REVIEW ARTICLE

MCBS
Mol Cell Biomed Sci. 2026; 10(2): 73-81
DOI: 10.21705/mcbs.v10i2.774

Artemisia princeps as a Potential Natural Iron Source: A Systematic Review of Pharmacological Evidence and Iron Bio-availability Gaps

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Artemisia princeps is widely used in traditional Asian medicine and is well known for its diverse pharmacological properties. Scientific evidence supporting its role as a natural source of iron remains limited. Several medicinal plants have been reported to contain measurable iron and to improve iron status. This systematic review aimed to examine the pharmacological activities of *A. princeps* critically and to contextualize the limited iron-related evidence for this plant, compared with other medicinal plants with established iron content or bioavailability. A systematic literature search was conducted in PubMed and ScienceDirect up to April 2025, following PRISMA guidelines and the PICOC framework. The extracted data were organized into two categories: (1) pharmacological activities of *A. princeps*, and (2) iron content and bioavailability-related outcomes of other medicinal plants. Eight studies investigating *A. princeps* were identified, predominantly reporting anti-inflammatory, antioxidant, and metabolic effects. Only one study reported the iron content of *A. princeps*, without evaluating iron bioavailability or haematological outcomes. In contrast, nine studies on plants such as *Astragalus membranaceus*, *Beta vulgaris*, and *Moringa oleifera* demonstrated improvements in haemoglobin levels and other iron-related parameters in animal models and, in some cases, human studies. Current evidence indicates that while *A. Princeps* possesses broad pharmacological activity; its potential as a source of bioavailable iron has not been adequately investigated. This review highlights substantial evidence gaps and underscores the need for targeted studies assessing the iron content, bioavailability, and haematological effects of A. princeps, rather than overstating its current role in iron-deficiency management.

Keywords: *A. princeps, iron deficiency anemia, biological products, plants, natural products*

Submission: January 5, 2026
Last Revision: February 23, 2026
Accepted for Publication: March 4, 2026

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Molecular and Cellular Biomedical Sciences, Vol.10 No.2, July 2026, p. 73-130
Print ISSN: 2527-4384, Online ISSN: 2527-3442
DOI: 10.21705/mcbs.v10i2.774

Introduction

Anemia remains one of the most pressing global public health challenges. It is characterised by low haemoglobin levels or a reduced number of circulating red blood cells, which impair oxygen delivery to tissues throughout the body.[1] Although anemia can affect individuals across all age groups, the highest prevalence is observed among vulnerable populations such as pregnant women and preschool-aged children. Global estimates indicate that approximately 41.8% of pregnant women and 47.4% of preschool-aged children are anemic.[2] The condition not only leads to clinical symptoms such as pallor, fatigue, shortness of breath, and weakness, but also contributes to adverse systemic outcomes, including increased risks of preterm birth, low birth weight, delayed child development, and elevated neonatal and perinatal mortality.[3-6]

Conventional efforts to prevent and treat anemia have primarily involved iron (Fe) supplementation in the form of tablets, capsules, or fortified foods.[7,8] However, the effectiveness of such interventions is often limited by gastrointestinal side effects, including nausea, constipation, and gastric irritation, which negatively impact patient compliance.[9,10] In addition, iron absorption from synthetic supplements may be limited in certain populations due to inhibitory interactions in the gastrointestinal tract or elevated hepcidin levels associated with chronic inflammation, which can impair iron uptake.[11] These limitations have spurred growing interest in plant-based and natural approaches as complementary strategies for managing anemia.

Medicinal plants have gained attention not only as potential sources of dietary iron but also as carriers of bioactive compounds, including flavonoids, polysaccharides, and antioxidants, which may indirectly support hematopoiesis and improve overall nutritional status.[1] Several plants, such as *Astragalus membranaceus*, *Beta vulgaris*, *Moringa oleifera*, and *Ipomoea batatas* have been reported to contain measurable iron levels and to improve hemoglobin concentrations and red blood cell indices in both animal models and human studies.[12-15] Importantly, investigations of these plants have increasingly incorporated assessments of iron bioavailability using in vitro digestion models and in vivo iron-deficiency anemia models, providing more robust evidence of their hematological relevance.

