Underutilized Fruiting Climber Urges Support for Survival: A Review on Bringing the Nutrient-dense Blood Fruit (Haematocarpus validus Miers) from Forest to Farm

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Systematic Review

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Underutilized Fruiting Climber Urges Support for Survival: A Review on Bringing the Nutrient-dense Blood Fruit (*Haematocarpus validus* Miers) from Forest to Farm

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Abstract

Blood Fruit or *Khoon Phal* (*Haematocarpus validus* Miers; Family: Menispermeaceae) is a red fruit commonly harvested from the wild. It is naturally distributed across various parts of Southeast Asia, whereas in India, it is dominated in the North Eastern and the Andaman and Nicobar regions. Fruits are abundant in iron, antioxidants, Vitamin C, carotene, phenols, flavonoids, and anthocyanin pigment. Traditionally, the fruit is valued among various ethnic groups and used in traditional medicine, culinary applications, making dyes, and other beverage preparations. Because of its medicinal and nutritional properties, the seeds and fruits of blood fruit are used to treat blood-related disorders, while the roots are used for relieving itching, and the tender shoots are used for managing jaundice. This climber is found widely in forests and is believed to support forest biodiversity by attracting frugivores and sustaining the understory dynamics of the forest. In addition, fruits show potential for value addition and livelihood promotion through community forest management, forest-based livelihoods, and agroforestry intervention strategies. Though the fruit has multiple benefits, research on its standardization, product development, and broader applications remains limited, and the available information is scarce. The fall in the blood fruit population in Northeast India can be ascribed to habitat destruction and deforestation, excessive harvesting, changing climate, and limited awareness about conservation. These challenges hinder the plant's natural regeneration and threaten the stable population numbers. Hence, this review will focus on documenting the multifaceted significance of the Blood fruit, identifying the knowledge gaps in its botanical and ecological study, and exploring the sustainable pathways for its conservation and commercialization in its natural distribution areas.

Keywords: Blood Fruit, North-east India, Ethnobotany, Indigenous Knowledge, Cultural Significance, Economic Potential

1. Introduction

The population explosion, increasing poverty, climate change, and other natural and human-induced crises pose significant challenges to socio-economic stability and food security worldwide. However, many wild edible fruits offer food and nutritional benefits, thrive well in the climate change era, and contributes to biodiversity conservation, and provide local livelihood opportunities. Wild edible fruit species are abundant sources of antioxidants, fibers, minerals, vitamins, and other vital nutrients (Alex et al. 2023). India is blessed with diverse climatic conditions and is home to a wide range of wild edible plants traditionally consumed by local communities. Earlier studies reported that wild edible fruit species have significantly contributed to human health and nutritional security (Hunde et al. 2011; Dinesha et al. 2024).

Though wild edible fruits have potential benefits, many remain underutilized and overlooked in daily diets (Ashwath et al. 2023; Dinesha et al. 2024). Among these lesser-known fruit species, Blood Fruit or Khoon Phal (*Haematocarpus validus* (Miers) Bakh. f. ex-Forman) is an important species that holds substantial cultural, ecological, and economic importance and stands out as a promising source of fruit, medicine, nutrition, and natural dye. *Haematocarpus* originates from two components: "haem," which denotes iron material, and "carpus," which denotes fruit. Initially, John Miers characterized this woody climber species (Singh and Bedi 2016). The matured fruits are bright red, containing an abundance of blood-red juice and a fibrous texture, which justifies the name 'Blood Fruit' or 'Khoon Phal.'

H. validus belongs to Menispermaceae or moonseed family and is a dicotyledonous species predominantly found in tropical and subtropical regions (Song et al. 2022). In this family plants are rich in alkaloid content, extensively use in traditional medicine. The fruits are traditionally gathered by locals, consumed fresh or dried, and used for preparing juice, wine, and dried powder. The blood fruits are widely used in traditional medicine, such as its fruits and seeds are employed to treat anemia, fever, and digestive issues; the roots are used to relieve itching; and the tender shoots are utilized for jaundice (Alex et al. 2023; Bohra et al. 2022). The Fruits are rich in antioxidants, iron, Vitamin C, beta-carotene, phenols, flavonoids, and anthocyanins. The vibrant red berries produce a natural dye, offering a sustainable option for textile dyeing in the region (Momin et al. 2017). Additionally, the plant plays an important role in maintaining local biodiversity by supporting various insects and animal species.

Ecologically, it is primarily found in undisturbed, moist, and evergreen forest patches and is believed to support forest biodiversity by attracting frugivores and sustaining the understory dynamics of the forest (Singh and Bedi 2016). Economically, this fruit species shows potential for value addition and livelihood promotion through community forest management and agroforestry intervention strategies. The nutritional, natural colorant and ethnomedicinal value of this fruit are well recognized, particularly among older members of various ethnic communities (Momin et al. 2017). However, research on its standardization, product development, and broader applications remains limited, and the available information is scarce. Researchers are showing growing interest in exploring bioactive compounds, reproductive biology, cultivation practices, and methods for sustainable harvesting. Its decline in Northeast India is linked to ecological and human-induced pressures, including habitat degradation and deforestation, unsustainable harvesting, climate change, and inadequate conservation measures. These issues hinder the plant's natural regeneration and compromise the stability of its population across native habitats.

Hence, this review will focus on documenting the multifaceted significance of Blood fruit, identifying the knowledge gaps in its botanical and ecological study, and exploring the sustainable pathways for its conservation and commercialization in its distribution areas.

2. Botanical Description, Growth Pattern, and Ecological Preferences

The genus Haematocarpus comprises two species namely *H. subpeltatus* Merr. and *H. validus* (Miers) Bakh.f. ex-Forman. *H. subpeltatus* is distributed in Asian countries like China, the Philippines, Borneo, and Sulawesi (Forman 1972; Mabberley 2008; Lian et al. 2021). Whereas, *H. validus* distribution is mainly reported from Bangladesh, India, Laos, Indonesia, Malaysia, and Thailand (Kanjilal et al. 1934; Singh and Bedi 2016). However, some studies also reported its distribution in Pakistan and some Southeast Asian countries (Momin et al.

