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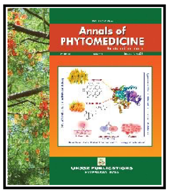

Review Article : Open Access

# Exploring the pharmacological potential of Phalsa (*Grewia asiatica* L.) and its application in modern industry

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**Abstract**

Phalsa is becoming known all over the world for its nutritional and medicinal benefits and is being developed as a new food ingredient for the food industry. Phalsa, due to its higher content of antioxidants, anthocyanin, and vitamins, stands up as an essential bioactive compound aiding in functional food trends. The strong antioxidant property of phalsa can relieve oxidative stress, one of the major risk factors in chronic conditions like heart problems, diabetes, and even cancer. The variety of phalsa makes it more versatile and expands its application in juices, jams, syrups, and nutraceuticals, as well as refreshing drinks and functional food in hotter regions. Some minor fruits like phalsa have a wide array of bioactive ingredients and are being researched to formulate new drug therapies due to their preventative capabilities. With the growing need for simplistic natural ingredients in food products, phalsa is a promising resource for cutting-edge food technologies. Phalsa seeks to eliminate food shortages and enhance health and sustainability by emerging modern methods with traditional knowledge. This paper focuses on the development of food technologies that enhance the pitch to the market of phalsa-based products within the food market that is having an increased demand for simple and natural constituents.

## 1. Introduction

Fruits are essential for a healthy diet, as recognized globally by organizations like the World Health Organization (WHO), which recommends daily consumption for optimal health. Research shows that fruits are rich in bioactive compounds, and in the last two decades, numerous studies have explored these compounds, highlighting their various health benefits (Mehmood *et al.*, 2019). Phalsa, a type of berry, is an integral part of daily life, cherished for its numerous health benefits. Phalsa (*Grewia asiatica* L.) is part of the Malvaceae or Tiliaceae family and belongs to the Grewia genus, which encompasses around 150 species. Phalsa is recognized by several names, like unnu, phulsa, and shukri (Singh and Singh, 2018). This plant yields small, berry-like fruits, typically blooming in warm climates and shedding its leaves in winter. Known for its rich nutritional profile, phalsa is grown on a limited scale in various states owing to its diminutive fruit size, frequent harvesting, and extended ripening period (Das *et al.,* 2012). The delicate fruit berries are believed to have originated across India and various regions of Southeast Asia, such as Sri Lanka, Pakistan, and Bangladesh (Wani *et al.,* 2015). In India, the primary cultivation regions for phalsa fruit include Gujarat, Bihar, Tamil Nadu, West Bengal, and Maharashtra, while it is also grown commercially in Rajasthan, Punjab, Uttar Pradesh, and Haryana. In India, phalsa is cultivated on a limited scale as a minor crop across various states, covering a total area of less than 1000 hectares (Kumar *et al.,* 2014). In Punjab, it covers only 30 hectares, producing about 196 tonnes of fruits per hectare annually (Singh *et al.*, 2015).

The fruits of phalsa contain a range of important nutrients that support an active, healthy lifestyle and serve as a rich source of energy. Berries are particularly high in bioactive compounds like anthocyanins, flavonoids, and tannins, which are closely associated with various health advantages (Ray and Bala, 2019). A total of 50 compounds were identified, including 6 anthocyanins, 2 phenolic acids, 21 flavonoids, 2 flavanones, 2 dihydro-flavonols, 3 isoflavonoids, 3 flavanols, 7 flavones, and 4 other phenolic compounds. Among these, flavanols accounted for a significant proportion, comprising 52.6% of the total (Koley *et al.*, 2020). Phalsa is an edible fruit that promotes health by slowing the process of aging and minimizing the risk of various diseases, such as rheumatoid arthritis, cancer, lung disease, and cardiovascular disorders (Sinha *et al.*, 2015).

There is limited research on postharvest handling, including the right harvest stage of maturity, which is crucial for flavor, market demand, and shelf life. Low-temperature storage is the most effective method to reduce spoilage and slow down processes that degrade fruit quality (Butnariu, 2023; Hassan *et al.*, 2022). This review examines phalsa's nutritional composition, bioactive compounds, phytochemical properties, and industrial applications, highlighting its pharmacological effects, including antioxidant, anticancer, anti-inflammatory, radioprotective, antidiabetic, antimicrobial, antimalarial, hepatoprotective, antihyperlipidemic, and analgesic activities.

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## 2. Botanical description of phalsa

*G. asiatica* is a shrub that typically grows to a height of about 4-5 meters. It has a gray stem, rough bark, and leaves that are cordate to ovate, measuring around 5-18 cm in length and up to 15 cm in width. The plant produces broad, yellowish flowers that are grouped in cymes, with several flowers clustered together (Jyoti *et al.,* 2015). They have a sagittate shape (arrowhead-shaped with pointed basal lobes extending backward) with five small petals (4-5 mm) that are concealed by five large sepals (12 mm). Flowering in phalsa was reported to occur from March to May. The flowers began to bloom at 6 AM and continued until 3 PM, with the peak blooming time around 10 AM (Randhawa and Dass, 1962).

The stigma showed peak receptivity on the day of anthesis. It is typically a cross-pollinated crop, with insects serving as the primary pollinators (Hiwale and Hiwale, 2015). The fruit is a fleshy, fibrous drupe, initially grayish violet, with spherical, depressed blackish spots covered in stellate trichomes. It contains 1-2 seeds, pointed with a notched surface and hard coating. The heart-shaped leaf has 5-7 nerves, parallel venations, serrated edges, and is pubescent on top and tomentose underneath (Dhawan *et al.*, 1993). Fully mature phalsa fruits are purple and may turn black when ripened on bushes. Fruits are rich in anthocyanin, which are considered antioxidants. The whole fruit, including the seeds, is eaten or used to make juice, and the shoots can be used to create baskets (Pujari, 2012).