A. princeps, commonly known as yomogi, is a medicinal plant widely used in traditional Korean, Japanese, and Chinese medicine.[16] It is well recognized for its diverse pharmacological activities, including anti-inflammatory, antioxidant, anti-cancer, and hepatoprotective effects.[17-20] Despite its extensive traditional use and broad biological activity, *A. princeps* is not typically recognized as a dietary source of iron. To date, only one primary study has reported the iron content of *A. princeps* and this study did not evaluate iron bioavailability or hematological outcomes. Consequently, direct evidence supporting the role of *A. princeps* in iron absorption or in the management of anemia remains extremely limited.

Given the widespread use of *A. princeps*, its rich phytochemical profile, and the emerging interest in plant-based strategies for anemia, a critical synthesis of the available evidence on iron is warranted. Therefore, this systematic review aims to summarize and critically evaluate existing studies on the pharmacological properties of *A. princeps* and to examine the limited evidence on its iron content, in the context of other medicinal plants with established iron-related effects. By explicitly highlighting current evidence gaps, this review seeks to inform future research directions rather than to overstate the present therapeutic potential of *A. princeps* as a natural iron source.

Materials and methods

Search Strategy

A systematic literature search was conducted in two main databases, PubMed, ScienceDirect, and Google Scholar, up to April 2025. The search focused on two main topics: (1) the pharmacological activities of *Artemisia princeps*, and (2) the iron content and bioavailability in medicinal plants. The keywords used in this study were ((“Artemisia princeps” OR “yomogi” OR “mugwort”) OR (“medicinal plant*” OR “herbal extract*” OR “functional food” OR “natural source of iron”)) AND (“iron content” OR “iron absorption” OR “iron metabolism” OR “iron bioavailability” OR “anemia” OR “iron deficiency” OR “iron supplementation” OR “iron fortification”). All identified articles were exported to reference management software (Mendeley), and duplicates were removed before screening.

By the PICOS model,[21] the following study selection and inclusion criteria were applied: (1) Population (P): Experimental studies (in vitro, in vivo, or clinical) evaluating medicinal plants, particularly Artemisia princeps, as well as other plants containing or potentially improving iron status. (2) Intervention (I): Administration of plant preparations or extracts containing iron, or testing the biological activities of Artemisia princeps. (3) Comparator (C): Control group without intervention, or a comparison group receiving standard Fe supplementation (e.g., ferrous sulfate). (4) Outcome (O): Biological activities such as increased haemoglobin, erythrocyte, ferritin levels, or measurements of iron content and bioavailability. (5) Context (C): Studies published between 2019 and April 2025, in English or Indonesian, with full-text access. Search results from all databases were exported to Mendeley Reference Manager, and duplicate records were removed before title and abstract screening.

Eligibility Criteria

This review included only original research articles published between 2019 and 2024 and available in English or another language that can be accurately translated. The articles included were experimental studies, both in vitro and in vivo, that evaluated the iron content, bioavailability, or biological activities of medicinal plants related to iron status, including but not limited to anti-anemia, antioxidant, and immunomodulatory effects. The primary focus was on studies of *A. princeps*, although other plants were included when relevant to iron content or effectiveness. Articles were excluded if they were merely literature reviews, meta-analyses, editorials, or commentaries. Studies with less valid methodologies, such as those with very small sample sizes or lacking clear control groups, were excluded from the analysis. Research using animal-derived materials, yeast, or non-plant microorganisms was also excluded because it did not align with the review's focus on medicinal plants as natural sources of iron.