2017; Sasikumar and Jaiswal 2022a). This blood fruit natural distribution in India is mainly found in the tropical deciduous and evergreen forests of the Northeastern region, particularly in Assam, Arunachal Pradesh, Meghalaya, Mizoram, and Tripura, due to the presence of specific environmental conditions favorable for its growth (Angami et al. 2022; Bohra et al. 2016; Lalmuansangi and Lalramnghinglova 2014; Sarkar et al. 2023). It is also reported in West Bengal and the Andaman and Nicobar Islands (Bohra et al. 2016).

Earlier studies reported that this species can thrive under extreme environmental conditions, including both arid regions and highly acidic soils (Bohra and Waman 2022). This large, woody climber can grow at elevations of up to 1000 meters or more (Rahim et al. 2015). One of the studies from Meghalaya reported that the fruit from the Tura range in West Garo Hills (300 m elevation) showed larger fruits with greater firmness, high total sugar (TSS), and fruit yield, and the highest mineral content (Sasikumar et al. 2025). Blood fruit climbers produce dark green, glabrous, and highly branched stems that spread over large and tall trees such as banyan, jackfruit, and *Baccaurea* species for support, creeping along their trunks (Bohra et al. 2016; Sangma and Thomas 2023). The leaves are simple, alternate, non-peltate, elliptic, three-veined, and petiolate (Momin et al. 2016). The bark is grayish-brown with a rough texture, and the branches are thick, containing thin, radiating layers of wood. It is dioecious, exhibits cauliflorous inflorescence, and can be axillary, extra-axillary, terminal panicles, or racemes (Momin et al. 2016). Flowers possess 12–15 sepals, six petals, six free stamens, six small staminodes, and six carpels. It has seasonal fruiting behavior and produces distinctive deep red pulp. The fruits are drupes, characterized by a narrow base and a stalked structure, with a style scar near the base and a smooth endocarp. The Northeastern region's flowering starts in October, and fruits are sold in the local markets from March through June (Momin et al. 2016). The seeds are curved, non-endospermic, with a short radicle and thick, elongated cotyledons (Lian et al. 2021). Seed dispersal mainly occurs through barochory (gravity-based), zoochory, and anthropochory.

Plate 1. a. Blood fruit, a woody climber, spreads over a large tree; 1. b-d. Blood fruit marketing in the local market of Garo Hills of Meghalaya

3. Systematic Review of Earlier Studies on Blood Fruit

3.1. Protocol for Systematic Review

The present study implements the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) protocol (Moher et al. 2009) to review and analyze the published information evidence about Blood fruit in Asia. In this analysis study, we examined the literature focused on the availability, awareness, consumption, distribution, exploitation, data, status, production, and utilization of Blood fruit from wild and semiwild areas. It includes available articles, book chapters, and technical reports on Google, Google Scholar, J-gate, Scopus, and Web of Science, for all time. Finally, 50 articles were considered in the synthesis after the elimination of duplicates, based on criteria (Table 1). The information from the literature was used to make a comprehensive list with the research focus, the distribution of the study area, and its sources (Table 1).

3.2. Key findings

The systematic review resulted in 48 articles across Asian countries. These 48 articles are categorized based on the research focus, including 15 on general reviews, 15 on health and nutrition, 8 on post-harvest and value addition, five on phytodiversity, three on taxonomy, and two on domestication and conservation (Table 1; Figure 1). Based on the region-wise distribution (Figure 2), India reported the most articles (44), followed by Bangladesh (3) and Malaysia (1). In India, Meghalaya reported a greater number of articles (20) than the Andaman and Nicobar Islands (14). It is observed that there was a notable increase in publications from 2014 to 2023 (Figure 3). Although many studies reported its distribution in East Asia, South Asia, and Southeast Asia, including Pakistan, no research was found except in India, Malaysia, and Bangladesh. Additionally, this offers directions for future research initiatives on domestication, conservation, and sustainable management.

Table 1. List of Earlier Studies on Blood Fruit in Asia

Sl. No.	Research Focus	State	Study Area	References
1	Phyto diversity	Assam	India	Kanjilal et al. 1934
2	Taxonomy	-	Malaysia	Forman 1972
3	Health and Nutrition	Andaman Islands	India	Singh and Banu 2014
4	Taxonomy	Chittagong Hills	Bangladesh	Khatun et al. 2014
5	Health and Nutrition	Andaman Islands	India	Singh et al. 2014
6	Phyto diversity	Mizoram	India	Lalmuansangi and Lalramnghinglova 2014
7	General review	Chittagong Hills	Bangladesh	Rahim et al. 2015
8	Taxonomy	Northeast Region	India	Singh and Bedi 2016
9	General Review	Andaman Islands	India	Bohra et al. 2016
10	General review	Meghalaya	India	Momin et al. 2016
11	Health and Nutrition	Meghalaya	India	Sangma 2016
12	General review	Meghalaya	India	Momin et al. 2017
13	Health and Nutrition	Andaman Islands	India	Alex et al. 2017
14	Health and Nutrition	Andaman Islands	India	Alex 2018
15	Health and Nutrition	Andaman Islands	India	Alex et al. 2018a
16	Health and Nutrition	Andaman Islands	India	Alex et al. 2018b
17	General Review	Meghalaya	India	Momin et al. 2018