## 3. Nutritional profile of phalsa

Phalsa extracts exhibit anti-inflammatory, antibacterial, and antifungal properties, aid digestion, support gut health, regulate blood sugar, and provide cooling benefits, making them effective for various health conditions (Tran *et al.*, 2020). The nutrient composition of underutilized fruit has been shown in (Table 1).

**Table 1: The nutritional content of phalsa fruit (Akram *et al.*, 2019; Kaur *et al.*, 2024; Khan *et al.*, 2019)**

| Nutrient value in 100 g fruit | | Minerals value in 100 g of fruit (mg) | | Amino acids (%) | | | |
|---|---|---|---|---|---|---|---|
| Calories (kcal) | 90.50 | Potassium | 372.00 | Lysine | 2.00 | Aspartic acid | 19.06 |
| Carbohydrates (g) | 21.10 | Calcium | 136.00 | Isoleucine | 8.01 | Glutamic acid | 11.0 |
| Protein (g) | 1.57 | Phosphorous | 24.20 | Leucine | 11.02 | Tyrosine | 3.00 |
| Fiber (g) | 5.53 | Sodium | 17.30 | Phenylalanine | 7.00 | Cysteine | 1.08 |
| Fat (g) | 0.10 | Copper | 0.48 | Threonine | 4.06 | Serine | 4.02 |
| Ash (g) | 1.10 | Cobalt | 0.99 | Methionine | 2.08 | | |
| Vitamin C - ascorbic acid (g) | 4.835 | Chromium | 1.08 | Tryptophan | 1.00 | | |
| Thiamine (mg) | 0.02 | Iron | 140.8 | Alanine | 1.03 | | |
| Riboflavin (mg) | 0.264 | Zinc | 144 | Histidine | 2.02 | | |
| Niacin (mg) | 0.825 | Nickel | 2.61 | Arginine | 2.07 | | |
| Retinol (µg) | 16.11 | | | Valine | 13.02 | | |
| Moisture content (%) | 76.3 | | | Proline | 3.01 | | |

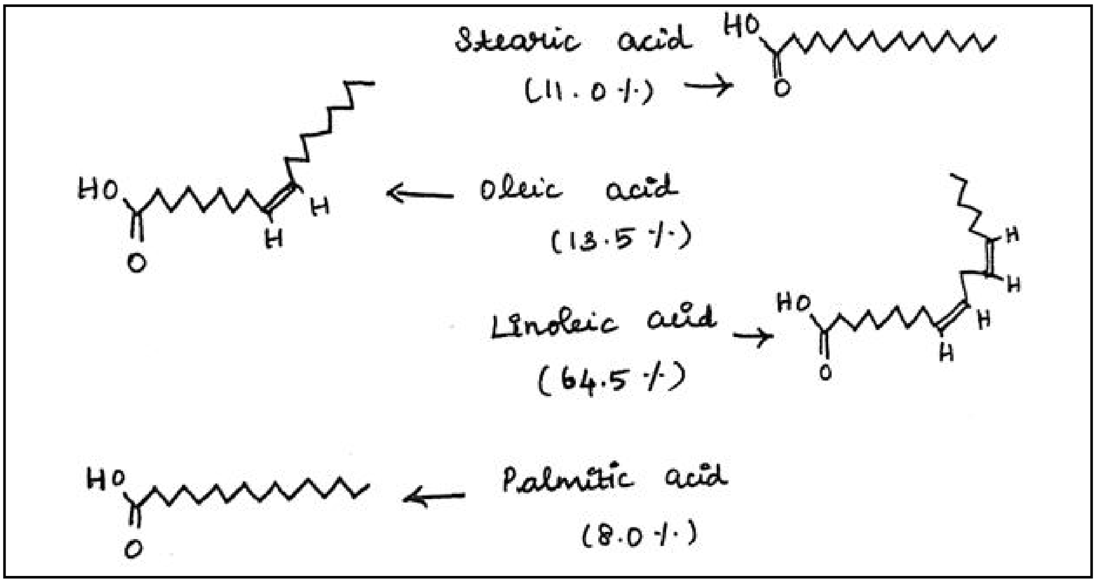


**Figure 1: Composition of free fatty acids in phalsa.**

### 3.1 Protein and amino acid

Nitrogen is a macronutrient in proteins, alongside hydrogen, oxygen, carbon, sulfur, and sometimes phosphorus, iron, and copper (Nandhini *et al.,* 2024). The phalsa is composed of eighteen different amino acids, along with the highest concentrations (Swain *et al.*, 2023). The fruit pulp holds a higher level of phosphoserine than any other free amino acid. Significant amounts of essential amino acids are found in both the peel and pulp. Furthermore, phalsa fruit is particularly high in histidine, threonine, and lysine (Elmuez *et al.,* 2014).

### 3.2 Oils in phalsa

Phalsa oil is distinguished by its yellow color and holds approximately 5% free fatty acids and unsaponifiable matter (3%). The free fatty acids of phalsa and their structures are illustrated in (Figure 1).