The methodological quality and risk of bias of the included studies were independently assessed by two reviewers using standardized tools appropriate to each study design. Animal studies were evaluated using the SYRCLE risk-of-bias tool, and in vitro studies were assessed against predefined methodological criteria. Any disagreements between reviewers were resolved through discussion until consensus was reached. The quality assessment was used to support the interpretation of the findings rather than as exclusion criteria.

Assessment of Methodological Quality and Data Analyses

Methodological quality assessment was conducted narratively based on several key aspects: clarity of study design, type of test model used (in vitro, in vivo, or clinical), use of control groups, measurement methods employed, and clarity of result reporting. Each study was evaluated for strengths and potential biases; however, quality assessment using scoring or formal validation tools was not conducted due to the high heterogeneity in study types and designs. Data analysis was performed descriptively. All extracted data were presented in narrative tables to describe the characteristics, approaches, and findings of each study. Additionally, a PRISMA diagram was created to illustrate the article selection and screening process. Due to the high diversity in model types, dosages, and parameters across studies, no quantitative meta-analysis was performed (Figure 1).

Results

Risk of Bias Assessment

Risk of bias assessment for animal studies was performed using the SYRCLE risk-of-bias tool. Overall, the included studies showed heterogeneous methodological quality. Selection bias related to baseline characteristics was generally assessed as low risk; however, random sequence generation and allocation concealment were frequently rated as unclear risk due to insufficient reporting. Performance bias was commonly assessed as high or unclear risk, as blinding of caregivers and investigators was rarely described. Similarly, detection bias was often unclear or high because blinding of outcome assessment was not reported in most studies. Attrition bias was generally low, as outcome data were largely complete, while reporting bias remained unclear in several studies due to the absence of published protocols. These findings indicate that although the included animal studies provide preliminary iron-related and pharmacological evidence, methodological limitations remain prevalent, warranting cautious interpretation of the results.

Characteristics of The Included Studies

The pharmacological activity of *A. princeps* was most extensively explored for its anti-inflammatory effects (3 studies) (Table 1). Other activities reported in individual studies included anti-cancer, anti-adipogenic, antihyperlipidemic, and anti-hepatoma effects. One study assessed the nutritional value and antioxidant capacity of *A. princeps* and confirmed the presence of iron (Fe) in the plant's phytochemicals (Table 2). This study reported only the iron content, without testing its bioavailability or its clinical effects on anemia. This highlights a research gap

Molecular and Cellular Biomedical Sciences, Vol.10 No.2, July 2026, p. 73-130
Print ISSN: 2527-4384, Online ISSN: 2527-3442
DOI: 10.21705/mcbs.v10i2.774