18	Domestication and Conservation	Andaman Islands	India	Bohra et al. 2018
19	Post-Harvest and Value Addition	Meghalaya	India	Raju and Deka 2018
20	Post-Harvest and Value Addition	Meghalaya	India	Sasikumar et al. 2019
21	Health and Nutrition	Andaman Islands	India	Bohra et al. 2020a
22	Domestication and Conservation	Andaman Islands	India	Bohra et al. 2020b
23	Phyto diversity	Chittagong Hills	Bangladesh	Abdullah et al. 2020
24	Post-Harvest and Value Addition	Meghalaya	India	Sasikumar et al. 2020a
25	Post-Harvest and Value Addition	Meghalaya	India	Sasikumar et al. 2020b
26	Health and Nutrition	Meghalaya	India	Sasikumar et al. 2020c
27	General Review	Andaman Islands	India	Bohra et al. 2021
28	General Review	Meghalaya	India	Chaurasiya and Singh 2021
29	Health and Nutrition	Meghalaya	India	Flory et al. 2021
30	Post-Harvest and Value Addition	Meghalaya	India	Sasikumar et al. 2021
31	General Review	Northeast Region	India	Angami et al. 2022
32	General Review	Andaman Islands	India	Alex et al. 2022
33	Post-Harvest and Value Addition	Meghalaya	India	Flory and Chaurasiya 2022
34	Phytodiversity	Andaman Islands; Tripura	India	Bohra et al. 2022
35	General Review	Andaman Islands	India	Bohra and Waman 2022
36	Phytodiversity	Mizoram	India	Lalduhawma et al. 2022
37	Health and Nutrition	Meghalaya	India	Sasikumar and Jaiswal 2022a
38	Health and Nutrition	Meghalaya	India	Sasikumar and Jaiswal 2022b
39	Post-Harvest and Value Addition	Meghalaya	India	Flory and Chaurasiya 2023a
40	Post-Harvest and Value Addition	Meghalaya	India	Flory and Chaurasiya 2023b
41	Health and Nutrition	Northeast Region	India	Rymbai et al. 2023
42	General Review	Meghalaya	India	Sangma and Thomas 2023
43	Health and Nutrition	Meghalaya	India	Sarkar et al. 2023
44	Health and Nutrition	Andaman Islands	India	Alex et al. 2023
45	General review	-	India	Srivastava et al. 2023
46	General review	-	India	Srivastava et al. 2024
47	General review	Sikkim	India	Subba et al. 2024
48	General review	Meghalaya	India	Sasikumar et al. 2025

