelling agent in food items, as a carrier molecule for controlling drug release, and as an adhesive material [53]. In a study performed by Mirza et al., a nanocomposite scaffold of Bael fruit with chitosan and hydroxyapatite revealed that the nanocomposite exhibits enhanced cell adhesion and proliferation [54]. Based on this study, we can say that a nanocomposite fabricated with Bael fruit gum has a high potential to be applied in bone tissue engineering.

3.9. Hepatotoxicity Property. Given the diverse medicinal properties of the Bael fruit, detailed study was conducted to evaluate the hepatoprotective effective of the fruit leaf extract by Singanan et al., in an alcohol-induced liver injury in an animal model [55]. The study measured the levels of TBARS (thiobarbituric acid reactive substances), a biomarker of lipid peroxidation, in the liver tissues of the rats. The results showed that the TBARS levels were significantly increased in the alcohol-intoxicated group, while the Bael-treated group had lower levels of TBARS compared to the alcohol-intoxicated group. The hepatoprotective effect of Bael leaves was found to be comparable to that of silymarin [55]. Similarly, the other study investigated the hepatoprotective and antioxidant effects of the fruit's leaf extract in carbon tetrachloride (CCl_4) induced liver toxicity in rats. The study also explored the potential synergistic effect of leaf extract with piperine. The results showed that CCl_4 administration caused marked liver damage and oxidative stress in rats. However, treatment with A. marmelos extract reduced the severity of toxicity in a dose-dependent manner. The low dose of A. marmelos extract (for example, 25 mg/kg) was found not to significantly reverse the hepatotoxicity, but when combined with piperine, it showed remarkable hepatoprotective effects.

The study concluded that A. marmelos extract exerted potential hepatoprotective activity through its antioxidant and anti-inflammatory properties. Moreover, the cotreatment with piperine enhanced its hepatoprotective effect, which may have therapeutic implications in the treatment of liver damage [56].

3.10. Antiviral Property. In recent days, viral infections have become a serious issue causing unexpected health problems around the world. Medicinal plants and their phytochemicals present have been a rich source of nutrients and drugs for the prevention and treatment of various viral diseases. Seselin, a bioactive compound found in Bael plant, has been found to have inhibitory potential against multiple targets of SARS-CoV-2, according to a study conducted using in silico molecular docking. The compound showed inhibitory potential to the receptors SARS-CoV-2S protein, COVID-19 main protease, and free enzyme of the SARS-CoV-2 main protease [57]. Similarly, in the study done by Badam et al., different bioactive compounds from the Bael fruit have been evaluated for the antiviral activity against human coxsackieviruses B1-B6. The inhibitory concentrations for these compounds were determined by plaque inhibition assay, and marmelide was found to be the most effective viricidal agent. These concentrations did not exhibit any toxicity to host cells, and marmelide interfered with early events in the virus's replicative cycle. The study suggests that Bael compounds, particularly marmelide, have potential as antiviral agents against coxsackieviruses [20, 58]. Furthermore, in the study investigated by Andleeb et al., the potential of Aegle marmelos (Bael) extracts from its leaves and fruits for their total phenolic and flavonoid contents, antioxidants, and antibiofilm activity, as well as in ovo antiviral activity against Newcastle disease virus (NDV), was studied. The results showed that the extracts had high levels of TPC and TFC and demonstrated potent antioxidant and antibiofilm activities. The extracts also showed promising antiviral activity against NDV, and molecular docking studies indicated a good interaction with the HN protein. These findings suggest that A. marmelos could be used as a potential remedy for NDV [59].

4. Entrepreneurial Aspects

4.1. Prospects for the Development of Functional Products. The fruit is the most precious and consumable component of the plant. Despite its excellent flavor, nutritive content, and therapeutic values, it is still regarded as an underutilized fruit. Because of the hard shell, the gluey texture, and the numerous seeds, the fruit is difficult to eat and is not popular as a table fruit. So, further processing is needed for the easy consumption of fruits, which have an enormous potential to be developed as nutraceuticals. With growing global awareness and interest in natural products, Bael has emerged as one of nature's most remarkable fruits, endowing us with numerous benefits. Bael can play a significant protective role against many infections and diseases. Commendable flavor and its characteristics increase its importance. However, the industrial production of fruit products is yet to be

Table 3: Functional food application of Bael fruit with their processing technique.

Product	Processing technology	Product feature	Reference
(1) Juice	Enzymatic extraction (using pectinase and cellulose)	Juice yield 82.9%	[60]
(2) Beverage	Extraction and fortification with whey protein and pectin	Protein-rich beverage	[61]
(3) Jam (mixed fruit)	Pulp extraction and preservation with sugar	45%, 1 : 1 Bael and mango pulp; 0.5% acidity	[11]
(4) Wine	Fermentation	10.08% alcohol after 88 h fermentation at pH 5	[14]
(5) Beer	Fermentation	Beer with 1.75% protein, 16 °Bx, pH 3.9	[62]
(6) Candy	Dipping in sugar syrup and drying	4-month shelf life in polythene pouch	[63]
(7) Slab	Drying	Pulp with 0.5% acidity, 0.07% KMS, and 35% TSS. Moisture 14.5%	[64]
(8) Powder	Dehydration and grinding	More amount of carbohydrate and iron	[65]
(9) Panjiri	Dehydration, grinding, and roasting	Pulp : butter oil : sugar = 1 : 1 : 1.5	[14]
(10) Preserve	Preservation with syrup	Syrup concentration maintained at 70%	[66]
(11) Leather	Pulp extraction, kneading, and drying	Preserve the fruits' nutraceutical properties	[67, 68]

commercialized. The fruit and its products are only available in the locally based market, although they have the potential to be developed into a business as a value-added product. This plant can be used to cope with health issues related to nutrition at an affordable cost. Plants can be promoted and used to help low-income countries improve their economies and create livelihoods. The functional food applications of the fruit are listed in Table 3. Powder, jam, squash, toffee, slabs, juice, and wine are all possible products made from fruit. Little research has been performed on processed products from the fruit, which is briefly mentioned in the following paragraphs.