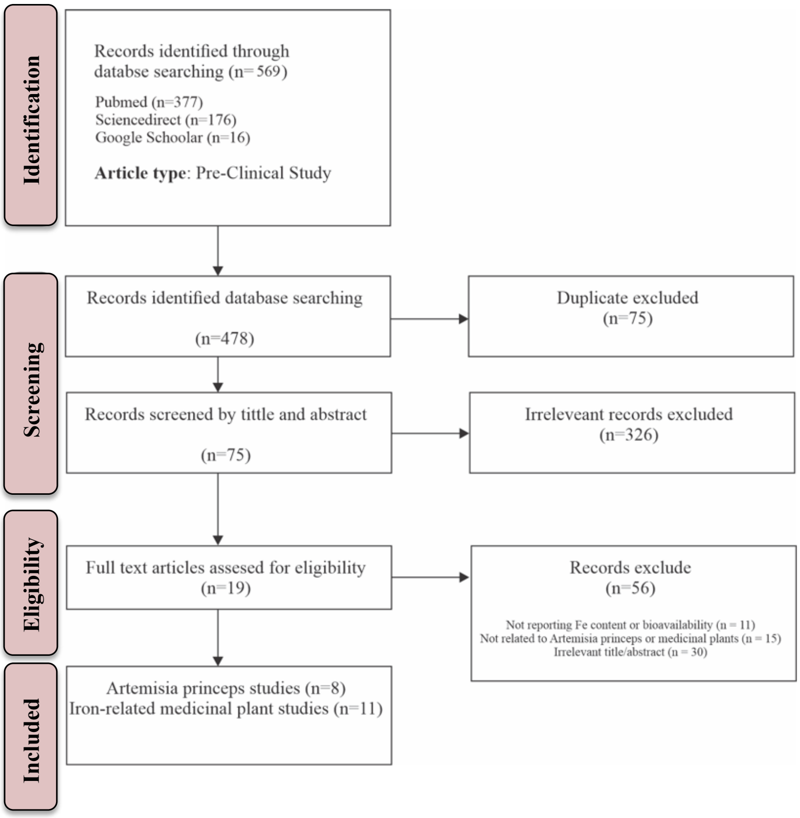

Figure 1. Flow diagram of selection of studies.

regarding the potential of *A. princeps* as an iron supplement.

The results of 11 studies investigating the iron (Fe) content and/or bioavailability of various medicinal plants and plant-based natural products (Table 3). The reviewed plants include *Astragalus membranaceus*, *Salacca edulis*, *Ulva prolifera*, *Beta vulgaris*, *Ipomoea batatas*, *Moringa oleifera*, and traditional herbal mixtures such as *Justicia secunda*, *Gossypium barbadense*, and *Hibiscus sabdariffa*. Intervention methods included plant extracts, functional food formulations (such as red beet pulp-based biscuits), and direct consumption of whole foods (such as sweet potatoes and apple cider vinegar). Test models mostly involved Wistar or Sprague-Dawley rats induced with anemia by phenylhydrazine or an iron-deficient diet, while one study was conducted in humans (third-trimester pregnant women). The majority of studies reported increases in hemoglobin (Hb) levels, hematocrit, erythrocyte count, and serum iron status following intervention. *Astragalus membranaceus*-Fe complex extract significantly increased Hb, ferritin, and antioxidant enzyme activity; *S. edulis* seed extract improved body weight and hematological status in anemic rats; and sweet potato consumption showed increased Hb levels in pregnant women. Other studies, such as *Beta vulgaris*, even showed better results than commercial Fe supplements (Iberet Folic). In addition to hematological effects, some plants, such as apple cider vinegar and Beta vulgaris, showed improvements in antioxidant parameters and organ function, indicating additional biological effects that support overall recovery from anemia.

Discussion

Three studies reported significant anti-inflammatory effects of *A. princeps*, with reductions in pro-inflammatory cytokines such as IL-6 and TNF-α.[23,24] This effect has broad implications, especially in chronic conditions that indirectly affect iron metabolism, such as anemia of chronic disease (ACD).[38,39] Chronic inflammation leads to dysregulation of hepcidin and impaired iron absorption.[40] Anti-inflammatory agents like *A. princeps* may play an indirect therapeutic role. However, no studies to date have directly examined whether these anti-inflammatory effects translate into improved iron absorption or haematological outcomes. Therefore, any potential benefit remains speculative.

Table 1. Summary of pharmacological studies on *A. princeps*.

