RESEARCH PAPER

Nutritional, Phytochemical, Physicochemical, Pharmacological And Ethnopharmacological Properties of Aegle Marmelos (Bael) Fruit Pulp And Its Potential Haematinic Role A Literature Review

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Abstract

Introduction: Iron deficiency anaemia (IDA) is a major nutritional and clinical problem in which inadequate iron availability limits haemoglobin synthesis and erythropoiesis. Aegle marmelos (L.) Corrêa, commonly known as Bael or Bilva, is an edible Rutaceae fruit with a long history of use in Indian traditional medicine. Objectives: This review integrates the supplied literature on the ripened fruit pulp, with emphasis on nutritional composition, phytochemicals, physicochemical characteristics, traditional uses, antioxidant and pharmacological properties, and the biological plausibility of a haematinic role in iron deficiency anaemia. material and methods: Evidence was collected from the supplied manuscript and supplemented with published review and research literature identified through web based scholarly searching Results: Ripened Bael pulp contains carbohydrates, dietary fibre, protein, minerals including iron, copper, calcium, phosphorus and potassium, and vitamins including vitamin C and B-group vitamins. Reported phytochemicals include phenolic acids, flavonoids such as rutin, organic acids, carotenoids and tocopherols; broader A. marmelos literature also describes coumarins, alkaloids, terpenoids and other bioactive classes, although not every constituent can be assumed to occur at the same concentration in ripe pulp. Vitamin C provides a plausible mechanism for enhancing non-haem iron absorption, while iron, copper and B-group vitamins provide nutritional relevance to erythropoiesis. Antioxidant activity may additionally support cellular and erythrocyte integrity. Experimental studies with Bael fruit preparations have reported favourable changes in haemoglobin, erythrocytes and haematocrit in radiation- or toxicant-related models. However, these are preclinical findings and do not establish efficacy in nutritional IDA. Importantly, direct human clinical evidence demonstrating that standardized ripe Bael pulp treats IDA or consistently improves haemoglobin, ferritin or transferrin saturation remains insufficient. The evidence therefore supports Bael pulp as a nutritionally valuable and potentially supportive haematinic food, rather than as an established replacement for evidence-based anaemia treatment. Standardized animal models and randomized human trials are needed to determine bioavailability, dose, efficacy and safety. [2,3,4,7,16,17]

Keywords: Aegle marmelos; Bael; Bilva; ripe fruit pulp; nutritional properties; phytochemicals; iron; vitamin C; antioxidant; haematinic; iron deficiency anaemia; haemoglobin; ferritin; erythropoiesis.

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2. Introduction

Aegle marmelos (L.) Corrêa is an edible fruit-bearing tree belonging to the family Rutaceae and is widely recognized in South Asian traditional medicine. The fruit is distinctive for its hard woody pericarp and aromatic, resinous, fibrous pulp. When mature, the pulp is generally pale orange, sweet and mildly astringent. The supplied literature emphasizes that medicinal composition and biological activity vary with plant part and maturity; consequently, evidence concerning leaves, roots, bark, seeds or unripe fruit should not automatically be attributed to ripened pulp. [2, 3, 6, 14, 20, 21, 23, 24, 27, 29, 32]

The present review focuses specifically on ripened fruit pulp and its possible relevance to haematological health. This distinction is particularly important for an anaemia-

focused review because the total nutrient composition of a food does not itself establish a therapeutic effect. A haematinic interpretation requires consideration of the amount and bioavailability of iron, relevant micronutrients, erythropoietic cofactors, antioxidant activity and, ultimately, evidence that clinically meaningful haematological outcomes improve.

The supplied ethnopharmacological manuscript proposes a traditional–biomedical relationship between Bilva pulp preparations, digestive function, iron availability and blood formation. Some of its therapeutic claims, including superiority to ferrous sulphate and demonstrated improvement of haemoglobin or ferritin, are not adequately supported by the supplied clinical evidence. Accordingly, those claims are not presented as established findings in this integrated review. Instead, traditional use, mechanistic plausibility, preclinical evidence and clinical evidence are clearly separated.