4.1.1. Powder. Fruit powder is a form of dried fruit that has been pulverized into a fine or ground powder that can be prepared simply by grinding dried fruit. This can be done with either dehydrated or freeze-dried fruit. Freeze-dried fruit will typically yield a finer powder than dehydrated fruit. It is a concentrated, pure type of fruit pulp that can be stored for a long time and has a high medicinal value. According to the findings of a study to characterize the nutraceutical properties of Bael powder prepared from fruits harvested at various developmental stages, a powder prepared from dehydrated unripe fruits possessed significantly higher amounts of potassium, iron, marmelosin, psoralen, and tannic acid, whereas powder prepared from dehydrated ripe fruits possessed significantly higher amounts of zinc, copper, polyphenols, and antioxalate. The powder prepared can be stored in a polythene bag to maintain a dry condition for a longer period [60]. Furthermore, Rmna et al. investigated the loss of antioxidant and physicochemical properties of fruit throughout processing, finding a loss of β-carotene and total phenolic content in vacuum-dried samples when compared to solar-dried and hot air oven-dried samples [69]. As a result, the study advises vacuum drying over solar and hot air oven drying for improved fruit powder qualities. Similarly, in the study done by Porwal et al., the Bael powder sample developed using the optimized spray-drying process contains higher amounts of ascorbic acid when compared to commercial fruit juice powders [70].

4.1.2. Beverage. Increasing demand for nutraceutical drinks has shifted the market towards natural drinks extracted from plant parts such as roots, flowers, fruits, leaves, or seeds that offer a variety of functional benefits. Numerous studies have been conducted successfully for the preparation of different beverages from Bael. A whey protein-enriched drink was formulated. A mixture of pectin, carboxymethyl cellulose, and whey protein concentrate with the fruit juice was prepared, and the drink with 16 °Bx total soluble solids (TSS), 3.9 pH, and 25% pulp was found to be the best [62]. Similarly, blended drinks from Bael and guava were prepared with the incorporation of different proportions of pulp. A ready-to-serve drink with 15% guava and 20% Bael pulp with 15% TSS and 0.26% acidity was considered the best in terms of overall acceptability [71]. Moreover, ready-to-serve drinks blended with other different fruits like tamarind, orange, pineapple, and lime were also successfully prepared [72]. The drinks were prepared by adding sugar, citric acid, and water to achieve the desired levels of TSS, acidity, and dilution. After the preparation, they were collected in sterilized bottles, which were pasteurized, cooled, and stored at the desired temperature.

4.1.3. Toffee. Toffee is a brittle confectionery made from a mixture of syrup and butter with added flavor and color. They prepare the bale fruit toffee by incorporating herbs like cinnamon and cardamom [73]. To get the desired flavor and nutritional content, the toffee was made by mixing the fruit pulp with sugar, butter, milk powder, corn flour, and citric acid, as well as various quantities of cinnamon and cardamom. The products were allayed for moisture, total ash, and acidity, and the prepared toffee with 0.5 g was found to be the best.

4.1.4. Slab. Fruit slabs are also a good method to make fruit more usable and acceptable. It was prepared by mixing the pulp with sugar, citric acid, and potassium metabisulfite. Pulp TSS and acidity are maintained at 35% and 0.5%, respectively. To maintain moisture content, the prepared slab was dried at 55-60°C for 15–26 hours. After drying, the final product is wrapped with butter paper and polyethylene as a moisture barrier [64].

4.1.5. Snarl. Because Bael fruit is not available all year, jam is a method of preserving it sometimes also in combination with other fruits. For instance, a mixture of Bael and mango was used to prepare the jam by Singh and Nath's product processing [62]. Various combinations of pulp were prepared, but the final optimized product contained 45% mixed pulp in an equal proportion, 70% TSS, and 0.5% acidity [62].

4.1.6. Leather. Fruit leathers are thin, dehydrated sheets that are made from pureed fruits or a blend of fruit juice concentrates and other high-quality ingredients that offer excellent nutritional value and sensory characteristics. Bael fruit pulp-based leather using sugar, citric acid, and a thickening agent to improve its palatability and increase utilization was prepared, and proximate analysis revealed that the final product contained 2% ash, 2.3% crude protein, 0.1% fat, 3.9% fiber, and 8.9% moisture. The developed Bael fruit leather was found to be safe for storage for 6 months at room temperature under vacuum-packed conditions. The product's microbial, physicochemical, and sensory properties were evaluated and found to be satisfactory [67, 68].

4.1.7. Other Product. The fruit could be used to prepare various value-added products. Dehydrated Bael was made from mature fruit by slicing it into thick slices and fumigating it with SO_2 for 30 minutes. After the fruit has been dried in an oven at 55–60°C, likewise, Bael candy, panjeri (a traditional Indian dish), Bael wine, and preserves can be prepared by different processing technologies [14]. These products are highly nutritious and different from market commodities. They are minimally processed, preserving their freshness and making them ready to use and consume.