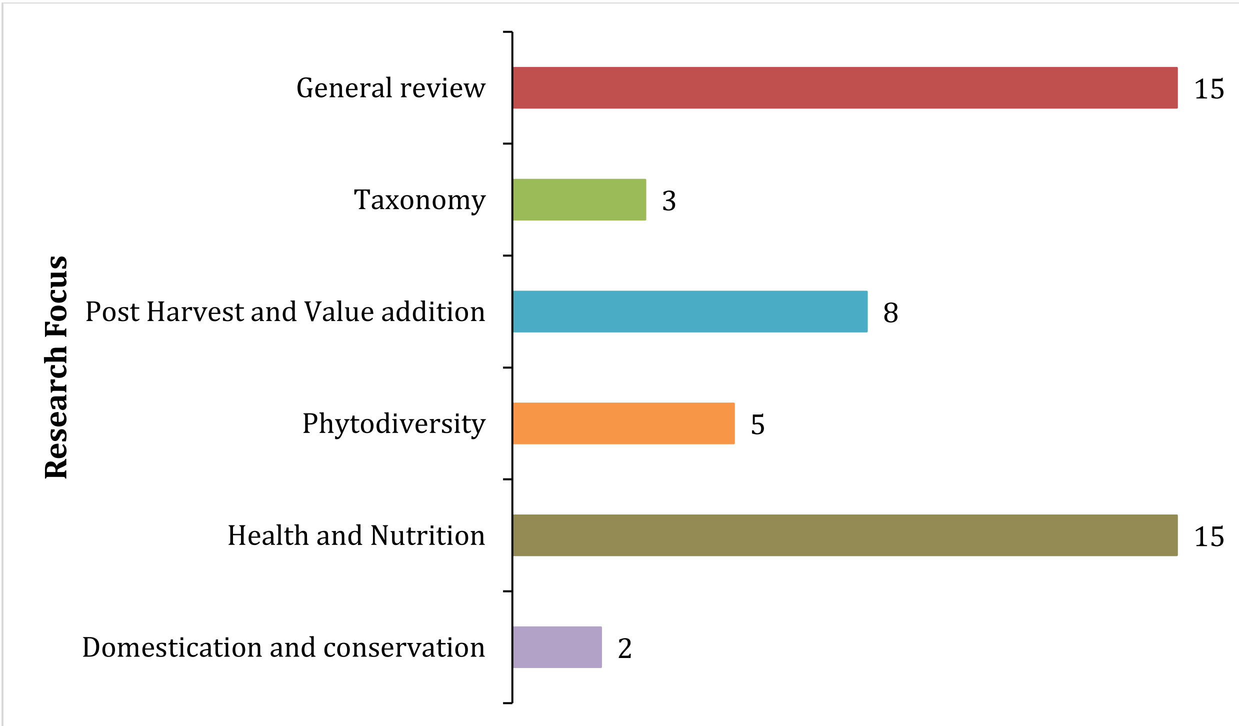

Figure 1. Research Focus-wise Publications of Blood Fruit

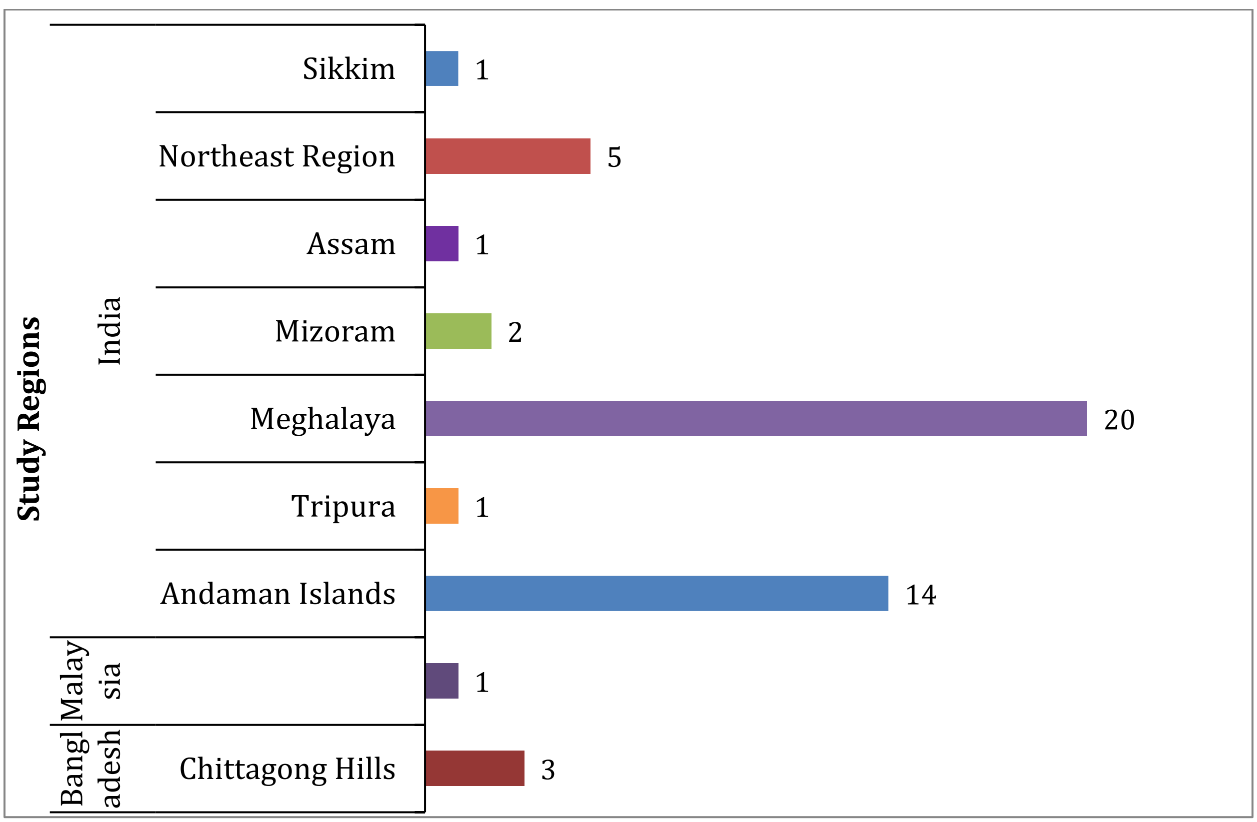

Figure 2. Region-wise Publications of Blood Fruit

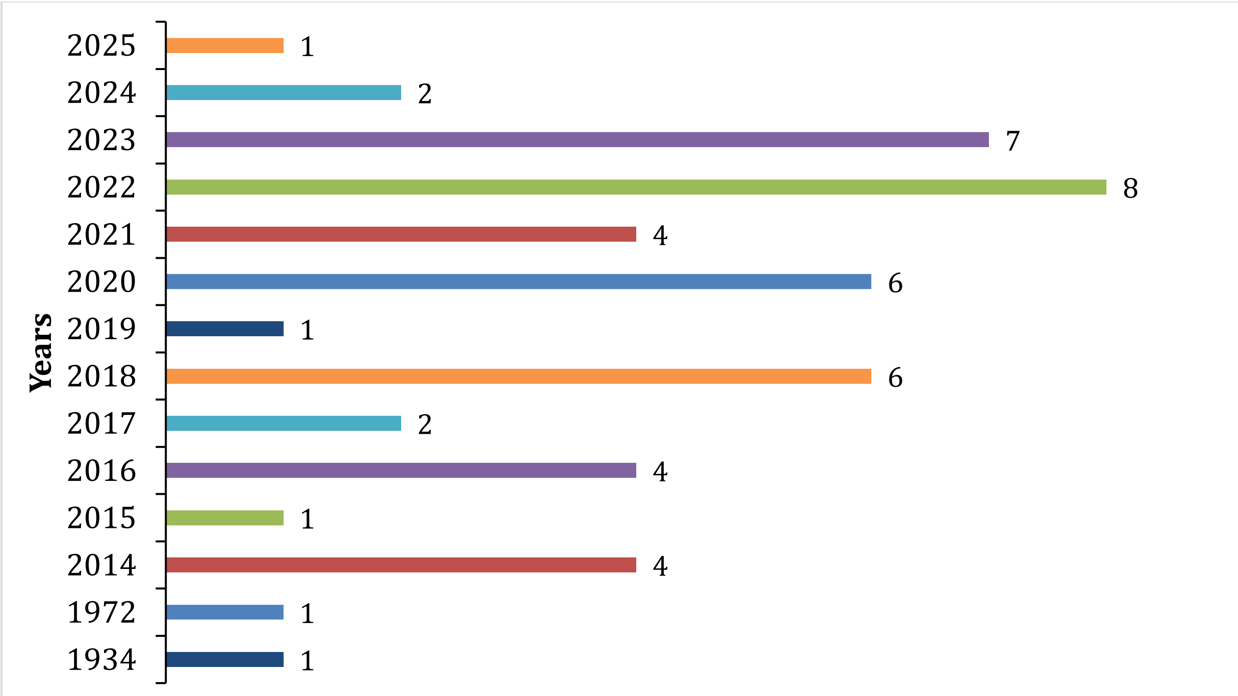

Figure 3. Year-wise Publications of Blood Fruit

4. Present Status of Blood Fruit

Blood fruit grows wild in most of its natural range, and forests continue to serve as the primary source for local communities. Earlier studies identified its habitat as tropical and subtropical moist and evergreen forests, characterized by old-growth large canopies, dense herbaceous undergrowth, hilly terrain below 1300 m altitude, and high precipitation (Lian et al. 2021; Singh and Bedi 2016). It was predominantly harvested from forests using unsustainable methods, significantly contributing to its wild population's decline. The seedlings that arose from the wild population exhibit significant variability in fruit size (Table 2), which was observed by Bohra et al. (2022) in the Andaman Islands and Tripura. Similar findings are also observed in three villages near the Tura region of Meghalaya, which are located within a 2-5 km radius (Plate 2). These observations can be used to select and domesticate high-performing genotypes.