3. Aim and Objectives

The primary aim is to provide a thorough literature review of the properties of ripened A. marmelos fruit pulp and critically evaluate its potential haematinic relevance in iron deficiency anaemia. [2,3,7]

- To summarize the botanical and physicochemical characteristics of ripened Bael fruit pulp.
- To describe its nutritional composition and major phytochemical constituents.
- To review traditional and ethnopharmacological uses relevant to digestive and restorative health.
- To summarize antioxidant and selected pharmacological activities of fruit and pulp preparations.
- To examine plausible mechanisms through which pulp nutrients and phytochemicals could support erythropoiesis and iron utilization.
- To critically assess evidence concerning haemoglobin, erythrocytes, haematocrit and other haematological parameters.
- To identify limitations and research priorities for establishing a haematinic effect in iron deficiency anaemia.

4. Literature Review Approach

This is a narrative literature review based primarily on the three supplied manuscripts. The revised ripe-pulp manuscript was used as the principal framework for evidence grading and scope. The ethnopharmacological manuscript and the broader Bael review material were used to incorporate traditional use, botanical distribution, nutritional tables, processing applications and pharmacological observations. Evidence involving other plant parts or unripe fruit was retained only where it provides contextual information or demonstrates an important limitation of extrapolation to ripe pulp. [2, 3, 6, 7, 20, 21, 23, 24, 29, 30, 32, 34, 41, 46, 47, 48, 56, 57, 58]

The integrated approach deliberately distinguishes four levels of evidence: (1) composition and nutritional plausibility; (2) in-vitro or mechanistic findings; (3) animal/preclinical outcomes; and (4) direct human clinical evidence. This prevents nutrient composition or traditional use from being presented as proof of therapeutic efficacy.

5. Botanical Description, Distribution and Ripening

Bael fruit is generally round, oval, oblong or pyriform, with a hard, smooth woody shell. The pulp is fibrous, resinous, aromatic, sweet and pale orange at maturity. The supplied material describes slow ripening and reports that full maturation can take a prolonged period. The fruit is important as both a food and a traditional medicinal resource in India and other parts of South and Southeast Asia. [2, 13, 14, 20, 21, 23, 24, 25, 27, 28, 29, 32, 41, 56, 57, 58]

The source material describes A. marmelos as occurring across the Indian subcontinent and extending into several tropical and subtropical regions. It can tolerate relatively difficult soil conditions and is cultivated or naturally distributed in several Indian states. Geographic and cultivar differences are important because they may influence nutrient and phytochemical composition.

6. Traditional and Ethnopharmacological ImportanceA. marmelos has a long history in Ayurveda and is also used in Siddha and Unani traditions. The supplied literature describes applications of different plant parts for gastrointestinal and other disorders. The fruit has traditionally been incorporated into preparations such as Chyavanprash and a variety of food products. Ripe fruit is described in the supplied material as having mild laxative activity, whereas unripe fruit has historically been associated with stronger astringent and gastrointestinal uses. [2, 6, 14, 15, 20, 21, 23, 24, 27, 28, 29, 32, 41, 48, 56, 57, 58]

Ayurvedic descriptors reported in the source include Deepana (associated with appetite/digestive stimulation), Pittasaraka, Mridurechana (mild laxative action), Hridya and other traditional actions. These descriptions are important ethnopharmacological context but should not be interpreted as biomedical proof of correction of iron deficiency anaemia.

The concept of Pandu Roga in classical Ayurvedic literature has been discussed in relation to pallor and blood-tissue depletion. However, correspondence between classical diagnostic categories and modern iron deficiency anaemia cannot be assumed without clinical characterization. Therefore, traditional use provides a hypothesis-generating foundation rather than clinical efficacy evidence.