4.2. Innovations in Processing Technology. Modern lifestyles and diets encourage adequate demand for and storage of fruits and their products, which influenced the development and application of various processing methods for fruit preservation. Examples of processing include drying, concentrating, heating, baking, frying, cooling, acidification, fermentation, and the use of additives like preservatives. Modern processing techniques include the application of high temperatures like sterilization and pasteurization, freeze-drying, aseptic packaging, vacuum packaging, microfiltration, and membrane processing. Processing techniques increase the quality and shelf life of a product. Processed fruit products generally include fresh-cut fruit; fermented products like cider, wine, beer, and pickling; thermally produced products like jams, candies, syrups, jellies, and beverages; and nonthermally processed products like juice, ice cream, and ready-to-eat beverages. Because fresh fruit is more perishable, antimicrobial and antibrowning agents could be incorporated into fresh-cut fruits by dipping, spraying, or coating them with edible ingredients. Other advanced processing approaches include high-pressure homogenization, microfluidization, ultrasound emulsification, high-pressure processing, and ultra-high-pressure processing. For heat- and cold-sensitive products, high-pressure processing like nonthermal pasteurization technology is used. This technology preserves the nutritional content of fruit juice and its biological properties, as well as the product's quality and shelf life. Similarly, ultra-high-pressure processing preserves bioactive compounds like vitamin C and carotenoids in products [74].

Use of masking techniques like encapsulation using extrusion, liposomes, and spray drying is used for encapsulating both liquid droplets and solid particles of a sensitive substance within an edible coating material such as cellulose, starch, alginate, chitosan, pectin, carrageenan, and gum to preserve bioactive components. The application of edible coatings is one of the effective technologies used to deliver active ingredients, shelf-life extension, and ease of handling. Major fruit processing techniques are listed in Figure 1.

Furthermore, a recent study has reported the engineering properties of the fruits (such as physical, frictional, thermal, textural, and mechanical behaviours) which would be beneficial for researchers and entrepreneurs in designing processing equipment for sorting, grading, puncturing, pulping, conveying, storage, packaging, transporting, and storing of the fruit [75, 76]. Similarly, in the study conducted by Sarkar et al., principal component analysis was performed for both fresh and differently dried fruit pulps based on nutritional, color, sensory, and texture properties which helps in product development and commercialization of the product [77].

4.3. Waste Utilization. Fruit waste is a significant challenge for many industries, particularly the food processing and agricultural sectors. Millions of tons of fruit waste are generated annually, resulting in environmental pollution and economic losses [78]. However, fruit waste can also be a valuable resource with enormous potential for the production of biofuels, animal feed, and fertilizers. Moreover, fruit waste utilization can contribute to a circular economy model and promote sustainable agriculture practices [78, 79]. The waste material resulting from the processing of fruits is predominantly composed of seed, skin, rind, and pomace, which contain a plethora of valuable bioactive compounds. These phytochemicals include carotenoids, polyphenols, dietary fibers, vitamins, enzymes, and oils, among others, and offer potential applications in various industries. For instance, they can be utilized in the food industry to develop functional or enriched foods, in the health industry for the production of nutraceuticals, in textile industry, among other applications. The conversion of fruit waste into bioactive components represents a critical pathway towards achieving sustainable development [80].

