

The role of bioactive compounds from grains and legumes for combating anemia: a review

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Abstract

Anemia is a major global health concern characterized by reduced hemoglobin concentration and impaired oxygen carrying capacity of blood primarily caused by iron deficiency and inadequate intake of essential micronutrients. In recent years, germinated grains, legumes and pseudocereals have gained considerable attention as functional foods due to their improved nutritional composition and the presence of biologically active compounds. This review aims to summarize and critically evaluate the role of bioactive compounds present in sprouted grains and legumes in the prevention and management of anemia. Relevant information was collected from peer-reviewed research articles, experimental studies and review papers focusing on sprouting induced biochemical changes, nutritional bioavailability and hematological benefits. Germination is a natural physiological process that activates endogenous enzyme within seeds, resulting in significant biochemical and nutritional modifications. During this process antinutritional factors such as phytic acid, tannins and enzymes inhibitors are significantly reduced thereby enhancing the bioavailability of essential minerals particularly iron and zinc. At the same time, germination increases the level of vitamin C and B-complex vitamins as well as bioactive phytochemicals such as flavonoids, phenolic compounds and ferritin-bound iron. These components play an important role in improving iron absorption, stimulating erythropoiesis and protecting erythrocytes from oxidative stress through antioxidant mechanisms. Several sprouted grains and legumes including mung bean (*Vigna radiata*), chickpea (*Cicer arietinum*), lentil (*lens culinaris*), soyabean (*Glycine max*), fenugreek (*Trigonella foenum-graecum*), wheat (*Triticum aestivum*), finger millet (*Eleusine coracana*), barley (*Hordeum vulgare*), horse gram (*Macrotyloma uniflorum*), quinoa (*Chenopodium quinoa*), sunflower (*helianthus annuus*) and pea (*Pisum sativum*) have demonstrated notable anti-anemic potential in nutritional and experimental studies. Evidence suggests that these sprouts improve hemoglobin levels, enhance iron bioavailability promote red blood cell production and provide antioxidant protection to erythrocytes. Therefore, sprouts grain and legumes may serve as a cost-effective and nutritionally valuable dietary approach for the prevention and management of anemia.

Keywords-Anemia, folic acid, grains, iron, legumes, sprouts

I. INTRODUCTION

Sprouts are seeds of herbaceous plants such as cereals, oilseeds, and various vegetables that have undergone germination. In recent years, they have evolved from traditional foods into widely recognized functional foods because of their dense nutrient composition and abundance of bioactive compounds. Sprout production involves a sequence of physiological and biochemical events triggered when a quiescent seed is exposed to favorable environmental conditions. The process generally follows three phases; 1. Sterilization and Disinfection: The initial

step where seeds are decontaminated to eliminate potential pathogens. 2. Soaking (Imbibition): Grains are soaked in water to reach full hydration, which activates metabolic pathways and restores cellular activity. 3. Sprouting (Germination): Seeds are placed in incubators or germinators under controlled temperature, humidity, and light conditions. During this stage, the embryo axis elongates, and the major storage reserves of the seed are mobilized to support the growing seedling.^{1,2}

Nutritional importance of sprouting acts as a natural form of "predigestion," transforming complex storage polymers into simpler, more bioavailable building blocks. Nutritional transformations include, Starch is converted into simple sugars (glucose and maltose), and proteins are hydrolysed into oligopeptides and free amino acids. Germination significantly increases the levels of vitamins, particularly Vitamin C, Vitamin B2 (riboflavin), and tocopherol. Antinutritional compounds like phytic acid, trypsin inhibitors and tannins are significantly reduced during sprouting, thereby improving mineral bioavailability by releasing previously chelated minerals.^{3,4}

Sprouts provide significant health regulation and disease prevention qualities because they are enriched with bioactive compounds and phytochemicals. These functional foods possess pharmacological properties that offer protection against chronic and degenerative diseases by neutralizing free radicals through high antioxidant capacity. Regular consumption is linked to cardio-protective and anti-hypertensive effect which help to lower blood pressure and improve cholesterol level. Additionally, they exhibit anti-inflammatory and anti-diabetic characteristics that assist in controlling blood sugar and reducing the risk of metabolic syndromes.⁵