7. Nutritional Properties of Ripened Bael Fruit Pulp

Published nutritional values vary according to cultivar, geographic origin, maturity, analytical procedure and whether fresh pulp, dried pulp or processed material is evaluated. The values below therefore represent reported study-specific values rather than immutable compositional standards. [3,4,16,17]

Component	Reported value	Unit/basis	Potential relevance

Water [3,4,16,17]	64.2	% fresh pulp	Hydration and food matrix
Carbohydrate [3,4,16,17]	31.8	g/100 g	Energy contribution
Dietary fibre [3,4,16,17]	2.2–2.9; higher values reported in some sources	g/100 g	Gastrointestinal and dietary quality
Protein [3,4,16,17]	1.8–4.7	g/100 g	Amino-acid contribution to tissue maintenance
Fat	0.3–0.39	g/100 g	Energy and nutrient contribution
Vitamin C [3,4,16,17]	8–73.2	mg/100 g	Antioxidant; may enhance non-haem iron absorption
Iron [3,4,16,17]	0.5–0.8; 0.60 in selected reports	mg/100 g	Dietary iron contribution
Copper [3,4,16,17]	about 0.19–0.21	mg/100 g	Relevant to normal iron metabolism
Calcium [3,4,16,17]	about 80–85	mg/100 g	General mineral nutrition
Phosphorus [3,4,16,17]	about 31.8–52	mg/100 g	Mineral and metabolic functions
Potassium [3,4,16,17]	about 585–610	mg/100 g	Electrolyte/mineral contribution
Thiamine [3,4,16,17]	about 0.13	mg/100 g	B-vitamin contribution
Riboflavin [3,4,16,17]	about 0.03	mg/100 g	B-vitamin contribution
β-carotene [3,4,16,17]	reported in source literature	mg/100 g in cited source	Carotenoid/antioxidant contribution

The supplied source also reports vitamin A, B-group vitamins and other micronutrients. Importantly, nutrient presence does not establish adequate dose, absorption or correction of deficiency. The iron concentration reported for fresh pulp is relatively modest on a per-100-g basis; consequently, a haematinic claim cannot be inferred from iron content alone.

8. Phytochemical Composition

Ripened Bael pulp contains several classes of bioactive compounds. Analytical work cited in the supplied review identified phenolic acids including gallic acid, 2,3-dihydroxybenzoic acid, chlorogenic acid, p-coumaric acid and vanillic acid, together with the flavonoid rutin. Organic acids, tocopherols and carotenoids have also been characterized. [2, 7, 12, 16, 31, 33, 34, 35, 42, 46, 47]

Phytochemical class	**Examples reported in the supplied literature**	**Possible relevance**
Phenolic acids [2,7,12,16]	Gallic acid; chlorogenic acid; p-coumaric acid; vanillic acid; 2,3-dihydroxybenzoic acid	Antioxidant activity
Flavonoids [2,7,12,16]	Rutin	Antioxidant and cellular protective potential
Carotenoids [2,7,12,16]	β-carotene and other carotenoid-associated compounds	Antioxidant/nutritional contribution
Tocopherols [2,7,12,16]	Tocopherol compounds	Lipid-phase antioxidant potential
Organic acids [2,7,12,16]	Various organic acids	Food chemistry and metabolic context
Coumarins [2,7,12,16]	Marmelosin, auraptene and related compounds reported across maturity/plant studies	Bioactivity; maturity dependent
Alkaloids/terpenoids [2,7,12,16]	Reported in broader A. marmelos literature	Contextual pharmacological relevance

Tannins [2,7,12,16]	More prominent in unripe fruit in the supplied review	Maturity-dependent; not to be assumed equivalent in ripe pulp

The broader literature on A. marmelos describes alkaloids, coumarins, flavonoids, phenolics, terpenoids, tannins, carotenoids, amino acids and fatty acids across different plant materials. Because phytochemical concentration is strongly dependent on plant part, maturity and extraction procedure, broad plant-level findings should not be represented as a quantitative profile of ripe pulp.