### 3.3 Phytochemical properties and bioactive compounds in phalsa

'Bioactive' comes from the Greek 'Bio' (life) and Latin 'Activus' (active) (Praveen Kumar *et al.,* 2024). Phalsa contains a high amount of bioactive compounds, including anthocyanins, flavonoids, and tannins. Nevertheless, the levels of these compounds are influenced by factors like cultivation conditions, harvest timing, and post-harvest storage practices. This fruit is known to contain diverse secondary metabolites, such as myricetin, naringenin, cyanidin, pelargonidin, hydroxymethylfurfural, and hydroxybenzoic acid (Choudhary *et al.*, 2018). Phytochemicals are extracted using solvents like petroleum ether, methanol, ethyl acetate, benzene, and distilled water (1.2%, 13.6%, 12.5%, 1.5%, and 1.3%, respectively). Leaves contain 5% ash, 2.1% acid-insoluble ash, and 2.5% water-soluble ash. The purple hue of phalsa berries are due to anthocyanins, which are a class of flavonoid-based pigments known for their health benefits, like anti-inflammatory effects and cardiovascular protection. The phytochemical analysis examined the fruit for the presence of anthocyanins, flavonoids, phenolic acids, vitamin C, and carbohydrates, while the seeds were found to contain tannins, starch, minerals, and oils (Zia-Ul-Haq *et al.*, 2013).

#### 3.3.1 Polyphenolic compound

Phalsa berries are abundant in polyphenolic compounds, including flavonoids and phenolic acids. Polyphenols are plant-based, non-nutritive compounds widely distributed across plants. These include phenolic acids, lignans, curcuminoids, stilbenes, chalcones, flavonoids (flavones, flavonols, flavanones, flavanonols, isoflavones), and anthocyanins (González-Castejón and Rodriguez-Casado, 2011). Curcuminoids include curcumin, demethoxycurcumin, and bisdemethoxycurcumin (Sudha Rani *et al.,* 2024). Polyphenols act as metabolic intermediates, aiding defense, signaling, and key biological processes (Sibi *et al.,* 2024). Phalsa may contain tannins, a type of polyphenolic compound recognized for its astringent properties.

#### 3.3.2 Flavonoids

Flavonoids, a class of polyphenolic secondary metabolites, are present in nearly all fruits and vegetables. They are characterized by a 15-carbon structure comprising two phenyl rings and a heterocyclic ring (Lei *et al.*, 2019). Glycoside-bound flavonoids, particularly flavonols and flavones, are the most prevalent types consumed in the human diet. Phalsa's stem, callus, leaves, and bark contain the highest concentrations of flavonoids. The flavonoid content in phalsa pomace was measured at 12.42056 CE mg/g (Gupta *et al.*, 2014). The rind or bark was found to contain 39.114 ± 65 mg of flavonoids (Khatune *et al.*, 2016).

#### 3.3.3 Anthocyanin

Anthocyanin, a type of flavonoid, is a water-soluble pigment found in the vacuoles of plants, including fruits and vegetables. Its color varies with pH, producing red, purple, and blue hues in different plant parts of botanical origin (Salamone *et al.*, 2012). The current study on phalsa highlights it as a valuable indigenous fruit loaded with seven anthocyanins. Cyanidin-3-O-(63 -acetylglucoside) is the most abundant, comprising 44-63%, followed by pelargonidin-3-O-(63 -acetylglucoside) at 8-14%, and peonidin-3-O-glucoside at 3-30%. Other identified anthocyanins include malvidin-3-O-glucoside pyruvic acid, delphinidin-3-O-glucoside, pelargonidin-3-O-malonylglucoside, and peonidin-3-O-(63 -acetylglucoside) (Dave *et al.*, 2016). The analysis showed that phalsa fruit extract is rich in anthocyanins and exhibits strong antibacterial effects against various Gram-positive and Gram-negative) species. Despite its potential applications, the plant remains under-researched. Further studies on its pigments are essential to promote the commercialization of phalsa products (Talpur *et al.*, 2017).

#### 3.3.4 Tannin

Tannin is a water-soluble astringent compound made up of polyphenolic biomolecules (secondary metabolites) that possess enough hydroxyl and carboxyl groups to form strong complexes with other macromolecules (Akhtar and Mirza, 2018). Tannins are abundant in plants, and phalsa contains them in leaves, stems, fruits, roots, bark, and seeds (Babu *et al.*, 2017). Elhassan and Yagi (2010) reported that the phalsa fruit has a total tannin content ranging from 1.13% to 2.46%.

#### 3.3.5 Quercetin and (+) -Catechin

A research study reported that phalsa fruit contains a high concentration of bioactive compounds, including quercetin, quercetin-3-O-β-D-glucoside, naringenin, and naringenin-7-O-β-D-glucoside. It also contains significant amounts of (+) -Catechin, a flavonoid derivative, along with related compounds like (–) -epicatechingallate, (–) -epigallocatechin, (+) -gallocatechin, and (–) -epicatechin(Agarwal and Mishra, 1979; Khurdiya and Anand, 1981). Some of the bioactive compounds and their functional properties with applications have been shown in (Table 2).

## 4. Pharmacological effects of phalsa

Phalsa fruit has long been utilized in traditional medicine to address a range of health issues, including inflammatory conditions, as well as respiratory, cardiac, and blood disorders. Its polyphenolic compounds in the phalsa plant, such as flavonols, phenolic acids, and anthocyanins, exhibit notable antioxidant activity. The pharmaceutical industry is shifting towards natural, plant-based remedies as synthetic drugs are increasingly being replaced due to consumers' growing preference for alternatives to conventional drug treatments (Chirumbolo, 2012). The edible and flavorful *G. asiatica* fruit is now recognized as a rich source of distinctive natural compounds for developing medicines to treat various conditions, including diabetes, inflammation, cancer, and microbial infections. Pharmacological studies have identified phenols, saponins, flavonoids, and tannins in the fruit (Shukla *et al.*, 2016).