Author (Year)	Study Type & Model	Investigated Activity	Measured Parameters	Key Findings
Toda *et al*., 2007 [22]	In vitro	Anti-adipogenic (inhibition of adipocyte differentiation)	Oil red O staining, mRNA/protein expression (PPAR γ, C/EBP α, SREBP-1c, MAPK proteins)	APE fractions reduced lipid accumulation and downregulated adipogenic markers and MAPK pathway proteins
Okamoto *et al*., 2020 [23]	In vitro	Anti-inflammatory (IL-8 inhibition)	SN13T; IL-8 ELISA assay; organic extraction; HPLC; compound isolation; NMR & MS	Fermented A. princeps extract significantly reduced IL-8 release; identified catechol and seco-tanapartholide C as active compounds with anti-inflammatory effects.
Kim *et al*., 2023 [17]	In vivo	Antihyperlipidemic	Lipid profile (TC, TG); HMG-CoA reductase inhibition assay	Eupatilin, a major compound of A. princeps, significantly reduced TC and TG levels; inhibits HMG-CoA reductase; has potential as an antihyperlipidemic agent
Shakya *et al*., 2024 [24]	In vitro	Anti-inflammatory via fermentation enhancement	Fermentation with *L. plantarum* SN13T and P. pentosaceus LP28; NO assay; metabolite analysis	Fermentation with SN13T enhanced the anti-inflammatory activity of Mentha extract; key bioactivity linked to RA → CA → DHCA conversion, genes hcrA/B/C involved; indirectly relevant to A. princeps fermentation potential.
Liu *et al*., 2021 [25]	In vitro	Anti-cancer (anti-stemness activity)	Cell viability assay (MTS); flow cytometry; western blotting for total and phosphorylated Stat3, YAP1, Oct-4, c-Myc, Nanog, CD44; qPCR for IL-6 expression	5-Desmethylsinensetin reduced proliferation and mammosphere formation; decreased $CD44^{+}/CD24^{-}$ and $ALDH1^{+}$ populations; suppressed expression of Oct-4, c-Myc, Nanog, CD44, p-Stat3, and YAP1 translocation; downregulated IL-6
Su *et al*., 2021 [26]	In vitro	Anti-hepatoma (cytotoxicity and apoptosis)	X-ray crystallography and ECD; cell viability assays to determine IC50; western blotting for cdc2, pcdc2, cyclinB1, Bcl-2, Bax	Compounds 3, 13, 17, and 18 showed significant cytotoxicity; compounds 1 and 16 had lower IC50 than sorafenib; compound 1 inhibited cell migration and invasion; induced G2/M arrest by downregulating cdc2 and pcdc2 and upregulating cyclinB1; induced apoptosis by downregulating Bcl-2 and upregulating Bax.
Li *et al*., 2024 [27]	In vitro	Anti-inflammatory	NMR, HRESIMS, single-crystal X-ray diffraction, and ECD; NO assay in LPS-induced BV-2 cells to evaluate inhibitory activity	All isolated compounds were evaluated for NO inhibition; except compounds 2, 4, 10, and 11, others showed significant inhibition with IC_{50} values of 0.73–18.66 µM

Table 2. Iron content and bioavailability of *A. princeps*

Author (Year)	Study Type & Model	Investigated Activity	Measured Parameters	Key Findings
Chen *et al*., 2025 [28]	Phytochemical analysis	Nutritional value and antioxidant activity	Calcium, magnesium, iron, aluminum, manganese, and sodium. Four vitamins were detected, including vitamins A, C, E, and B_2	*Artemisia princeps* contains measurable levels of Fe (350.04±15.28 mg/kg); no study on bioavailability or anemia-related outcomes

Of all the *A. princeps* studies analyzed, only one reported its iron content (approximately 350 mg/kg), and no bioavailability or hematological activity tests were conducted.[28] This contrasts with plants like Astragalus

Print ISSN: 2527-4384, Online ISSN: 2527-3442
DOI: 10.21705/mcbs.v10i2.774

Table 2. Summary of studies on iron content and bioavailability from medicinal plants.