The senior villagers and herbal healers from Asanong, Meghalaya, express their deep concern about the decreasing blood fruit in their surroundings. Earlier, it was plentiful in their surrounding areas and was easily available in local markets at a lower price. But now various fruit sizes of a small bunch (200-500 g) are sold for 100 rupees in the local markets (Rongram and Tura, Meghalaya) (Plate 1.b-d). Habitat destruction (shifting cultivation and commercial areca nut monocropping), lack of awareness, and domestication are the primary causes of natural population decline.

Based on the previous studies on morphometric analysis of blood fruit, the fruit weight in India ranges from 15 to 21 g, whereas fruits from Bangladesh are larger, averaging around 28 g (Table 2). The fruit length varies between 2 and 5 cm, while the width ranges from 2 to 3.16 cm. The peel constitutes the larger portion of the fruit, accounting for 52-64 %, followed by pulp (19-26 %) and seed (14-28 %). Within India, the states of Mizoram, Meghalaya, and Tripura produce relatively larger fruits (around 21 g) than the Andaman and Nicobar Islands (Table

2). Notably, fruit from Tripura is characterized by a larger size, medium length, thicker peel and pulp, and smaller seeds.

Plate 2. Fruits and Seeds of Blood Fruit Collected from Three Villages near Tura, Meghalaya

Table 2. Morphometric analysis of the fruits from different regions of India and Bangladesh

Region		Fruit weight (g)	Fruit length (cm)	Fruit width (cm)	% to fruit weight			References
					Peel	Pulp	Seed	
India	Andaman and Nicobar	15.16	3.58	2.80	54.03	24.80	21.17	Bohra et al. 2022
	Tripura	21.17	4.30	3.10	54.77	26.17	19.06	Bohra et al. 2022
	Meghalaya	21.34	3.87	2.90	57.16	19.41	23.43	Chaurasiya and Singh, 2021
	Mizoram	21.21	4.18	3.16	52.05	19.71	28.38	Lalduhawma et al. 2022
Bangladesh	Chittagong Hills	28.00	4.00-5.00	2.00-2.50	64.00	22.00	14.00	Rahim et al. 2015
	Chittagong Hills	28.00	4.00-5.00	2.00-2.50	64.29	21.43	14.29	Khatun et al. 2014

5. Biochemical Studies on Blood Fruit

Blood fruit is rich in anthocyanins, responsible for its deep red color and antioxidant properties. Previous studies report (Table 3) that the amount of anthocyanin present in Blood fruit is approximately 195.93 mg/ 100g of pulp (Sangma 2016; Bohra et al. 2020a). The analysis conducted using GC-MS showed that the fruit and leaf extracts comprised 54 and 48 phytochemicals, respectively. Quinic acid is a predominant volatile found in Blood fruit (29.13 %), known for its hepatoprotective, anti-inflammatory, and antioxidant effects (Alex et al. 2022). In addition, high Choline content has been quantified in both fruit (197.81 mg/100g dry weight) and leaf (> 500mg /100g dry weight), supporting traditional use for liver problems (Alex et al. 2017, 2018a). The fruit also constitutes a significant level of ascorbic acid (5.33 mg/ 100g), beta-carotene (138.42 IU), protein (7.60 %), carbohydrates (8.68

%), and a small amount of starch (0.23 g/ 100g) (Sangma, 2016). Both fruits and leaves are high in iron (57.29 and 38.44 mg / 100g dry weight, respectively), more than commercial fruits like apples, citrus, jackfruit, and mango (Table 4). Also, the fruit exhibits a high potassium/ sodium ratio (280.65), along with other macro and micronutrients. A high unsaturated/ saturated fatty acid ratio is found in fruit and leaf, with abundant linoleic acid (Alex et al. 2022). Furthermore, HR LCMS analysis has detected various alkaloids such as choline, metanephrine, (S)-reticuline, ambelline, sinomenine, and ecogenone in both leaf and fruit, these compounds are associated with hepatoprotective, anti-inflammatory, anti-rheumatic, cardiovascular, anti-microbial, anti-carcinogenic, and antioxidant activities (Alex et al. 2017). Additionally, the fruit has a TSS content of 14.5 ° Brix, a total sugar of 7.14 %, and a total titratable acidity is 0.26 % (Sangma 2016).

Table 3. Key Bioactive Compounds and Their Potential Health Benefits

Health Benefits	**Bioactive Compounds**	**Concentration** (mg/100g dried fruit)	**Supporting Research Studies**	**References**
Hepatoprotective	Quinic acid	292.95	Fruit predominantly contains Quinic acid, which is known for its hepato-protective properties	Alex et al. 2022
	Choline	197.81		
Anti-inflammatory	Quinic acid	292.95	All three bioactive compounds exhibit anti-inflammatory effects	Alex et al. 2022, 2023
	Sinomenine	45.73		
	Anthocyanine	195.93		
Anti-arthritic	Sinomenine	-	Leaf extracts contain Sinomenine (45.73 mg/100 g), which is known for its anti-arthritic properties. It supports traditional use for arthritis.	Alex et al. 2023
Antioxidant	Phenols	1508.08	High phenolic content and significant antioxidant activities were observed through DPPH, ORAC, ABTS, and FRAP assays.	Sasikumar et al. 2020c
	Quinic acid	292.95		
	Anthocyanine	195.93		
Antimicrobial	2-Bromotetradecane, Heptadecane, Palmitic acid	-	Ethyl acetate extract exhibited antimicrobial activity	Sasikumar et al. 2020c
Anti-obesity, and Cardiovascul	Conjugated Linoleic Acid	-	Leaves rich in conjugated linoleic acid (2.5 %) and linoleic acid (55.54 %) are beneficial for heart	Alex et al. 2022

ar	Linoleic acid	-	health and overall body weight management	
Anemia	Iron (Fe)	57.29	Fruits contain a high iron content. A 10g of dried fruit provides 72% of the daily requirement for an adult.	Alex et al. 2022
Neuroprotective	Quinic acid	292.95	Quinic acid has been associated with neuroprotective effects.	Alex et al. 2022
Skin Disorders	Ascorbic acid	5.33	Traditionally used to treat skin issues	Alex et al. 2022
Ophthalmic Disorders	Beta-carotene	138.42 IU	This bioactive compound helps to cure eye-related problems	Sangma, 2016
Natural Food Colorant	Anthocyanin	195.93	The fruit's bright red color makes it suitable as an eco-friendly dye for food and handicrafts.	Alex et al. 2022