Anemia is a widespread blood-related disorder that occurs when your body has a decreased hemoglobin level, a reduced number of red blood cells or a lower capacity for the blood to carry oxygen. Due to this, the body doesn't receive the oxygen supply it needs to function at its best. It is important to understand that anemia isn't actually a disease on its own; instead, it is usually a manifestation of an underlying issue, such as a nutritional deficiency or a pathological disorder. On a global scale, this is a major public health concern: Over two billion people worldwide are affected by anemia. It is significantly more common in developing and low-income countries. The high prevalence in these areas is often linked to malnutrition, parasitic infections and limited access to healthcare services. Women of reproductive age, pregnant women, infants and children are particularly susceptible to anemia due to their increased physiological requirement of iron. Anemia is a complex condition with many different causes, but the most common one globally is iron deficiency. It can also be triggered by other nutritional gaps, such as a lack of vitamin B12 or folic acid, as well as chronic diseases, infections or genetic disorders. To make it easier to diagnose, medical professionals group anemia into several categories including hemolytic, aplastic and hereditary types and often classify it based on whether the red blood cells appear small, normal or large in size.^{6,7,8}

II. MECHANISM OF SPROUTS FOR THE TREATMENT OF ANEMIA

Sprouts are highly beneficial for individuals suffering from Iron Deficiency Anemia (IDA), the most common form of anemia. They support iron levels in the body through two key mechanisms. First, sprouting reduces the presence of phytic acid, a natural compound in seeds that inhibits mineral absorption. As this compound breaks down during germination, the bioavailability of iron significantly increases, allowing the body to absorb it more effectively. Second, certain sprouts, particularly legumes, can be cultivated to enhance the production of ferritin, a protein

capable of storing up to 4,500 iron ions. This makes sprouts a stable and efficient natural source of iron, contributing positively to improved iron status and overall health.⁹

Furthermore, sprouts are rich in enzymes and amino acids that support overall metabolism and may contribute to improved red blood cell formation. Through these combined effects, sprouts serve as a natural, nutrient-dense dietary approach for the prevention and management of anemia.

III. ROLE OF VARIOUS SPROUTS IN THE TREATMENT OF ANEMIA

Vigna radiata

Mung bean sprouts (*Vigna radiata*) are nutrient-dense functional foods with potent anti-anemic and antioxidant properties. Germination significantly enhances their nutritional profile increasing vitamin C level up to 24 times and total flavonoids nearly sevenfold compared to dormant seeds. These sprouts are effective at reversing hemolytic anemia by stimulating red blood cell production and restoring hemoglobin level. They further protect cells from oxidative damage by lowering stress markers and boosting protective glutathione. Chemically, they contain beneficial sterols, organic acids and high level of flavonoids like quercetin-3-o-glucosid, which help neutralize free radicals. Additionally, sprouting improves iron bioavailability by reducing “anti-nutritional” phytic acid. Ultimately, mung bean sprouts serve as highly digestible resource for supporting blood health and defending against chronic oxidative stress-related disease.^{10,11,12}

Cicer arietinum

Chickpeas (*Cicer arietinum*) or Bengal gram are essential cool-season legumes known for their high-quality protein, dietary fiber and vital minerals like iron and zinc. They exist in two main varieties: the Desi and Kabuli type, both offering antioxidant and anti-inflammatory benefits. A key traditional processing technique is sprouting, which significantly boosts their nutritional value by reducing anti-nutritional factors such as phytic acid and tannins. During germination, the enzyme phytase breaks down phytic acid, which otherwise prevents iron absorption. This process effectively releases bound iron, greatly increasing its bioavailability for the human body. Furthermore, sprouted chickpea are rich in folate which is critical for red blood cell formation. These biochemical changes support blood enrichment and aid in managing conditions like anemia and splenosis, while protecting blood cells from oxidative damage caused by reactive oxygen species, improving overall well-being.^{13,14}

Lens culinaris

Lentils (*lens culinaris*) contain high iron and zinc but are inhibited by antinutritional factors like phytic acid. Research emphasizes dual-fortification using NaFeEDTA and ZnSO₄.H₂O to combat anemia. This Spray-Shake-Dry protocol ensures uniform distribution, increasing iron bioavailability by 519.5% in certain varieties. Enhancement occurs through dephytinization, reducing phytic acid by 8% to 15% and dehulling to remove inhibitory polyphenols. These processes lower PA: Fe and PA: Zn molar ratios, which are critical for absorption. Fortified lentils maintain stability after one year of storage. A 50g serving meets substantial portions of Estimated average Requirements. This cost-effective strategy improves dietary quality without requiring major behavioral changes from consumers. Ultimately, dual-fortified lentils offer a sustainable solution to chronic malnutrition and widespread nutritional disorders globally. This maximizes minerals uptake for vulnerable populations.^{16,17}