9. Physicochemical and Sensory Properties

Ripe Bael pulp is characterized by an aromatic flavour, sweet taste, mild astringency, fibrous texture and pale-orange colour. The fruit has high moisture and substantial carbohydrate content, while its pulp matrix contains fibre and naturally occurring phytochemicals. The hard pericarp contributes to the characteristic storage and processing properties of the fruit. [3,4,16]

Bael pulp is used to prepare juice, squash, nectar, jam, jelly, marmalade, candy, toffee and dried or powdered products. Processing can change vitamin stability, moisture content, phenolic retention and extractability. Consequently, fresh ripe pulp, dehydrated powder, edible leather, aqueous extracts, hydroalcoholic extracts and other formulations should be treated as distinct materials in research.

10. Functional Food and Processing Applications

Product/form	Description from supplied literature	Research consideration
Fresh pulp	Edible ripe pulp with characteristic aromatic, sweet and fibrous properties	Best representation of the review's primary plant material
Juice/squash/nectar	Pulp-based beverages	Sugar and dilution can alter nutrient density
Jam/jelly/marmalade	Processed fruit products	Heating may affect heat-sensitive constituents
Candy/toffee	Pulp combined with sugar and other ingredients	Not equivalent to fresh pulp nutritionally
Dried powder	Dehydrated pulp used in food preparations	Concentration and storage may alter composition
Extracts	Aqueous, methanolic or hydroalcoholic preparations reported in experimental studies	Solvent and dose substantially influence exposure

11. Antioxidant and Pharmacological Properties

Antioxidant activity is one of the most consistently described biological properties of Bael fruit preparations. The supplied literature reports fruit-pulp extracts evaluated using DPPH, nitric oxide, reducing-power, hydrogen peroxide, ABTS and superoxide radical-scavenging assays. These studies support antioxidant capacity but do not by themselves establish clinical benefit in anaemia. [2, 7, 9, 16, 31, 33, 34, 35, 36, 38, 39, 40, 42, 46, 47, 48, 52]

Preclinical studies have also reported hepatoprotective, antidiabetic, antimicrobial, anti-inflammatory, chemopreventive and radioprotective activities in different A. marmelos preparations. Several of these studies use plant parts, extracts or experimental doses that differ from fresh ripe pulp. They therefore provide pharmacological context rather than direct evidence for a haematinic effect.

Radioprotective investigations are of particular relevance because bone marrow and blood parameters can be affected by radiation. The supplied literature reports that hydroalcoholic fruit preparations protected experimental animals from radiation-associated injury and that fruit extract pretreatment was associated with improved survival and reduced lipid peroxidation. These observations suggest biological activity under oxidative stress but should not be interpreted as evidence that the pulp treats nutritional IDA.

12. Potential Haematinic Mechanisms

Potential mechanism	Rationale	Strength/limitation of evidence
Dietary iron contribution [3,4,16,17]	Iron is required for haemoglobin synthesis.	Composition evidence; therapeutic effect not established.
Vitamin C and non-haem iron absorption [3,4,16,17]	Vitamin C can facilitate reduction and intestinal absorption	Biologically established mechanism; specific effect of Bael pulp not clinically quantified.

	of non-haem iron.	
Copper and iron metabolism [3,4,16,17]	Copper participates in normal iron transport and utilization.	Nutritional plausibility; no direct Bael-specific clinical proof.
B-group vitamins/folate	Folate is required for DNA synthesis and normal erythropoiesis; B vitamins support normal metabolism.	Presence in food does not establish correction of deficiency.
Antioxidant protection	Phenolics, vitamin C, tocopherols and carotenoids may reduce oxidative damage to cellular components.	Mostly in-vitro/preclinical evidence.
Digestive/nutritional support	Traditional use emphasizes digestive function and nutrient utilization.	Ethnopharmacological rationale; clinical haematinic effect remains unproven.