**Table 2: Bioactive compounds, properties, and applications of plant parts of phalsa (Mehmood *et al.*, 2020; Kaur *et al.*, 2024)**

| Plant parts | Bioactive compounds | Functional properties | Application |
|---|---|---|---|
| Fruits | Antioxidants (vitamin C, polyphenols), Anthraquinones, flavonoids, tannins, Quercetin and quercetin glycosides, quercetin-3-O-β-D-glucoside, naringenin and naringenin glycosides, naringenin-7-O-β-D-glucoside, delphinidin-3-glucoside, pelargonidin-3–5-diglucoside, cyanidin-3 -glucoside, and catechin. | Digestive health, anticancer, antioxidant, anti-inflammatory, satiety, analgesic, antipyretic, and anti-inflammatory activities. | Dietary supplements, functional foods, juice production, skin health, traditional medicines, and food preservation. |
| Flowers | Quercetin and quercetin glycosides, including quercetin-3-O-β-D-glucoside, naringenin-7-O-β-D-glucoside, β-sitosterol, grewinol, 3,21,24-trimethyl-5,7-dihydroxyhentriacontanoic acid λ-lactone, 2-hydroxy-3-methyl, 3,4-altrosan, 4H-pyran-4-one, hexadecanoic acid, tetradecanoic acid, and lupenone. | Antioxidant, anti-inflammatory, anti-cancer effects. | Nutraceuticals, herbal medicines, dietary supplements, functional foods. |
| Stem | β-sitosterol, β-amyrin, taraxerol, lupeol, friedelin, betulin, lupenone, and erythroid. | - | - |
| Leaves | Kaempferol, quercetin and their glycosides, Flavonoids, phenolic acids. | Antimicrobial, anti-inflammatory, wound healing. | wound healing, nutraceuticals, herbal medicines. |
| Seeds | Fatty acids, phytosterols, omega-3 fatty acids. | Cardioprotective activities, anti-inflammatory, brain development. | Oil extraction for nutraceutical use, fish oil supplements, functional foods. |

### 4.1 Oxidative stress-reducing effect/antioxidant effect

Research indicates that freeze-dried phalsa contains higher antioxidant levels than fresh fruit, with significantly elevated phenolic (294.453 ± 4.696 mg GAE/g) and flavonoid (116.96 ± 10.71 mg GAE/g) content. Polyphenolic compounds were extracted from methanolicphalsa peel and pulp, then fractionated into anthocyanin and flavanol proportions for further study (Islary *et al.*, 2016). Different parts of the phalsa plant exhibit varying antioxidant properties. The pomace of phalsa fruit shows levels of tannins (0.52 ± 1.25 g/100 g), saponins (1.05 ± 0.96 g/100 g), flavonoids (12.42 ± 0.56 mg/g), and alkaloids (1.56 ± 1.2 g/100 g), indicating a significant antioxidant content in the waste. However, the antioxidant activity decreases with storage; seed size reduces from 49.0 to 19.4 TEAC mol/g, peel from 87.8 to 33.13 TEAC mol/g, and pulp from 56.1 to 25.8 TEAC mol/g (Shukla *et al.*, 2016).

The roots possess a significant antioxidant content, exhibiting ABTS (96.42 ± 2.17%), DPPH (82.6 ± 5.66%), and FRAP (82.53 ± 3.16%) values. Dried leaf extracts showed phenolic and flavonoid contents ranging from 2.15 mg/100 g to 1.65 mg/100 g, along with potential antioxidant properties (Sharma *et al.*, 2016). *In vitro* tests of *G. asiatica* demonstrated antioxidant activity, including free-radical scavenging effects using the DPPH (1,1-diphenyl-2-picrylhydrazyl) assay, providing evidence of anti-ageing and stress-relief benefits (Dwivedi and Manigauha, 2017).

### 4.2 Spasmolytic effect

The fruit extract of phalsa showed spasmolytic effects on rabbit jejunal tissue at 0.3-10 mg/ml, with an $EC_{50}$ of 4.4 mg/ml. At 10 mg/ml, it temporarily stopped contractility, while 80 mM potassium ions induced sustained contractions (Ghayur *et al.*, 2021b).

### 4.3 Anticancer effect

The fruit and leaves of phalsa exhibit anticancer properties, effectively inhibiting five different cancer cell lines: NCI-H522, MCF-7, HEK-293, HELA, and HEP-2. Phalsa methanolic extract (250-500 mg/kg) increased life expectancy in male Swiss albino mice with Ehrlich's ascites carcinoma (EAC) by 41.22%-61.06%, and inhibited breast cancer cells, but not cervical (HELA) or laryngeal (HEP-2) cells. This study evaluated the anticancer potential of *G. asiatica* ethanolic extract on the $HepG_2$ cell line. The extract significantly reduced cell proliferation in various assays, demonstrating its effective cytotoxicity and potential as an anticancer therapy. Further animal and human studies are needed for future cancer treatment applications (Butt *et al.*, 2023).

### 4.4 Cytotoxicity effect

The *in vitro* cytotoxic and antitumoral activities of phalsa leaf methanol extract against Ehrlich's ascites carcinoma (EAC) cells were evaluated using the methylthiazolyl tetrazolium assay. It was tested on four human cell lines (HELA, MCF-7, HL-60, K-562), with $IC_{50}$ values of 177.8, 199.5, 53.70, and 54.90 µg/ml, respectively (Periyasamy *et al.*, 2012).

### 4.5 Anti-inflammatory effect

Phalsa fruit exhibits strong anti-inflammatory effects. Methanol and n-hexane extracts of *G. asiatica* containing steroids, glycosides, flavonoids, tannins, saponins, and terpenoids, show membrane stabilization in human RBCs. Stabilization effects ranged from 40.89% to 80.91% at various doses, indicating strong anti-inflammatory activity compared to diclofenac potassium (Khanal *et al.*, 2016). Phalsa, when orally administered as methanolic extracts at doses of 250 mg/kg and 500 mg/kg, significantly ($p$> 0.1) reduces swelling in carrageenan-induced rat paw edema. Similarly, phalsa root extract, dried and extracted with methanol and water (200 mg/kg and 400 mg/kg), also significantly reduces edema (0.1 ml of 1% wt/vol) in carrageenan-induced rat paw edema, comparable to the positive control, indomethacin (19 mg/kg) (Paviaya *et al.*, 2013). Methanol extracts of phalsa fruit exhibited notable anti-inflammatory activity in albino mice, with the most pronounced effect observed at a dose of 500 mg/kg (Akhtar *et al.*, 2016).