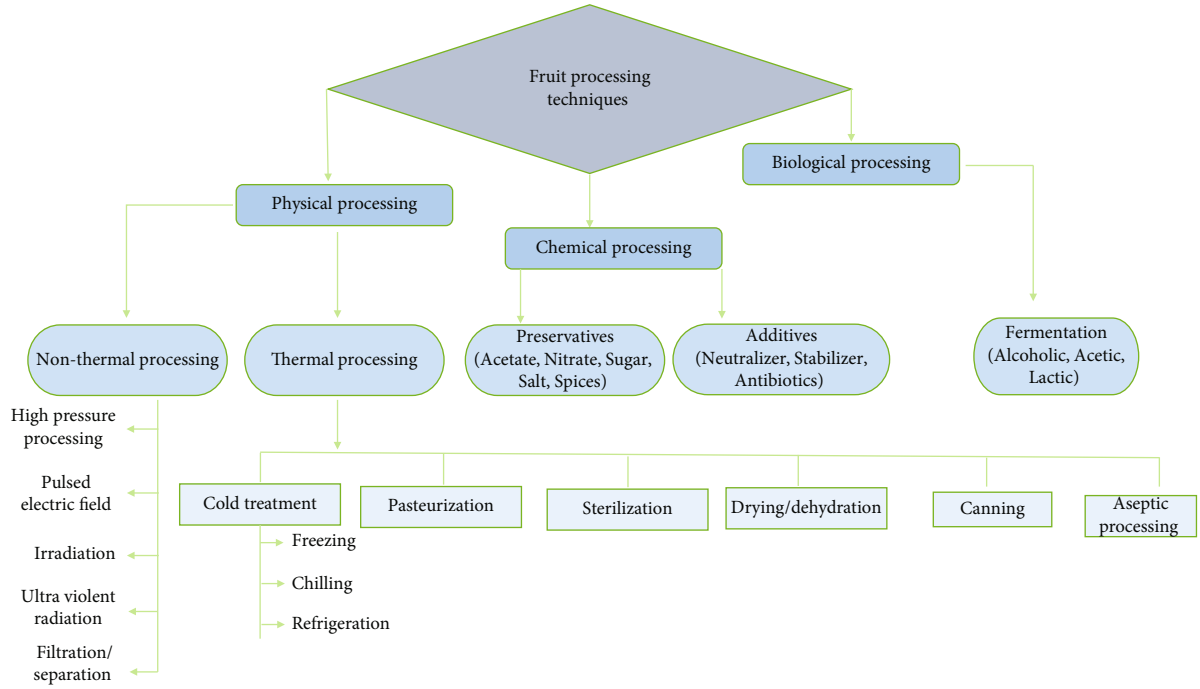


Figure 1: Schematics represent different innovative techniques used in the fruit processing industry.

The processing of Bael fruit generates a significant amount of waste, including the peels, seeds, and pulp residues. The disposal of Bael fruit waste poses environmental problems such as soil and water pollution and methane emissions. Nevertheless, Bael fruit waste also presents a valuable resource that can be utilized for various purposes. Recent studies have demonstrated the potential of Bael fruit waste in producing bioactive compounds, such as polyphenols, flavonoids, and carotenoids [81]. Similarly, in a recent study, pectin from Bael pulp residue was extracted and its physicochemical properties were evaluated which showed antioxidant activity and a total phenolic content of 58.5 mg GAE/g. Additionally, the prebiotic potential of the extracted pectin was confirmed. The study shows that Bael pulp residue can serve as an alternative source of high-value pectin for various biological applications [82].

4.4. Way Forward. The global trade of medicinal plants and their products is expected to be worth USD 5 trillion by 2050 [83]. Despite the various nutritional and medicinal properties of Bael fruit, there seems to be a lack of information available in the literature regarding its economic status and market value. Extensive searches of various databases and publications have yielded no concrete data on the financial potential of this fruit in the global market. This lack of information poses a significant obstacle to the development of the Bael fruit industry and the promotion of this fruit as a functional food ingredient. Therefore, further research is required to explore the commercial potential of Bael fruit and to determine its economic viability as an ingredient in the food industry. Such studies could help to identify gaps in the current market and pave the way for the development of innovative and sustainable value chains for this underutilized fruit.

5. Conclusion

Considering scientific literature, many edible plant species, due to their characteristics, can be developed as new ingredients useful to generate health benefits or to be exploited for the preparation of food supplements or medicinal foods. Such plants are gaining importance around the world, in both poor and developed countries, owing to the high expense of synthetic medicines, as well as their common adverse side effects. Herbal drugs are abundantly available as they are cheap and have no side effects. People's changing behavior towards healthy food habits and their health has led to the growing development of functional food products in the market. Therefore, the study of underutilized plants and their products has been explored for several ethnobotanical purposes. Historically, Bael has been used to treat several human diseases. The presence of different bioactive compounds and their nutritional composition makes it a potential fruit to be developed as a nutraceutical. Despite having many health benefits, the fruit is still underutilized and has been used locally. Apart from exploring the possibilities of using the different plant parts as medicine, the production of different functional products by using its fruits should be promoted at a commercial level. In the future, it could be developed as a functional food product and play a significant role in healthy living.

Conflicts of Interest

The authors declare that there is no conflict of interest.

Acknowledgments

We gratefully acknowledge the University Grants Commission (UGC), Nepal, for supporting this work through the research Grant "Innovative Technology Development and Materials Characterization (2020-2021)" in the frame of "Innovative Technology Development and Scientific Exploration on Nation's Priority Areas."

References

[1] K. Baral and B. R. Upreti, "Resource assessment of Bel (*Aegle marmelos*) and potentiality to establish its processing enterprise in Tanahun district of Nepal," *Banko Janakari*, vol. 26, no. 1, pp. 32–37, 2016.

[2] D. Kumar Sekar, G. Kumar, L. Karthik, and K. V. B. Rao, "A review on pharmacological and phytochemical properties of *Aegle marmelos* (L.) Corr. Serr. (Rutaceae)," *Pelagia Research Library Asian Journal of Plant Science and Research*, vol. 1, no. 2, pp. 8–17, 2011.

[3] S. S. Mali, R. L. Dhumal, V. D. Havaldar, S. S. Shinde, N. Y. Jadhav, and B. S. Gaikwad, "A systematic review on*Aegle marmelos*(bael)," *Research Journal of Pharmacognosy and Phytochemistry*, vol. 12, no. 1, p. 31, 2020.

[4] M. S. Baliga, H. P. Bhat, N. Joseph, and F. Fazal, "Phytochemistry and medicinal uses of the bael fruit (*Aegle marmelos* Correa): a concise review," *Food Research International*, vol. 44, no. 7, pp. 1768–1775, 2011.

[5] P. Axay, G. Dipak, C. Manodeep, and K. Jagdish, "*Aegle marmelos* (Linn.): a therapeutic boon for human health," *International Journal of Research in Ayurveda & Pharmacy*, vol. 3, no. 2, 2012.

[6] K. Bhar, S. Mondal, and P. Suresh, "An eye-catching review of *Aegle marmelos* L. (golden apple)," *Pharmacognosy Journal*, vol. 11, no. 2, pp. 207–224, 2019.