Medicinal Plant Name	Plant Part Used	Iron Content/Role	Experimental Model	Dosage	Key Findings	Ref
Salacca edulis Reinw.	Seed	Naturally high iron content; potential alternative iron supplement	Female Wistar rats with iron-deficiency anemia	1.75 g/kg BW/day or 0.175 g/100 g BW/day for 14 days	Significantly increased body weight compared to the control group, indicating a potential anti-anemia effect	Melati *et al*., 2019 [29]
Ulva prolifera	Sulfated polysaccharide (low molecular weight)	Synthesized complex (SUE-iron (III)) with 20.3% iron	Iron-deficiency anemia rat model	Low dose group (SUE-iron (III) with iron concentration of 0.8 mg/mL, 0.7 mg kg −1 BW, Fe), and high dose group (SUE-iron (III) with iron concentration of 2.3 mg/mL, 2.0mg kg−1 BW, Fe)	SUE-iron (III) restored Hb, RBC, serum iron, and erythropoietin to normal levels; reduced inflammation; proposed as an effective and safe iron supplement	Li *et al*., 2019 [30]
Astragalus membranaceus	Polysaccharide complex (APS)	Synthesized APS–iron (III) complex	Iron-deficiency anemia mouse model	APS–iron (III) complex at 50 µg/mL	- Increased hemoglobin, SOD, CAT; decreased MDA faster than Niferex & $FeSO_4$ - Enhanced lymphocyte proliferation by 35.7% vs APS alone - High complement fixing activity (0.589 mg/mL) - Histology showed no pathological changes; considered safe	Jasiwal *et al*., 2019 [12]
Sauropus androgynous & *Moringa oleifera*	Leaf extract	Potential anti-anemia via synergistic effect; not quantified iron content	Iron-deficiency anemia in female Wistar rats	*S. androgynous* : 300 mg/day *M. oleifera* : 80 mg/day Combination: 150 mg/day (*S. androgynous*) + 40 mg/day (*M. oleifera*)	The combined extract significantly increased haemoglobin and ferritin levels while reducing malondialdehyde (MDA) compared with the anemic control group. The effects of the combined treatment were closer to normal physiological values than those observed with single-extract administration. Greater efficacy than individual extracts	Indrayani *et al* ., 2019 [31]
Sauropus androgynus	Leaves (chlorophyll extract; CSA)	No specific Fe content quantified	Iron-deficiency anemia in pregnant Wistar rats	0.016 mg/mL CSA	Increased hemoglobin, serum iron, and ferritin; normal fetal growth, indicating safety in pregnancy	Suparmi *et al*., 2021 [32]
Moringa oleifera	Leaves (aqueous extract)	Not quantified; used to ameliorate iron -deficiency anemia	Female Sprague–Dawley rats rendered anemic by a 3-week basal diet deficient in iron + 10 g tannic acid/kg die	1 mL of leaf extract at 5%, 10%, or 15% concentration, orally once daily (post -anemia induction)	Dose-dependent increases in hematocrit, hemoglobin, RBC count, and platelets vs anemic control	Rabeh *et al*., 2021 [33]
Beta vulgaris (Beetroot)	Pomace (powder in biscuits)	24 mg/100g	Phenylhydrazine-induced anemia in albino rats	15% beetroot pomace in 10% functional biscuit formulation (AnB group)	Improved Hb, RBC count, and antioxidant enzymes in anemic rats after 28 days; recovery of minor kidney and liver dysfunction; shows anti-anemia and antioxidant potential	Jasiwal *et al*., 2014 [13]
Apple (*Malus domestica*)	Vinegar (rich in polyphenols & flavonoids)	0.11 ± 0.01 mg/L	PHZ-induced hemolytic anemia in Wistar rats	1 mL/kg/day for 5 weeks (gavage)	Increased Hb concentration, RBC count, and reduced hemolysis; improved hematological profile despite not directly supplementing iron	Oussauid *et al*., 2022 [34]
Justicia secunda, *Gossypium barbadense*, *Hibiscus sabdariffa*, *Sorghum bicolor*	Leaves (aqueous extracts)	not quantified iron content	Phenylhydrazine-induced anemia in Wistar rats	2000 mg/kg body weight for 15 days (oral)	All extracts improved Hb, RBCs, and hematocrit; J. secunda had the highest efficacy (~99.06% hematologic recovery), followed by Sorghum bicolor and Gossypium.	Fagbohoun *et al*., 2022 [35]
Ipomoea batatas (Sweet potato)	Tuber (whole food)	Nutrient-rich, including iron; not quantified iron content	Pregnant women (third trimester) in South Lampung, Indonesia	Regular consumption in the daily diet, Sweet potato + Fe tablet (amount not specified)	Significant increase in mean hemoglobin levels after sweet potato consumption; better outcome than the Fe tablets group in the short term	Nuryani *et al*., 2022 [15]
Beta vulgaris (Beetroot)	Root extract (ethanolic)	not quantified iron content	Phenylhydrazine-induced anemia in rats	100ml/kg body weight	Improved Hb (23.8 g/dL), RBC (15.16×10^6/µL), and serum iron (31.5 µg/dL); better than the iron supplement group on all parameters	Ali *et al*., 2023 [36]
Mung bean	Seed	peptide-ferrous chelate (MBP-Fe) 55.16 ± 0.16 mg/g	Mice with iron-deficiency anemia (IDA)	Low-dose MBP- Fe group (1.5 mg Fe/ kg BW), high-dose MBP-Fe group (3 mg Fe/ kg BW), and MBP/Fe group (3 mg Fe/ kg BW)	MBP-Fe and MBP/Fe restored hemoglobin, RBC, HCT, serum iron, and body weight; reduced liver/spleen damage; and upregulated Dmt1, Fpn1, and Dcytb gene expression. High-dose MBP-Fe showed stronger reparative effects than inorganic or organic iron forms.	Ding *et al*., 2024 [37]