6. Nutritional and Medicinal Properties

6.1. Health Benefits and Therapeutic Uses

Many studies have reported numerous health benefits and therapeutic applications of Blood Fruit due to its rich bioactive compounds, like quinic acid, sinomenine, and phenolics contribute to hepatoprotective, neuroprotective, anti-anemic, anti-inflammatory, antioxidant, and anti-arthritic effects (Sasikumar et al. 2020c; Alex et al. 2022). These studies support the traditional use of blood fruits and their plant parts for curing various ailments (Alex et al. 2023). The unsaturated fatty acids, like conjugated linoleic acid (CLA) and linoleic acid, present in the fruit also show antimicrobial activity and support cardiovascular and anti-obesity benefits (Table 3). High iron content (57.29 mg/100g) in fruits helps in anemia treatment. Traditionally, the extracted dry powder from fruits is used as an eco-friendly dye for food and handicrafts (Alex et al. 2022).

6.2. Comparison with Other Commercial Fruits

Blood fruit stands out nutritionally among other commercial fruits such as apple, citrus, jackfruit, and mango. It has a high potassium content (1740–1890 mg/100g), far exceeding apple, citrus, jackfruit, and mango (Table 4). Its vitamin C (13.15–17.94 mg/100g), and carotenoids (18.47 mg/100g), are also higher, promoting immunity, support vision, cell protection, and skin health. On the other hand, blood fruit was reported lower in protein and sugar than jackfruit or mango. It also has high antioxidant capacity and unique phytochemicals like quinic acid, anthocyanins, and choline. Considering the comparative nutritional profile (Table 4), blood fruit has the potential to be used as a functional food in sustainable diets and nutraceuticals.

Table 4. Nutritional Comparison of Blood Fruit with Mango, Citrus, Jackfruit, and Apple (Momin et al. 2018; Lalduhawna et al. 2022)

Nutritional Profile (mg/100g)	**Blood Fruit**	**Apple**	**Jackfruit**	**Mango**	**Orange**
Vitamin C	13.15- 17.94	7.94	11.08	10.88	10.13
Iron	0.57	0.10	0.50	0.20	0.10–0.20
Potassium	1740–1890	107	303	168	181
Carotenoids	18.47	0.02	0.50–0.70	4.93–14.94	0.10–0.20
Protein	600	300	1500	800	900
Carbohydrate (g/100g)	6.99–11.27	13.80	23.50	15.00	8.30
Total Sugar (g/100g)	11.27	10.40	19.10	14.80	8.20
Antioxidants	High	Low–Moderate	Moderate	Moderate	Moderate
Unique Compounds	Quinic acid, choline, anthocyanins,	Quercetin	Lectin	Mangiferin	Hesperidin, naringin

7. Socio-Economic and Cultural Significance

7.1. Traditional knowledge and uses among various ethnic communities

The ethnomedicinal value of this fruit is well recognized, particularly among older members of village communities (Momin et al. 2017). The Blood fruits are consumed raw, used in traditional medicine, and serve as a natural dyeing agent by local communities, including various ethnic groups across Asian countries. The knowledge of the fruit's uses and significance has been passed down through generations by elders. Currently, blood fruits are primarily gathered from the nearby wild areas; however, there is significant potential to promote their cultivation in agroforestry, and other land use systems.

Every part of the climber has unique and significant medicinal importance. Blood fruits are used as folk medicine among various ethnic groups, and this knowledge has been passed from generation to generation. For instance, ethnic communities of Chittagong in Bangladesh, namely the Chakma and Marma use tender shoots to cure jaundice. As fruits are rich in high iron (0.57 mg/100 g) content, hence used to treat anemia and blood-related disorders, they are also used by the Garo community in Meghalaya. The next morning, overnight water-soaked ripe fruits are consumed as medicine (Momin et al. 2018). Furthermore, root extract is also utilized for itching (Rahim et al. 2015).

7.2. Culinary Uses and Value-Added Products for Sustainable Commercialization

The blood fruit is rich in Anthocyanin content, which is the reason for its deep red color, and is used as a natural colorant in food. It has become an integral part of the Garo community in Meghalaya and is used as a wild fruit snack, to make mixed drinks and juice, in jam, and to make fermented beverages like wine (Momin et al. 2016; Chaurasia and Singh 2021). In Tripura, fruit is used for the preparation of squash, pickle, and Chutney (Bohra et al. 2016). In addition, Chakma and Marma communities in the Chittagong Hills of Bangladesh added the blood fruit to rice cakes and puddings, and also dried the ripened fruit, and stored it for future use (Khatun et al. 2014). The culinary uses and value-added products of blood fruits are discussed in Table 5.