[7] P. N. Atul, D. V. Nilesh, R. A. Akkatai, and K. S. K. R. Shahu, "A review on *Aegle marmelos*: a potential medicinal tree," *International Research Journal of Pharmacy*, vol. 3, no. 8, 2012.

[8] K. Kumar, M. Umadevi, and D. Bhowmik, "Recent trends in medicinal uses and health benefits of Indian traditional herbs *Aegle marmelos*," *The Pharma Innovation*, vol. 1, no. 4, 2012.

[9] S. Jyotsana, R. M. Painuli, and R. D. Gaur, "Plants used by the rural communities of district Shahjahanpur, Uttar Pradesh," *Indian Journal of Traditional Knowledge*, vol. 9, no. 4, 2010.

[10] M. K. Gautam, V. Purohit, M. Agarwal, A. Singh, and R. K. Goel, "*In vivo* healing potential of *Aegle marmelos* in excision, incision, and dead space wound models," *The Scientific World Journal*, vol. 2014, Article ID 740107, 9 pages, 2014.

[11] R. L. Bhardwaj and U. Nandal, "Nutritional and therapeutic potential ofbael(*Aegle marmelos*Corr.) fruit juice: a review," *Nutrition & Food Science*, vol. 45, no. 6, pp. 895–919, 2015.

[12] A. K. Bhattacherjee, A. Dikshit, and D. K. Tandon, "Nutraceutical changes during ripening of bael [*Aegle marmelos* (L.) Correa] fruits harvested at different maturity periods," *Indian Journal of Traditional Knowledge*, vol. 19, no. 2, pp. 416–422, 2020.

[13] H. N. Murthy, M. A. Bhat, and D. Dalawai, "Bioactive compounds of bael (*Aegle marmelos* (L.) Correa)," in *Bioactive compounds in underutilized fruits and Nuts*, Springer, 2019.

[14] A. Venthodika, N. Chhikara, S. Mann, M. K. Garg, S. A. Sofi, and A. Panghal, "Bioactive compounds of *Aegle marmelos* L., medicinal values and its food applications: a critical review," *Phytotherapy Research*, vol. 35, no. 4, p. 2021, 2020.

[15] P. Maity, D. Hansda, U. Bandyopadhyay, and D. K. Mishra, "Biological activities of crude extracts and chemical constituents of bael, *Aegle marmelos* (L.) Corr," *Indian Journal of Experimental Biology*, vol. 47, pp. 849–861, 2009.

[16] G. C. Jagetia, P. Venkatesh, and M. S. Baliga, "*Aegle marmelos* (L.) Correa inhibits the proliferation of transplanted Ehrlich ascites carcinoma in mice," *Biological & Pharmaceutical Bulletin*, vol. 28, no. 1, pp. 58–64, 2005.

[17] K. Papi Reddy, A. B. Singh, A. Puri, A. K. Srivastava, and T. Narender, "Synthesis of novel triterpenoid (lupeol) derivatives and their in vivo antihyperglycemic and antidyslipidemic activity," *Bioorganic & Medicinal Chemistry Letters*, vol. 19, no. 15, pp. 4463–4466, 2009.

[18] P. Kumaravelu, D. P. Dakshinamoorthy, S. Subramaniam, H. Devaraj, and N. S. Devaraj, "Effect of eugenol on drug-metabolizing enzymes of carbon tetrachloride- intoxicated rat liver," *Biochemical Pharmacology*, vol. 49, no. 11, pp. 1703–1707, 1995.

[19] F. G. Shoba and M. Thomas, "Study of antidiarrhoeal activity of four medicinal plants in castor-oil induced diarrhoea," *Journal of Ethnopharmacology*, vol. 76, no. 1, pp. 73–76, 2001.

[20] L. Badam, S. S. Bedekar, K. B. Sonawane, and S. P. Joshi, "*In vitro* antiviral activity of bael (*Aegle marmelos* Corr) upon human coxsackieviruses B1-B6," *Journal of Communicable Diseases*, vol. 34, no. 2, pp. 88–99, 2002.

[21] H. Takase, K. Yamamoto, H. Hirano, Y. Saito, and A. Yamashita, "Pharmacological profile of gastric mucosal protection by marmin and nobiletin from a traditional herbal medicine, *Aurantii Fructus Immaturus*," *Japanese Journal of Pharmacology*, vol. 66, no. 1, pp. 139–148, 1994.

[22] P. Rani and N. Khullar, "Antimicrobial evaluation of some medicinal plants for their anti-enteric potential against multi-drug resistant Salmonella typhi," *Phytotherapy Research*, vol. 18, no. 8, pp. 670–673, 2004.

[23] J. Wei, S. Wang, D. Pei et al., "Antibacterial activity of hydroxytyrosol acetate from olive leaves (*Olea europaea* L.)," *Natural Product Research*, vol. 32, no. 16, pp. 1967–1970, 2018.

[24] F. Mujeeb, P. Bajpai, and N. Pathak, "Phytochemical evaluation, antimicrobial activity, and determination of bioactive components from leaves of *Aegle marmelos*," *BioMed Research International*, vol. 2014, Article ID 497606, 11 pages, 2014.

[25] J. A. Duke, *Handbook of Biologically Active Phytochemicals and Their Activities*, CABI, 1992.

[26] V. Pratheepa, S. Ramesh, and N. Sukumaran, "Immunomodulatory effect of *Aegle marmelos* leaf extract on freshwater fish Cyprinus carpio infected by bacterial pathogen Aeromonas hydrophila," *Pharmaceutical Biology*, vol. 48, no. 11, pp. 1224–1239, 2010.