The proposed haematinic role is therefore best understood as a multi-component nutritional hypothesis rather than as a demonstrated pharmacological action. The combination of iron with vitamin C and other micronutrients is biologically plausible, but bioavailability and effective clinical dose remain to be determined. [3,4,16,17]

13. Evidence on Haematological Parameters

Direct human evidence specifically demonstrating that standardized ripened Bael pulp improves iron deficiency anaemia was not identified in the supplied literature. The available evidence is primarily compositional, mechanistic and preclinical. [1,8,9]

Study/model	Preparation/material	Parameters/outcomes	Interpretation
Agrawal & Goyal, 2011; irradiated mice [1,8,9,16]	A. marmelos fruit extract	Erythrocytes, haemoglobin, haematocrit	Favourable changes compared with irradiated controls; radioprotective model, not IDA.
Himat et al., 2026; arsenic toxicity in mice [1,8,9,16]	Ethanolic fruit extract; source identified as unripe fruit	Hb, PCV, total erythrocytes	Mitigation of toxicant-associated changes; not direct evidence for ripe pulp or IDA.
Ripe-pulp analytical studies [1,8,9,16]	Fresh ripe pulp	Iron, vitamin C, B vitamins, copper and antioxidant-associated compounds	Supports nutritional plausibility only; no clinical Hb/ferritin outcome.
Radiation/oxidative-stress studies [1,8,9,16]	Hydroalcoholic fruit preparations	Survival, oxidative stress and tissue protection	Supports preclinical biological activity; not proof of

			haematinic treatment.

The distinction between models is critical. Radiation-induced cytopenia and arsenic-associated haematological changes are pathophysiologically different from uncomplicated nutritional iron deficiency. An intervention that protects blood parameters in a toxicant or radiation model cannot automatically be considered an iron-repletion therapy.

14. Haematological Outcomes Recommended for Future Research

Outcome	Why it should be measured
Haemoglobin (Hb)	Primary marker of anaemia severity and response
RBC count	Provides information about erythrocyte production
Haematocrit/PCV	Assesses red-cell volume fraction
MCV	Helps characterize microcytic versus other anaemia patterns
MCH and MCHC	Characterize haemoglobin content/concentration of erythrocytes
Serum ferritin	Assesses iron stores, interpreted with inflammation
Serum iron [3,4,16,17]	Reflects circulating iron but is variable
Transferrin saturation	Provides information on circulating available iron
Reticulocyte count	Can help assess erythropoietic response
Inflammatory markers	Important because inflammation alters ferritin and iron metabolism

15. Safety and Evidence Limitations

Bael fruit is widely consumed as a food, but the safety profile of concentrated extracts or powdered preparations cannot automatically be assumed to be identical to fresh fruit. Dose, solvent, extraction procedure, maturity, duration of exposure and formulation may influence biological activity and safety. [3, 7, 16, 18, 19, 20, 23, 24, 36, 37, 38, 39, 40, 41, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58]

The principal evidence limitation is the absence of robust human clinical trials specifically testing standardized ripe Bael pulp in confirmed iron deficiency anaemia. Other limitations include variation in cultivar, maturity, preparation, extraction methods, analytical methods and outcome measures. Claims based on Bilva Majja Churna should not be transferred directly to fresh ripe pulp because formulation-specific nutrient concentrations may differ substantially.

The supplied ethnopharmacological manuscript reports numerical values for iron, vitamin C and folic acid in a particular Bilva Majja Churna formulation. Those values should be regarded as formulation-specific and should not be presented as the composition of fresh ripe pulp without direct analytical verification.

16. Research Gaps and Future Directions

1. Standardize fruit maturity, cultivar, geographical origin, storage and pulp preparation. [3,4,7,16]
2. Quantify iron, vitamin C, folate, vitamin B12, copper and other relevant micronutrients using validated analytical methods.
3. Determine iron bioavailability and absorption rather than relying only on total iron concentration.
4. Characterize the phytochemical profile of ripe pulp separately from unripe fruit and other plant parts.
5. Use a validated animal model of nutritional iron deficiency anaemia before drawing haematinic conclusions.
6. Measure Hb, RBC, Hct/PCV, MCV, MCH, MCHC, ferritin, serum iron and transferrin saturation in experimental studies.
7. Compare fresh pulp, standardized pulp powder and defined extracts as separate interventions.
8. Assess whether antioxidant activity contributes to erythrocyte protection independently of iron repletion.
9. Conduct adequately powered randomized controlled human studies before making therapeutic claims.