### 4.6 Antidiabeticeffect

Type II diabetes is a global issue where blood glucose levels rise due to inadequate insulin secretion or improper cellular utilization. However, the fruits of *G. asiatica* are known to be effective in treating diabetes (Tariq *et al.*, 2020). A 95% ethanol extract of the fruit was administered to diabetes-induced albino rats, resulting in a reduction in blood glucose levels, thereby confirming the significant hypoglycemic or antidiabetic properties of *G. asiatica* (Sabzoi *et al.*, 2021). The study on the phalsa plant's leaf extract revealed that oral administration of phalsa leaf extract (200 mg/kg and 500 mg/kg) for 21 days to both streptozotocin-induced and control rats (50 mg/kg body weight) resulted in a dose-dependent reduction in blood glucose levels and enhanced glucose tolerance (Latif *et al.*, 2012).

### 4.7 Antihyperglycemic effect

The rats were administered a methanolic extract of phalsa fruit via oral ingestion (100-200 mg/kg body weight per day) for 28 days. During this period, levels of GSH, liver glycogen, serum glucose, superoxide dismutase, and malondialdehyde activity were measured, showing notable decreases (Khattab *et al.*, 2015). In a study using streptozotocin (STZ)-induced hyperglycemic rats, the phalsa fruit was tested for its antihyperglycemic properties. The ethanolic extract of leaves, administered in doses of 100, 200, and 400 mg/kg, demonstrated strong antihyperglycemic activity (Bhangale *et al.*, 2013).

### 4.8 Immunomodulator effect

Dried leaf powders were processed with petroleum ether to eliminate fats, followed by ethanol extraction to obtain phytocompounds. The ethanol extract contained carbohydrates, alkaloids, triterpenes, glycosides, steroids, tannins, saponins, and flavonoids. These bioactive compounds demonstrated significant immune-stimulatory properties when tested on Swiss albino rats, highlighting the potential of the extracts for enhancing immune responses (Singh *et al.,* 2019).

### 4.9 Antimicrobial effect

Plants develop diverse defenses against pathogens like viruses, fungi, and bacteria (Barathi *et al.,* 2024). The methanolic extract of phalsa fruit demonstrated inhibitory effects against two bacterial strains: *Escherichia coli* and *Lactobacillus acidophilus* (Rajagopal *et al.*, 2016). The phalsa plant leaves demonstrated significant non-bacterial activity, including potent antifungal effects against *Saccharomyces cerevisiae* and antibacterial activity against both Gram-positive bacteria (*Bacillus subtilis*) and Gram-negative bacteria (*Pseudomonas aeruginosa*) (Shrimanker *et al.*, 2013). The studies on phalsa plant bark and fruit against various bacterial strains found significant inhibition only in *Escherichia coli*, *Proteus vulgaris*, and *Staphylococcus epidermidis*, with inhibition zones of 6.51 ± 0.40 mm, 6.33 ± 0.48 mm, and 7.33 ± 0.85 mm, respectively (Naqvi *et al.*, 2012).

### 4.10 Antiviral effect

Methanol extracts of *G. asiatica* exhibited antiviral activity against Urd bean leaf crinkle virus (ULCV) in black-gram beans (*Phaseolus nigra*). The highest inhibition of the ULCV virus, up to 90%, was observed after spraying with varying concentrations of the *G. asiatica* methanol extract (Sangita *et al.*, 2009).

### 4.11 Antimalarial effect

The study proposed that phalsa leaves may possess both antiemetic and antimalarial properties. The crude methanol extract resulted in a 69.0% decrease in malarial activity. When male chicks were administered the extract at doses of 50 mg/kg and 100 mg/kg, the inhibition of emetic response was 39.15% and 59.68%, respectively. The methanolic leaf extract demonstrated both antimalarial and antiemetic effects (Zia-Ul-Haq*et al.,* 2012).

### 4.12 Antihyperlipidemic effect

Qayyum and Asif (2017) studied aqueous methanolic extract (30:70) of phalsa fruit and showed significant reductions in triglycerides, cholesterol, clotting factors, and LDL while increasing HDL in hyperlipidemic rats. Norwegian rats were treated with a methanolic extract of phalsa bark (200 mg/kg and 400 mg/kg body weight) for 15 days. This reduced lipoprotein density, total cholesterol, VLDL, and triglycerides, while significantly increasing HDL levels, indicating a positive effect on lipid profiles (Khatune *et al.*, 2016).

### 4.13 Antifertility effect

Seeds have been utilized for their antifertility properties, demonstrating the ability to interfere with fetal implantation (Embryo adheres to uterine lining for nourishment and pregnancy initiation). They are also considered to possess abortifacient effects, making them significant in traditional and alternative approaches to fertility control (Pokharkar *et al.*, 2010)

### 4.14 Blood alteration effect

The fruit extract of *G. asiatica* help to restore altered blood parameters, including RBCs, WBCs, hemoglobin, hematocrit, neutrophils, monocytes, lymphocytes, and eosinophils, caused by radiation exposure in mice (Singh *et al.*, 2007).

### 4.15 Antidementia effect

The methanolic extract of *G. asiatica* (MEGA) at 200 mg/kg restored memory loss caused by scopolamine-induced amnesia. It reduced oxidative stress markers (lipid peroxidation, MDA) and increased superoxide dismutase levels, improving neuronal cell structure and elevating acetylcholine levels while reducing head twitches (Paul *et al.*, 2020).