[27] I. Lampronti, D. Martello, N. Bianchi et al., "*In vitro* antiproliferative effects on human tumor cell lines of extracts from the Bangladeshi medicinal plant *Aegle marmelos* Correa," *Phytomedicine*, vol. 10, no. 4, pp. 300–308, 2003.

[28] S. Rahman and R. Parvin, "Therapeutic potential of *Aegle marmelos* (L.)-an overview," *Asian Pacific Journal of Tropical Disease*, vol. 4, no. 1, pp. 71–77, 2014.

[29] T. Husain Khan and S. Sultana, "Effect of *Aegle marmelos* on DEN initiated and 2-AAF promoted hepatocarcinogenesis: a chemopreventive study," *Toxicology Mechanisms and Methods*, vol. 21, no. 6, pp. 453–462, 2011.

[30] S. Jatav, P. Dwivedi, M. Singh, N. Sehra, and B. B. Mishra, "Properties and important molecules of medicinal interest in wood apple (*Aegle marmelos*)," in *Synthesis of Medicinal Agents from Plants*, pp. 127–150, Elsevier, 2018.

[31] A. Chandrasekara, J. Daugelaite, and F. Shahidi, "DNA scission and LDL cholesterol oxidation inhibition and antioxidant activities of *Bael* (*Aegle marmelos*) flower extracts," *Journal of Traditional and Complementary Medicine*, vol. 8, no. 3, pp. 428–435, 2018.

[32] D. Subramaniam, P. Giridharan, N. Murmu et al., "Activation of apoptosis by 1-hydroxy-5,7-dimethoxy-2-naphthalene-carboxaldehyde, a novel compound from *Aegle marmelos*," *Cancer Research*, vol. 68, no. 20, pp. 8573–8581, 2008.

[33] A. Perumal, S. Krishna, and M. Madhusree, "GC-MS analysis, antioxidant and antibacterial activities of ethanol extract of leaves of *Aegle marmelos* (L.) Corrêa," *Journal of Drug Delivery and Therapeutics*, vol. 8, no. 4, pp. 247–255, 2018.

[34] K. R. Paudel, R. Karki, and D. W. Kim, "Cepharanthine inhibits in vitro VSMC proliferation and migration and vascular inflammatory responses mediated by RAW264.7," *Toxicology In Vitro*, vol. 34, pp. 16–25, 2016.

[35] V. Vimal and T. Devaki, "Linear furanocoumarin protects rat myocardium against lipidperoxidation and membrane damage during experimental myocardial injury," *Biomedicine & Pharmacotherapy*, vol. 58, no. 6–7, pp. 393–400, 2004.

[36] N. Kakiuchi, L. Senaratne, S. L. Huang et al., "Effects of constituents of Beli (*Aegle marmelos*) on spontaneous beating and calcium-paradox of myocardial cells1," *Planta Medica*, vol. 57, no. 1, pp. 43–46, 1991.

[37] N. Kamalakkannan and P. S. M. Prince, "Hypoglycaemic effect of water extracts of *Aegle marmelos* fruits in streptozotocin diabetic rats," *Journal of Ethnopharmacology*, vol. 87, no. 2–3, pp. 207–210, 2003.

[38] P. C. Sharma, V. Bhatia, N. Bansal, and A. Sharma, "A review on bael tree," *Natural Product Radiance*, vol. 6, no. 2, 2007.

[39] P. V. Seema, B. Sudha, P. S. Padayatti, A. Abraham, K. G. Raghu, and C. S. Paulose, "Kinetic studies of purified malate dehydrogenase in liver of streptozotocin-diabetic rats and the effect of leaf extract of *Aegle marmelose* (L.) Correa ex Roxb," *Indian Journal of Experimental Biology*, vol. 34, no. 6, pp. 600–602, 1996.

[40] R. IIavarsan, S. Monideens, and M. Vijayalakshmi, "Antiulcer activity of *Aegle marmelos*," *Ancient Science of Life*, vol. 21, no. 4, pp. 256–259, 2002.

[41] C. V. Rao, S. K. Ojha, K. Radhakrishnan et al., "Antiulcer activity of *Utleria salicifolia* rhizome extract," *Journal of Ethnopharmacology*, vol. 91, no. 2-3, pp. 243–249, 2004.

[42] J. Dhuley, "Investigation on the gastroprotective and antidiarrhoeal properties of *Aegle marmelos* unripe fruit extract," *Hindustan Antibiotics Bulletin*, vol. 45-46, no. 1-4, pp. 41–46, 2003.

[43] T. K. Mahato, "Exploring antibacterial & antiulcer activity of *Aegle marmelos* Linn. : a review," *International Journal of Pharmaceutical Chemistry and Analysis*, vol. 7, no. 3, pp. 107–112, 2020.

[44] S. Karakaya, "Bioavailability of phenolic compounds," *Critical Reviews in Food Science and Nutrition*, vol. 44, no. 6, pp. 453–464, 2004.

[45] S. Sundaram, E. Gupta, and S. Alok, "Phytochemical evaluation and determination of antioxidant activity in different parts of *Aegle marmelos*," *International Journal of Pharmaceutical Sciences and Research*, vol. 11, no. 11, pp. 5898–5911, 2020.