membranaceus, which has been tested in animal models of iron-deficiency anemia and shown to increase hemoglobin levels, ferritin, and antioxidant activity.[12] Astragalus has even been studied as an Fe-polysaccharide complex, which demonstrated efficient absorption and additional immunomodulatory effects. Compared with these plants, *A. princeps* currently lacks sufficient experimental evidence to support its use as a primary natural iron source, and its role may be better characterized as a supportive or adjunct plant with indirect benefits. This may be due to limited attention to mineral content in East Asian ethnopharmacology research, or to the assumption that *A. princeps* is more relevant for inflammatory and metabolic therapy.

Studies on other plants show a more integrative approach. *B. vulgaris* (red beet) has been tested in both extract and functional food forms and has been shown to improve hematological parameters (Hb, RBC) and enhance liver and kidney functions.[13,36] Other studies on *S. edulis*, *I. batatas*, and *M. oleifera* report similar effects.[15,29,35,41] Not only do these studies show increased Hb levels, but several also report reduced malondialdehyde (MDA) and increased antioxidant enzymes such as SOD and GPx, supporting the role of active compounds in reducing oxidative stress associated with anemia.[42] These plants therefore have greater immediate translational potential for development as plant-based iron supplements than *A. princeps*.

From a mechanistic perspective, iron bioavailability is influenced by the chemical form of iron (Fe^{2+} vs. Fe^{3+}), binding compounds such as phytates, tannins, and polyphenols, and the expression of transport proteins such as DMT1 and ferroportin. A previous study showed that iron supplementation from naturally fermented sources triggers increased expression of Divalent Metal Transporter 1 (DMT1) and Ferroportin1 (Fpn1) in the intestinal mucosa, enhancing active iron absorption.[37] Similar mechanisms have yet to be explored in *A. princeps*, making this an important research gap. From a methodological standpoint, most of the studies in this review used animal models, with intervention durations ranging from 14 to 42 days. Variation in extract types, doses, and the parameters tested leads to high heterogeneity, making a quantitative meta-analysis impossible. Furthermore, few studies included a positive control, limiting the ability to compare effectiveness. None of the *A. princeps* studies assessed iron status post-intervention, although some showed antioxidant and hepatoprotective potential. From a practical standpoint, the current evidence suggests that *A. princeps* is not yet suitable for development as a standalone natural iron supplement. Nevertheless, its strong anti-inflammatory and antioxidant properties indicate potential value as an adjunct ingredient in multi-component formulations aimed at improving iron metabolism, particularly in inflammatory conditions where iron absorption is impaired.