### 4.16 Radioprotective effect

The extract displayed significant radical scavenging and radioprotective effects in protein carbonyl assays. Mice treated with the extract for 30 days had notably higher numbers of spermatocytes, spermatogonia "A," spermatogonia "B," and spermatids compared to the control group (Sharma and Sisodia, 2010). Mice were divided into four groups, with one receiving a 700 mg/kg dose of phalsa extract for 15 days before gamma radiation exposure. Brain tissue analysis showed that phalsa fruit pulp powder reduced lipid peroxidation (LPO), increased glutathione (GSH), and protected against oxidative damage (Ahaskar *et al.*, 2007). In other *in vitro* and *in vivo* studies reveal that phalsa extract showed potential as a protective agent. In mice brains, a 700 mg/kg bodyweight dose of phalsa fruit extract significantly lowered GSH and LPO levels compared to the control group (Sharma and Sisodia, 2009).

### 4.17 Analgesic effect

The analgesic effects on both central and peripheral systems of aqueous and methanolic extracts of phalsa root bark extracts were evaluated using the acetic acid-induced writhing test and Eddy's hot plate test in male Swiss albino mice. The aqueous extract (400 mg/kg body weight) showed the highest analgesic effect at 46.24%, compared to 41.14% for the methanolic extract and indomethacin (10 mg/kg body weight) (Paviaya *et al.*, 2013). Phalsa fruit extract exhibited analgesic effects, assessed *via* hot plate and writhing tests. Administered to Swiss albino mice (100-400 mg/kg), it showed effects comparable to the positive control (Das *et al.*, 2012).

### 4.18 Hepatoprotective effect

Polysaccharides from the phalsa plant, particularly the hot fraction containing galacturonic acid, show strong hepatoprotective and therapeutic effects against $CCl_4$-induced liver damage. In mice, pre-treatment with 100 mg/kg polysaccharides significantly reduced ALT (hot: 31.2-39.2 U/l, cold: 33.4-47.4 U/l) and AST (hot: 36.3-46.1 U/l, cold: 38.4-53.8 U/l), performing comparably to Silymarin (25 mg/kg) (Abou Zeid *et al.*, 2015). Serum levels of AST, ALT, and ALP were evaluated, showing that pre-treatment with whole ethanol, polysaccharides, ethyl acetate, and aqueous ethanol extracts effectively lowered these markers in liver-damaged rats, comparable to silymarin's effects (Zhao *et al.*, 2004).

### 4.19 Antiplatelet effect

The methanolic leaf extract of *G. asiatica* exhibits antiplatelet activity, inhibiting platelet aggregation in a dose-dependent manner (1-10 mg/ml), indicating its potential for treating cardiovascular or inflammatory conditions (Zia-Ul-Haq *et al.*, 2012).

### 4.20 Antiemetic and nootropic effect

Crude fruit extracts of the plant exhibited significant antiemetic activity in experimental model dogs, with full effectiveness achieved at a dose of 120 mg/kg body weight (Yaqeen *et al.*, 2008). Nootropic drugs enhance brain function through improvements in memory, blood circulation, and oxygen delivery to the brain. Fruit extracts were tested on memory-impaired rats, showing memory improvements and stress reduction (Paul *et al.*, 2020).

### 4.21 Vasorelaxant effect

Crude fruit extracts prepared with water and 70% methanol were applied to rabbit jejunum tissue, rat gastrointestinal tissues, and endothelium-intact arteries. Higher extract concentrations reduced vascular endothelium relaxation, highlighting the plant's antispasmodic and vasodilatory effects (Ghayur *et al.*, 2021a).

### 4.22 Inhibition of acetylcholinesterase (AChE) and butyrylcholinesterase (BChE) effect

A study found that *G. abutilifolia* extract effectively inhibits acetylcholinesterase and butyrylcholinesterase, showing comparable activity to reference standards like donepezil and galantamine. These enzymes play key roles in Alzheimer's disease, suggesting the extract's potential as a treatment (Rafe *et al.*, 2018).

### 4.23 Gelling polymeric effect

The mucilage from *G. asiatica* (Phalsa) serves as a natural polymeric material for gel preparation, showing effective gelling properties at a concentration of 5.50-6.50%. Its composition supports sol-gel alternation, offering promising industrial applications, though its standardization for widespread use remains unachieved (Gupta *et al.*, 2019).

## 5. Phalsa's role in modern industry

### 5.1 Application in the medical industry

The unripe fruit has been used to treat respiratory, cardiac, and blood disorders and fever. Various plant parts, including stems, leaves, and fruits, are studied for their therapeutic effects, addressing conditions like throat issues, tuberculosis, indigestion, and cancer (Dev *et al.*, 2019). Phalsa seeds have abortifacient and anti-implantation effects. With its low glycemic index, the juice helps manage diabetes, obesity, and coronary heart disease (Tiwari *et al.*, 2014). An infusion made from the stem and root bark is used as a demulcent and febrifuge and to treat diarrhea. It contains cyanidin 3-glucoside (an anthocyanin), vitamin C, minerals, and dietary fiber (Gochar *et al.*, 2017). An ethnomedicinal field study was carried out in five Indian villages, where a questionnaire survey revealed that local inhabitants used the leaf and root extracts of phalsa to treat rheumatism and promote wound healing (Singhal *et al.*, 2017).