[46] N. A. Siddique, M. Mujeeb, A. K. Najmi, and M. Akram, "Evaluation of antioxidant activity, quantitative estimation of phenols and flavonoids in different parts of *Aegle marmelos*," *African Journal of Plant Science*, vol. 4, no. 1, pp. 1–5, 2010.

[47] G. Angajala, R. Ramya, and R. Subashini, "*In-vitro* anti-inflammatory and mosquito larvicidal efficacy of nickel nanoparticles phytofabricated from aqueous leaf extracts of *Aegle marmelos* Correa," *Acta Tropica*, vol. 135, no. 1, pp. 19–26, 2014.

[48] V. Arul, S. Miyazaki, and R. Dhananjayan, "Mechanisms of the contractile effect of the alcoholic extract of *Aegle marmelos* Corr. on isolated guinea pig ileum and tracheal chain," *Phytomedicine*, vol. 11, no. 7–8, pp. 679–683, 2004.

[49] H. Pynam and S. M. Dharmesh, "Antioxidant and anti-inflammatory properties of marmelosin from bael (*Aegle marmelos* L.); Inhibition of TNF- α mediated inflammatory/tumor markers," *Biomedicine & Pharmacotherapy*, vol. 106, pp. 98–108, 2018.

[50] S. Balakumar, S. Rajan, T. Thirunalasundari, and S. Jeeva, "Antifungal activity of *Aegle marmelos* (L.) Correa (Rutaceae) leaf extract on dermatophytes," *Asian Pacific Journal of Tropical Biomedicine*, vol. 1, no. 4, pp. 309–312, 2011.

[51] M. Jindal, V. Rana, V. Kumar, R. S. Singh, J. F. Kennedy, and A. K. Tiwary, "Sulfation of *Aegle marmelos* gum: synthesis, physico-chemical and functional characterization," *Carbohydrate Polymers*, vol. 92, no. 2, pp. 1660–1668, 2013.

[52] A. Roiy, A. K. Mukherjee, and C. V. N. Rao, "The structure of bael (*Aegle marmelos*) gum," *Carbohydrate Research*, vol. 54, no. 1, pp. 115–124, 1977.

[53] N. Mahammed, D. V. Gowda, R. D. Deshpande, and S. Thirumaleshwar, "Design of phosphated cross-linked microspheres of bael fruit gum as a biodegradable carrier," *Archives of Pharmacal Research*, vol. 38, no. 1, pp. 42–51, 2015.

[54] S. Mirza, I. Zia, R. Jolly, S. Kazmi, M. Owais, and M. Shakir, "Synergistic combination of natural bioadhesive *bael fruit gum* and chitosan/nano-hydroxyapatite: a ternary bioactive nanohybrid for bone tissue engineering," *International Journal of Biological Macromolecules*, vol. 119, pp. 215–224, 2018.

[55] V. Singanan, M. Singanan, and H. Begum, "The hepatoprotective effect of bael leaves (*Aegle marmelos*) in alcohol induced liver injury in albino rats," *International Journal of Science and Technology*, vol. 2, no. 2, pp. 83–92, 2007.

[56] D. Rathee, A. Kamboj, and S. Sidhu, "Augmentation of hepatoprotective potential of *Aegle marmelos* in combination with piperine in carbon tetrachloride model in Wistar rats," *Chemistry Central Journal*, vol. 12, no. 1, p. 94, 2018.

[57] R. Nivetha, S. Bhuvaragavan, T. Muthu Kumar, K. Ramanathan, and S. Janarthanan, "Inhibition of multiple SARS-CoV-2 proteins by an antiviral biomolecule, seselin from *Aegle marmelos* deciphered using molecular docking analysis," *Journal of*

Biomolecular Structure and Dynamics, vol. 40, no. 21, pp. 11070–11081, 2021.

[58] S. Chhetri, S. Kundu, A. Tamang, S. Mahato, and A. Mahato, "The Bael (Aegle marmelos L. Corr.): Health benefits and its varietal wealth," *Environment and Ecology*, vol. 19, no. 4A, pp. 1355–1361, 2021.

[59] R. Andleeb, M. U. Ijaz, A. Rafique et al., "Biological activities of methanolic extract of *Aegle marmelos* against HN protein of Newcastle disease virus," *Agronomy*, vol. 11, no. 9, 2021.

[60] A. Singh, H. K. Sharma, P. Kaushal, and A. Upadhyay, "Bael (*Aegle marmelos* Correa) products processing: a review," *African Journal of Food Science*, vol. 8, no. 5, pp. 204–215, 2014.

[61] K. Y. Ullikashi, M. R. Kammar, and S. R. Lokapure, "Development of value added products from bael fruit (*Aegle marmelos*)," *International Journal of Current Microbiology and Applied Sciences*, vol. 6, no. 7, pp. 2652–2659, 2017.

[62] A. K. Singh and N. Nath, "Development and evaluation of whey protein enriched bael fruit (*Aegle marmelos*) beverage," *Journal of Food Science and Technology Mysore*, vol. 41, no. 4, pp. 432–436, 2004.

[63] T. Sarkar, M. Salauddin, and R. Chakraborty, "In-depth pharmacological and nutritional properties of bael (*Aegle marmelos*): a critical review," *Journal of Agriculture and Food Research*, vol. 2, 2020.