Table 5. Culinary Uses and Value-Added Products of Blood Fruits

Culinary Use	Description	Ethnic Communities and their Region	References
Fresh Consumption	A sweet-tart flavored fruits are eaten raw or used as a wild fruit snack.	Garo communities in Meghalaya	Momin et al. 2016; Chaurasiya and Singh 2021
Juice and Beverages	Used to make juices or mixed drinks.	Garo communities in Meghalaya	Momin et al. 2016; Chaurasiya and Singh 2021
Squash	Squash preparation	Tripura; Chakma communities in Chittagong, Bangladesh	Khatun et al. 2014; Bohra et al. 2016
Traditional Desserts	Added to rice cakes, puddings, or sweet sticky rice for flavor and color.	Chakma and Marma communities in Chittagong, Bangladesh	Khatun et al. 2014
Natural Food Coloring	Juice is used as a natural dye for dishes or baked goods.	Garo communities in Meghalaya	Bohra et al. 2016; Sangma 2016
Jams	Used in jams.	Garo communities in Meghalaya	Momin et al. 2016
Sauces	Made into tangy sauces.	Tripura	Bohra et al. 2016
Fermented Products	Fruits are used for the preparation of traditional fermented products like wine.	Garo communities in Meghalaya	Momin et al. 2016; Sangma 2016
Pickle	Pickles from green fruits.	Tripura	Bohra et al. 2016

Chutney	Chutneys from green fruits.	Tripura	Bohra et al. 2016
Dried fruits	Fully matured fruits are stored for future consumption.	Chakma and Marma communities in Chittagong, Bangladesh	Chaurasiya and Singh 2021

7.3. Economic and Livelihood Aspect

Blood fruit is not commonly found in mainstream markets, but it holds significant culinary and cultural importance in certain regions. Generally, Blood fruits are harvested from the wild, due to high demand and limited availability, fruits are overharvested. It made this fruit vulnerable in some regions where this fruit is highly valued. For example, in Meghalaya, there is a high demand for blood fruits due to their high nutritional value. This species has a well-established local market and a bunch of 10-15 fruits costs around Rs. 100 (Momin et al. 2016). A single fruit cluster can weigh between 0.5 and 1.5 kg. The huge surge in demand and higher market price provides ample scope for scaling up the commercial cultivation of these plants.

8. Propagation and Domestication

8.1 Propagation efforts

Few studies have been undertaken for standardizing growing media (Bohra and Waman, 2022), the effect of growth hormones on seed germination (Bohra et al. 2018), and seed pretreatment techniques (Bohra et al. 2020b) to support conservation efforts and improve germination rates. Results found that the use of vermicompost significantly improved seed germination (69.0 %) and seedling vigor index (5466.9) (Bohra et al. 2020b). Considering these findings, vermicompost growing media is advised for the germination of blood fruit in the nursery, and treatment of seeds with thiourea (0.1%) or GA3 (1000 mg/l) for 24 h (Bohra et al. 2018).

Based on the review of the earlier studies, comprehensive research remains scarce on Blood fruit regeneration and domestication through vegetative means. Recalcitrant seeds, underdeveloped embryos, and dioecious nature are the major challenges associated with seed-based propagation, leading to slow regeneration capacity. However, a few studies have focused only on seed germination, leaving other propagation methods like vegetative propagation techniques (Cuttings, grafting, and micropropagation) underexplored. Moreover, blood fruit takes around seven years to mature and flowers if it is grown from seeds, whereas it takes around four years when it is vegetatively propagated from cuttings (Momin et al. 2016). Thus, standardized regeneration protocols are required to produce quality planting materials for conservation and domestication, both sexually and vegetatively.

8.2. Potential for agroforestry, home gardens, and other land use systems

So far, no systematic efforts have been made for blood fruit domestication, and in most places, fruits are harvested by local people from the wild (Bohra et al. 2016). Based on our field studies, we have observed that Blood fruit is growing naturally and vigorously on the dominant native trees (*Schima wallichii*, *Artocarpus heterophyllus*, *Ficus* species, and *Terminalia chebula*) and the areca nut plantations, particularly, in the Garo Hills, Meghalaya, India. In the interior parts of the Garo Hills where mechanization is limited and field is left without intensive weeding and tending operations which mimics natural farming or do-nothing farming, people are allowing blood fruit to grow on native trees and on areca nut palms also, which is similar to the traditional coffee-based agroforestry system in Coorg Karnataka, India (Pinard et al. 2014). It is also observed that the Blood fruit woody climbers are growing on bamboo trees, and people are also growing pineapples in between bamboo thickets. Hence, maintaining natural conditions (growing native trees along with commercial crops) can be conducive for Blood fruit cultivation, Arecanut+ Blood fruit+ Native trees, and Bamboo+Blood fruit+Pineapple. Native trees + Blood fruit can be the potential agroforestry systems, especially in their native regions of Northeastern India. As a nutrient-dense, medicinal fruit-producing climber, it can be effectively incorporated as a shade crop in overlapping agroforestry systems like black pepper and betel wine overlapped multistory cropping systems. It grows well in extreme conditions due to several adaptive traits like drought tolerance, hardy physiology, resilience to acid and poor soils, minimal care, and resistance to pests and diseases (Rahim et al. 2015; Bohra et al. 2018). Factors such as its dioecious nature, underdeveloped embryos, recalcitrant seeds, and various anthropogenic pressures pose a threat to its survival (Khatun et al. 2014; Bohra et al. 2020b).

9. Conservation status

The Northeastern region is witnessing a reduction in its endemic plant species, including *H. validus*, as they face the danger of extinction in the current Anthropocene era. The India State of Forest Report (ISFR) 2021 reported a substantial forest cover decline in the Northeastern states. This forest cover loss is primarily caused by shifting cultivation, logging, and other human activities, leading to habitat destruction and fragmentation that endanger endemic biodiversity. If the same condition lasts, there is no doubt about the loss of these species in the future years. Although this species is not listed under the endangered category of the IUCN list, many studies have mentioned it as an endangered, vulnerable, and threatened species (Abdullah et al. 2020; Srivastava et al. 2023) in their local and regional studies. On the other hand, some studies also reported that the blood fruit is highly threatened, needs critical morphological documentation, and requires significant attention for conservation (Rahim et al. 2015). Thus, it serves as an urgent reminder for all the local communities, government bodies, and research institutes to promptly implement effective conservation efforts.