### 5.2 Application of phalsa in the food and beverage industry

The leaves of phalsa plants serve as animal fodder, while in certain regions, the bark is used as a substitute for soap. The mucilaginous extract from the bark is utilized in clarifying sugar and jaggery. Fibers extracted from the bark are used to make rope. The wood, known for being fine-grained, yellowish-white, durable, and flexible, has multiple applications (Singh *et al.*, 2009). Ripe phalsa berries are widely used as functional food ingredients, enjoyed fresh, in sweets, or processed into beverages. They offer nutritional benefits, promote health, and enhance sensory appeal in various product formulations (Donno *et al.*, 2019). The study included four experiments: analyzing physicochemical properties, determining the optimal fruit-to-water ratio for juice, evaluating recipes for beverages (RTS, nectar, squash), and studying storage stability. Based on the results, ideal compositions were RTS (10% juice, 13% TSS, 0.3% acidity), nectar (20% juice, 13% TSS, 0.3% acidity), and squash (25% juice, 45% TSS, 1.2% acidity), achieving excellent sensory scores and storage stability (Prakash *et al.*, 2014).

Fruit juices of karonda, phalsa, and jamun were bio-fortified using probiotics, where phalsa juice fermented with *Saccharomyces cerevisiae* exhibited the highest phenolic (771.01 ± 1.37 mg GAE/ml) and flavonoid (394.09 ± 2.66 mg QE/ml) levels. Fermentation with *Lactobacillus casei* lowered the pH and raised acidity in phalsa juice, while *Lactobacillus acidophilus* increased the total soluble solids and enhanced the phytochemical and bioactive properties of phalsa, jamun, and karonda juices (Roy, 2023). Phalsa pulp and pear juice were blended in various ratios for crush preparation, stored at ambient conditions, and evaluated for three months. The results showed that TSS increased, while ascorbic acid, anthocyanin, and phosphorus decreased. The $T_5$ blend (80:20) was preferred based on sensory attributes (Pangotra *et al.*, 2018). Juice production is notably higher in the tall variety, as it is linked to the edible portions, resulting in an increased amount of total sugars and non-reducing sugars compared to the dwarf variety. Additionally, the tall variety exhibits higher levels of seed protein, titratable acidity, and reducing sugars than the dwarf type (Mehmood *et al.*, 2020) and below (Figure 2) shown as follows.