[64] S. Panda and A. Kar, "Periplogenin-3-O- -D-glucopyranosyl -(1→6)- -D-glucopyaranosyl- -(1→4) -D-cymaropyranoside, isolated from *Aegle marmelos* protects doxorubicin induced cardiovascular problems and hepatotoxicity in rats," *Cardiovascular Therapeutics*, vol. 27, no. 2, pp. 108–116, 2009.

[65] S. A. Kumar, I. Chakraborty, and A. K. Chaurasiya, "Bael preserve-syrup as booster of human health as a health drink," *The Bioscan*, vol. 9, no. 2, 2014.

[66] S. Kr and K. Db, "Bael (*Aegle marmelos*) a super fruit of an hour: a review Sawale KR, Deshpande HW and Kulkarni DB," *International Journal of Chemical Studies*, vol. 6, no. 3, pp. 1720–1723, 2018.

[67] S. K. Hazra, T. Sarkar, M. Salauddin, H. I. Sheikh, S. Pati, and R. Chakraborty, "Characterization of phytochemicals, minerals and *in vitro* medicinal activities of bael (*Aegle marmelos* L.) pulp and differently dried edible leathers," *Heliyon*, vol. 6, no. 10, p. e05382, 2020.

[68] Y. Yusran, E. Erniwati, A. Khumaidi, J. P. Wijesinghe, and D. L. Thanaweera, "Effect of probiotic Pediococcus acidilactici MTCC 5101 supplementation on hemoglobin levels and gut microbiome among young anemic women of Punjab," *Journal of Nutrition & Food Sciences*, vol. 6, no. 6, p. 6, 2016.

[69] W. Rmna, W. Wmcb, and T. Bmks, "Retention of physicochemical and antioxidant properties of dehydrated bael (*Aegle marmelos*) and palmyra (*Borassus flabellifer*) fruit powders," *Procedia Food Science*, vol. 6, pp. 170–175, 2016.

[70] P. Porwal, K. P. Rajendra, K. Kishor, and K. Kishor, "Optimization of process parameters for the production of spray dried bael (*Aegle marmelos* Correa) powder," *The Pharma Innovation*, vol. 6, no. 9, pp. 386–392, 2017.

[71] R. Nidhi, R. Gehlot, S. S. Singh, and M. K. Rana, "Changes in chemical composition of bael-guava blends ready-to-serve beverage and squash during storage," *Haryana Journal of Horticultural Sciences*, vol. 36, no. 1/2, pp. 46–48, 2007.

[72] S. Hiwale, "Bael (*Aegle marmelos* Correa.)," in *Sustainable Horticulture in Semiarid Dry Lands*, pp. 177–195, Springer India, 2015.

[73] D. K. Bhatt and S. Verma, "A study on development of herbal food product-bael (*Aegle marmelos*) fruit toffee," *IOSR Journal of Environmental Science*, vol. 10, no. 3, pp. 5–14, 2016.

[74] D. Sun-Waterhouse, "The development of fruit-based functional foods targeting the health and wellness market: a review," *International Journal of Food Science and Technology*, vol. 46, no. 5, pp. 899–920, 2011.

[75] S. Murakonda, G. Patel, and M. Dwivedi, "Characterization of engineering properties and modeling mass and fruit fraction of wood apple (*Limonia acidissima*) fruit for post-harvest processing," *Journal of the Saudi Society of Agricultural Sciences*, vol. 21, no. 4, pp. 267–277, 2022.

[76] A. Sonawane, S. S. Pathak, and R. C. Pradhan, "Physical, thermal, and mechanical properties of bael fruit," *Journal of Food Process Engineering*, vol. 43, no. 6, article e13393, 2020.

[77] T. Sarkar, M. Salauddin, S. Kumar Hazra, and R. Chakraborty, "A novel data science application approach for classification of nutritional composition, instrumental colour, texture and sensory analysis of bael fruit (*Aegle marmelos* (L) Correa)," *International Journal of Intelligent Networks*, vol. 1, pp. 59–66, 2020.

[78] K. S. Ganesh, A. Sridhar, and S. Vishali, "Utilization of fruit and vegetable waste to produce value-added products: conventional utilization and emerging opportunities-a review," *Chemosphere*, vol. 287, Part 3, article 132221, 2022.

[79] K. Q. Lau, M. R. Sabran, and S. R. Shafie, "Utilization of vegetable and fruit by-products as functional ingredient and food," *Frontiers in Nutrition*, vol. 8, p. 261, 2021.

[80] N. A. Sagar, S. Pareek, S. Sharma, E. M. Yahia, and M. G. Lobo, "Fruit and vegetable waste: bioactive compounds, their extraction, and possible utilization," *Comprehensive Reviews in Food Science and Food Safety*, vol. 17, no. 3, pp. 512–531, 2018.

[81] A. Sonawane, S. Pathak, and R. Chandra Pradhan, "Bioactive compounds in bael fruit pulp waste: ultrasound-assisted extraction, characterization, modeling, and optimization approaches," *Biointerface Research in Applied Chemistry*, vol. 11, no. 2, pp. 9318–9334, 2020.

[82] R. Surolia and A. Singh, "Study on physicochemical properties, structural morphology, and prebiotic potential of extracted pectin from a novel source: bael pulp (*Aegle marmelos*) residue," *Journal of Biotech Research*, vol. 13, pp. 247–259, 2022.

[83] W. Zahra, S. N. Rai, H. Birla et al., "Economic importance of medicinal plants in Asian countries," *Bioeconomy for Sustainable Development*, pp. 359–377, 2020.