17. Discussion

The integrated literature supports the view that ripened A. marmelos fruit pulp is a nutritionally valuable food containing carbohydrates, fibre, protein, minerals and several vitamins and phytochemicals. Iron, vitamin C and copper are particularly relevant to a haematinic hypothesis. Vitamin C can facilitate absorption of non-haem iron, while copper has a recognized role in iron metabolism. Folate and other B vitamins contribute to normal cellular and erythropoietic processes. The antioxidant constituents of Bael may additionally provide cellular protection.

Nevertheless, the distinction between plausibility and efficacy is essential. A food can contain iron and iron-absorption-promoting nutrients without supplying sufficient bioavailable iron to correct established iron deficiency. Likewise, antioxidant activity in chemical assays does not establish correction of anaemia. The available preclinical evidence is encouraging but is based mainly on models of radiation, toxicant exposure or other biological stress rather than nutritional iron deficiency.

The traditional use of Bilva provides an important ethnopharmacological foundation and supports further investigation. However, traditional descriptions and modern biomedical outcomes should not be treated as interchangeable. A scientifically defensible haematinic claim requires standardized plant material, a confirmed IDA population or model, appropriate controls, validated haematological and iron-status outcomes, and reproducible statistical evidence.

Accordingly, the most appropriate present interpretation is that ripened Bael pulp has potential nutritional and

supportive relevance to haematological health and deserves investigation as a functional food or adjunctive dietary intervention. It cannot yet be described as a clinically established treatment for iron deficiency anaemia.

18. Conclusion

Ripened Aegle marmelos fruit pulp is a nutrient-rich edible material with important nutritional, phytochemical, physicochemical and ethnopharmacological characteristics. Reported constituents include carbohydrates, fibre, protein, iron, copper, calcium, phosphorus, potassium, vitamin C and B-group vitamins, together with phenolic acids, flavonoids, carotenoids, tocopherols and other bioactive compounds. Its vitamin C and iron content provides a plausible nutritional basis for supporting non-haem iron absorption, while copper, folate and antioxidant-associated constituents may contribute to normal erythropoietic and cellular functions.

Experimental studies of Bael fruit preparations have reported favourable changes in selected haematological parameters in radiation- or toxicant-related models, but these findings do not establish efficacy in nutritional iron deficiency anaemia. Direct human evidence for standardized ripe Bael pulp remains insufficient. Therefore, Bael pulp should presently be regarded as a potentially supportive nutrient-rich food with haematinic potential rather than as a proven anti-anaemic therapy. Rigorous analytical, preclinical and clinical studies are required to establish its iron bioavailability, effective dose, haemoglobin response, effects on ferritin and transferrin saturation, and long-term safety.

19. Integrated Evidence Summary

Domain	Evidence from supplied literature	Overall interpretation
Nutrition	Iron, vitamin C, copper, B vitamins, protein, fibre and minerals reported	Strong compositional rationale; not proof of treatment
Phytochemistry	Phenolic acids, rutin, carotenoids, tocopherols and broader bioactive classes	Supports biological plausibility
Physicochemical	Fibrous, aromatic, sweet, pale-orange ripe pulp; processing applications	Relevant to food use and formulation
Traditional medicine	Longstanding Ayurvedic/Siddha/Unani use and digestive/restorative applications	Ethnopharmacological rationale
Antioxidant activity	Multiple in-vitro assays and preclinical observations	Potential cellular protective role
Haematological preclinical evidence	Changes in Hb/RBC/Hct in stress models	Encouraging but indirect for IDA
Human clinical evidence	No robust standardized ripe-pulp IDA trial identified in supplied sources	Insufficient for therapeutic claim
Research readiness	Clear candidate mechanisms and measurable outcomes	Suitable for controlled preclinical and clinical investigation

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