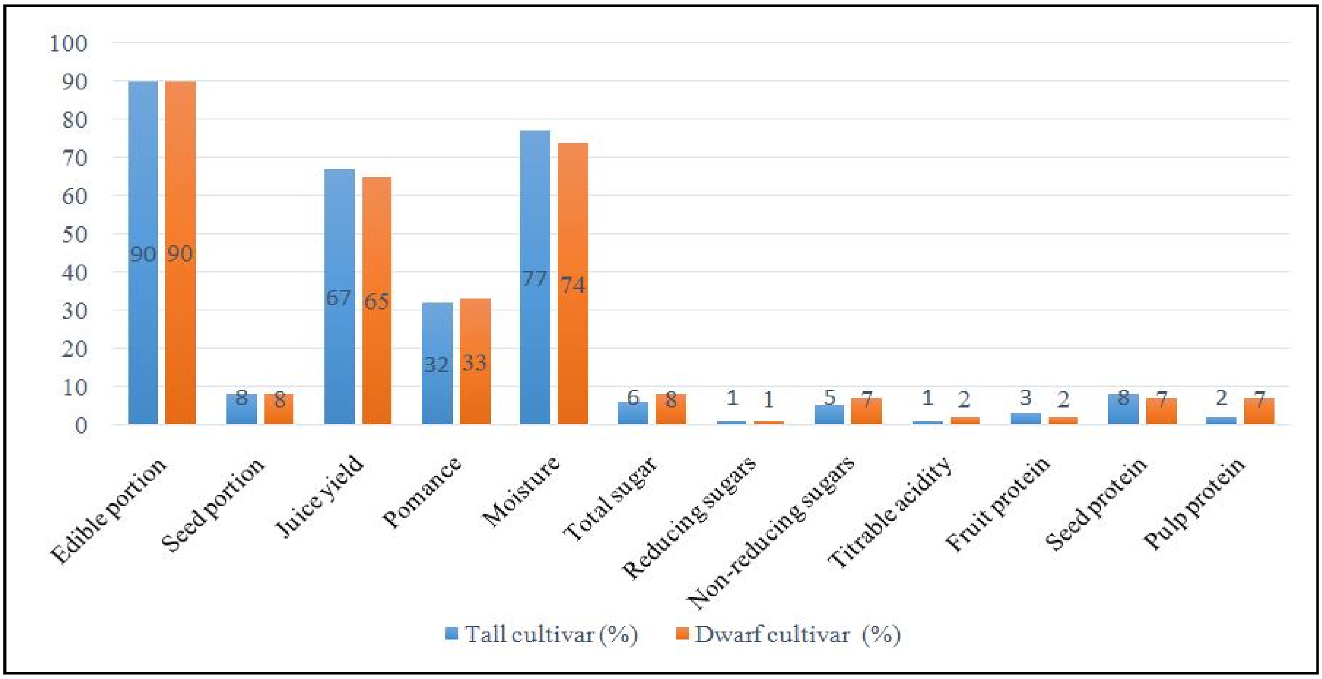


**Figure 2: Nutritional comparison of tall and dwarf cultivars of phalsa.**

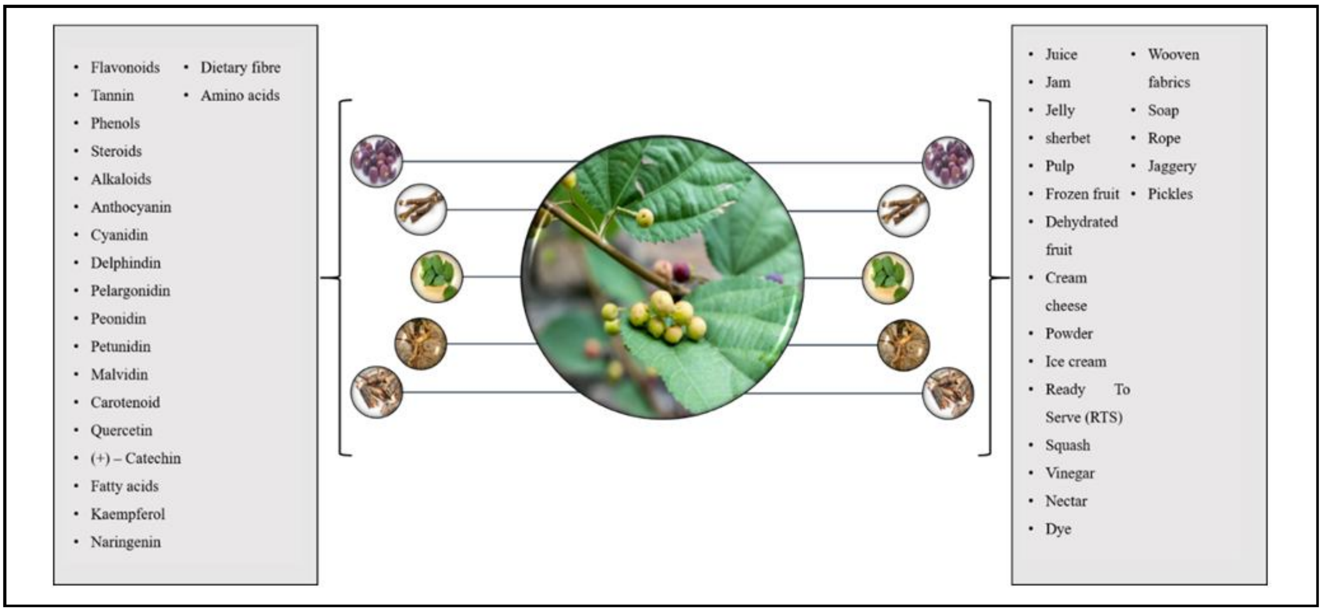


**Figure 3: Phalsa products and their nutrition.**

### 5.2.1 Squash

The study standardized a protocol for phalsa-blended squash using varying ratios of phalsa and guava pulp. After three months of storage, no microbial growth was observed. The 70:30 phalsa-guava blend ($T_4$) was the most acceptable based on sensory evaluation (Gupta, 2020). This study aimed to produce an economical, high-quality phalsa diet squash (DSP) by replacing sucrose with artificial sweeteners (sucralose, saccharine). It analyzed the degradation kinetics of key nutrients, revealing a gradual decline in phenolics, vitamin C, and phosphorus. $DSP_4$ (50% sucralose, 50% saccharine) was the most accepted variant (Rashid *et al.*, 2021).

### 5.2.2 Jam

Phalsa leaves, fruit pulp, and sugar can be combined to create a jam that serves as a delightful topping for baked goods. Boiling phalsa leaves and fruits in water produces a flavorful and nutritious herbal tea (Mitra *et al.*, 2008).

### 5.2.3 Sub-zero and dried product

The study aimed to develop cream cheese using frozen and dehydrated phalsa. Sensory evaluation and microbial analysis showed 18 cfu/ml in frozen phalsa-based cream cheese and 14 cfu/ml in dehydrated phalsa, concluding that dehydrated phalsa was more effective (Nawaz *et al.*, 2020).

### 5.2.4 Vinegar

This study evaluated vinegar production from *G. subinqualis* (Phalsa) and *Cucumis melo* (Cantaloupe). A composite blend optimized fermentation efficiency, yielding 79.5% ethanol and 71.75% acetic acid. The vinegar retained phenolics, anthocyanins, and antioxidants, with microbial growth and degradation kinetics modeled. The process met FSSAI norms (HARISH, 2019). Some of the value-added products and their nutritional benefits derived from various parts of the phalsa plant are shown in (Figure 3).

## 6. Current and future prospective

Phalsa (*G. asiatica*) has a unique market potential, owing to its economic fruits, medicine, and its use in a variety of food products. Due to the lack of organized large-scale production, supply remains inconsistent, leading to fluctuations in availability and pricing. This scenario limits market potential, restricting opportunities for broader distribution, processing, and export. Encouraging systematic cultivation with improved agricultural techniques could enhance production, stabilize supply chains, and create a more sustainable and profitable market. Phalsa's sweet and tart flavor mainly makes it a beverage, but it can be used in food, being more tempered with sugar. But its short lifespan of 1-2 days restricts its use. To enjoy its full potential, better post-harvest handling and value addition must be done. Some emerging technologies include the modified atmosphere packaging method, which potentially helps in the domestic cold chain systems, greatly limiting postharvest loss and increasing shelf-life. Getting health attainers to be better and more willing to try new products, Phalsa transforms into a whole new range of products – juices, syrups, jams, and nutraceuticals. Further on, developing new cultivars with larger fruits, better yield potential, and expanding their role in more external hemispheres. Phalsa may, in turn, turn out to be an important crop in domestic and international markets.

## 7. Conclusion

Phalsa is an extract with great potential for commercialization in the pharmaceutical and food industries, which remains largely underutilized. Its bioactive compounds, such as antioxidants, anthocyanins, and other nutritional contents, make it an important functional ingredient to address health problems and for incorporation into beverages, jams, syrups, and nutraceuticals, which meet the growing demand for health and natural foods. Its ease of cultivation also makes it profitable and environmentally friendly, especially in low-income countries. Furthermore, phalsa researchers make use of global trends of utilizing underdeveloped food processing technologies and functional/ less processed foods, phalsa stands to contribute significantly to ensuring nutrition safety and boosting economic prospects. It is suggested that subsequent research needs to enhance its therapeutic efficiency, widen its scope in the food supply chain, and combine traditional wisdom with new ideas.

## Conflict of interest

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

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