The strength of this review lies in its systematic approach and clear thematic focus, including recent articles (2019–2024) from two major databases. Using the PICOC framework clarifies the article selection focus, and the PRISMA flowchart ensures transparency in the screening process. However, restricting the review to English and Indonesian may exclude relevant publications in local languages, particularly Chinese and Korean, which may have investigated *A. princeps* more extensively. The implications of these findings are the need for further research, specifically to evaluate the iron content and bioavailability of *A. princeps*. Such research could begin by characterizing iron content using AAS or ICP-MS, with particular attention to plant parts (e.g., leaves vs. roots), as mineral distribution in Artemisia species varies significantly. This would be followed by in vitro digestion simulations and then absorption tests on Caco-2 cell models or animal anemia models. Evaluation of dosage, formulations, and side effects should also be considered, especially to ensure the safety of long-term preparations before human trials.

A. princeps demonstrates substantial pharmacological potential; its role as a natural iron source remains scientifically underexplored. Compared with other medicinal plants with established iron bioavailability, *A. princeps* should currently be considered a promising complementary plant rather than a primary iron source, underscoring the need for targeted, mechanism-based research before clinical application.

This review identifies several innovative research opportunities regarding *A. princeps* and iron metabolism. Future studies should prioritize standardized assessments of iron bioavailability, distinguishing between total iron content and absorbable iron using advanced analytical techniques, such as ICP-MS combined with in vitro digestion and Caco-2 cell models. Given its consistent anti-inflammatory and antioxidant activities, *A. princeps* may serve as an innovative adjunct rather than a primary iron source. Mechanism-based studies evaluating its effects on

Print ISSN: 2527-4384, Online ISSN: 2527-3442
DOI: 10.21705/mcbs.v10i2.774

iron regulatory pathways, including hepcidin signaling and intestinal iron transporters (DMT1 and ferroportin), are particularly warranted. From a translational perspective, the development of multi-component or co-formulated products incorporating *A. princeps* with bioavailable iron sources or fermented matrices may offer a novel strategy for improving iron utilization, especially in inflammation-associated anemia. These directions highlight how the current evidence base can inform future methodological and formulation-driven innovation.

Conclusion

A. princeps possesses broad pharmacological activities. However, evidence supporting its role as a natural source of iron remains very limited. Only one study reported its iron content but did not evaluate bioavailability or haematological effects. In contrast, several other medicinal plants, including Astragalus membranaceus, Beta vulgaris, and Moringa oleifera, have demonstrated more consistent evidence in improving iron status. Therefore, while A. Princeps shows pharmacological promise; further targeted studies on iron content, bioavailability, and anemia-related outcomes are required before it can be considered a viable natural iron source.

Acknowledgment

The authors would like to acknowledge the financial support provided by the Internal Research Grant for Lecturers of Universitas Jenderal Achmad Yani (UNJANI) (Grant No. Skep/188/Unjani/VI/2025). The authors also thank all colleagues who contributed to discussions and technical assistance during the preparation of this manuscript.

Authors' Contributions

JNP, TAB, EK, and R contributed to the conception and design of the study. JNP was responsible for data acquisition. EK performed the data analysis and interpreted the results. TAB prepared the manuscript. JNP, TAB, and R contributed to the design of figures and/or tables. All authors critically revised the manuscript and approved the final version for publication.

Ethical Statement

This article is based exclusively on the review and analysis of previously published literature. No primary data were collected, and no human participants, human biological materials, or animals were involved in this study. Therefore, ethical approval from an institutional review board or ethics committee was not required.

Conflict of Interest

All authors declare that they have no conflict of interest.

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