10. Major Challenges in Cultivating Blood Fruit

- **Limited Awareness and Knowledge**: There is a general lack of awareness about blood fruit's nutritional value, cultivation potential, and market opportunities among farmers and consumers, which limits its domestication as a cultivated crop (Sasikumar et al. 2025; Momin et al. 2018).
- **Limited Research and Scientific Management**: Information and research on crop improvement, seed and vegetative propagation, scientific management, and conservation are extremely scarce. This lacks the development of effective cultivation practices and identification of superior, disease-resistant, and high-yielding cultivars (Momin et al. 2018)
- **Seed dormancy and Germination issues**: Blood fruit species are dioecious, have underdeveloped embryos and recalcitrant seeds, and show seed dormancy, hence requires pollinators, pre-treatment of seeds with thiourea and using nutrients substrate like vermicompost to achieve good germination rates and seedling vigor (Bohra et al. 2020b).

- **Indiscriminate Harvesting and Conservation Concerns:** The plant is generally harvested from the wild, and increasing demand has led to unsustainable harvesting, threatening the natural population, and making it critically endangered in some regions.
- **Limited Distribution and Genetic Diversity:** Its natural distribution is limited to some of the Southeast Asian countries; in India, its distribution is limited to the Andaman and Nicobar Islands and the North Eastern States. This limits the availability of planting material and reduces its wider adaptability.
- **Lack of Storage and Post-harvest Infrastructure:** Blood fruit is highly perishable, and a lack of storage infrastructure and processing units reduces its marketability and economic potential (Sasikumar et al. 2025). Hence, bioprospecting of blood fruit opens up new avenues for rising value-added products.
- **Need for Conservation and Domestication:** Efforts are made to promote in situ (natural habitat) and ex-situ (agroforestry, gene bank, home garden, nursery). Domestication and cultivation of underutilized fruits in agricultural fields and home gardens are crucial for protecting wild populations and ensuring sustainable use (Momin et al. 2018; Dinesha and Shridevi 2025).

11. Research Gaps and Future Directions

The nutritional, natural colorant and ethnomedicinal value of this fruit is well recognized, particularly among older members of village communities. However, research on its standardization, product development, and broader applications remains limited, and the available information is scarce. The decline of blood fruit in Northeast India is the result of multiple interconnected ecological and human-driven factors, including habitat destruction and deforestation, excessive harvesting, climate change, and limited conservation awareness. These issues reduce the plant's natural regeneration and maintain stable population numbers. Based on the review of the literature, there remains a scarcity of comprehensive research on Blood fruit regeneration. Recalcitrant seeds, underdeveloped embryos, and dioecious nature are the major challenges associated with seed-based propagation leading to slow regeneration capacity. However, a few studies have focused only on seed germination, leaving other propagation methods like vegetative propagation techniques (Cuttings, grafting, and micropropagation) underexplored. Thus, standardized regeneration protocols are required to produce quality planting materials.

Earlier studies on Blood fruit primarily focus on its morphology, phytochemistry, and ethnomedicinal uses, with limited genetic data (Table 1). Blood fruit species are dioecious (separate male and female plants); hence it is a highly cross-pollinated crop. Male flowers have six stamens with enlarged connective tissue (Momin et al. 2018). Identification of chromosome number, genome size, and detailed pollen studies remains unreported. Although some of the studies reported organellar gene sequencing (Momin et al. 2017) and phylogenetic studies of Blood fruit (Wang et al. 2012; Wefferling et al. 2013), few reported information was related to other families such as Papaveraceae (Hoot et al. 2015). As per available data, no genomic conservation efforts or molecular studies documented. Therefore, there is a need to focus on genetic characterization to support conservation and breeding programs.

Morphometric analysis of the fruits from different regions of India and Bangladesh were compared (Table 1). Both the pulp and peel of the fruits contribute around 60 % of the fruit weight; the rest is a single seed that constitutes around 40 %, indicating future research to improve pulp content for the processing industry (Sangma

2016; Chaurasiya and Singh 2021). Generally, blood fruit consists of very low pulp content and larger seeds. Hence, there is a need to focus on fruit quality improvement, propagation studies, and seedless or small-seeded fruit production. Due to its high perishable (short shelf life of 4-5 days), spoils rapidly during harvesting, storage, and transportation (Sasikumar et al. 2017). Therefore, further studies on improving shelf life, storage, and quality improvement of fruits are needed.

12. Conclusion

In conclusion, Blood Fruit is closely integrated with the lives of many ethnic groups in Southeast Asia. The presence of high anthocyanins, Vitamin C, iron, TSS, and other phytoconstituents makes the Blood fruit ideal for winemaking and other value-added products. However, lower pulp content and larger seeds are the major challenges in processing fruits into different value-added products. As a nutrient-dense, medicinal fruit-producing climber, it can be effectively incorporated as a shade crop in overlapping agroforestry systems. Although it grows well in extreme conditions, its domestication remains limited. Factors such as its dioecious nature, underdeveloped embryos, recalcitrant seeds, and various anthropogenic pressures pose a threat to its survival. Despite being native to South and Southeast Asia, studies on this species are scarce. Apart from India and Bangladesh, no other countries have reported substantial studies. Only preliminary studies have documented its presence in the Chittagong Hills in Bangladesh. In contrast, India has conducted more extensive research, particularly in the Andaman and Nicobar, Meghalaya, Mizoram, and Tripura. These studies cover aspects such as phytochemical composition, development of value-added products, and general reviews. However, due to limited domestication, only two studies have focused on seed propagation. There is a complete lack of research on its vegetative growth, quality improvement, and the selection and development of elite genotypes. Based on earlier studies, the blood fruit has lower pulp content and larger seeds, which hinders commercialization. Hence, there is a need to focus on fruit quality improvement, propagation studies, and seedless or small-seeded fruit production. Further research needs to be focused on vegetative propagation techniques, quality and quantity improvement, and the development of value-added products, which can be helpful in successful domestication, commercialization, and economic resilience.

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Study conception and design by Dinesha S, Shridevi B Teli, and Kencharaddi HG. Material preparation, data collection, and analysis were performed by Sanren Pungjung, Baluti Passah, Shridevi B Teli, and Dinesha S. The first draft of the manuscript was written by Shridevi B Teli, Dinesha S, Kencharaddi HG, and Arvind Kumar Chaurasiya. All authors read and approved the final manuscript.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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