Medicago sativa

Medicago sativa commonly known as alfalfa is highly versatile functional food packed with vitamins A, B₁₂, C and K along with flavonoids and phenolics. Germination enhances its nutritional profile by producing GABA and L-ascorbic acid while making proteins more digestible. Pharmacologically, it displays potent anti-inflammatory properties by inhibiting NF-κB and reducing cytokines like IL-6 and TNF-α. Its cardiovascular benefits include serving as a hypolipidemic agent that lowers LDL and triglycerides while increasing HDL level. Furthermore, alfalfa is clinically effective against anemia it boosts serum iron and restores hemoglobin levels as efficiently as synthetic supplements. Its high antioxidant capacity also provides significant neuroprotection, reducing cerebral infarct size by scavenging free radicals. These diverse attributes make alfalfa clinically essential for managing chronic metabolic syndrome, hyperlipidemia and oxidative stress-related conditions.^{18,19}

Phaseolus vulgaris

Phaseolus vulgaris sprouts are tools for anemia recovery by enhancing iron bioavailability and antioxidant protection. Germination significantly improves iron uptake by up to 163% by reducing phytic acid, which typically inhibits absorption. During sprouting, energy reserves are mobilized, increasing levels of rutin and caffeic acid compared to mature seeds. These compounds protect blood cell membranes from oxidative stress. The anti-anemic process involves freeing iron for intestinal uptake, transporting it as transferrin to the bone marrow for heme synthesis and absorbing ferritin. Additionally, high flavonoids concentration prevents erythrocyte damage, while the dense nutrient profile stimulates erythropoiesis to increase red blood cell production. Ultimately, these sprouts provide a bioavailable strategy for restring systemic oxygen transport while simultaneously offering cellular protection and potent metabolic enhancement across diverse, complex biological systems.^{20,21,22}

Glycine max

Soybean (*glycine max*) sprouts have been reported that are functional foods that undergo significantly nutritional shifts during germination. This process increases vitamins A, B₁, C AND E while reducing anti-nutritional phytic acid. A standout feature is phytoferritin (SSF) a protein storing up to 4,500 iron atoms, protecting them from dietary chelators that typically inhibit absorption. Our bodies utilize this iron through two pathways: proteolytic release via DMT-1 transporters and direct endocytosis. Consequently, soybean iron is as bioavailable as medical iron sulfates. Biofortification can increase iron content sevenfold without compromising growth. For maximum therapeutic benefits, the source recommends cultivating sprouts in darkness and selecting germplasms with high ferritin concentrations. While some compounds like proanthocyanidins can interfere the reduction in phytates and rise in vitamin C during germination make these sprouts a highly effective tool against anemia.^{24,25,26,27}

Trigonella foenum

Fenugreek (*Trigonella foenum*) Germinated seeds or sprouts are particularly effective at treating iron deficiency and hemolytic anemia by restoring hemoglobin levels, hematocrit values and red blood cells counts. This increased efficacy is largely due to the germination process reducing phytic acid, which significantly improves the bioavailability of iron compared to dried seeds. Additionally, these sprouts contain proteins rich in lysine and L-tryptophan that stimulate erythropoiesis, leading to the production of reticulocytes that are more resistant to breaking down prematurely. The high concentration of flavonoids and polyphenols in sprouted fenugreek provides a robust

antioxidant defense by neutralizing reactive oxygen species and boosting protective glutathione levels. Beyond blood health, fenugreek supplementation helps protect vital organ including the heart, liver and kidneys from oxidative stress and histopathological damage caused by toxins or nutritional gaps.^{28,29,30}

Triticum aestivum

Wheat (*Triticum aestivum*) sprouts are a powerful functional food used to manage anemia by enhancing red blood cell production. During sprouting, essential nutrients like iron, folic acid and B-complex vitamins become more bioavailable. A key feature is their high chlorophyll content known as “green blood” due to its structural similarity to hemoglobin. This chlorophyll stimulates hematopoietic activity and works with high iron levels 126mg per 100g to regenerate hemoglobin. Furthermore, antioxidants like vitamin C and flavonoids protects cells from oxidative stress and improve iron absorption. Germination also reduces phytic acid, which normally blocks mineral uptake. Studies on mice demonstrate that wheat grass juice significantly boosts hemoglobin levels and erythrocyte counts. Consequently, these sprouts provide a natural supplement for blood building through improved absorption and nutrient delivery offering promising solution.^{31,32,33}

Eleusine coracana

Finger millet (*Eleusine coracana*) commonly known as ragi is a nutrient packed exceptionally rich in calcium and iron making it a vital and affordable tool for addressing iron deficiency anemia in groups like adolescent girls. Although raw ragi contains anti-nutrients like phytates and tannins that hinder mineral absorption, processing methods such as germination and malting effectively neutralize the compounds. This enzymatic action can increase iron bioavailability by nearly four times. Beyond minerals, ragi provides polyphenols and flavonoids, offering antioxidant, anti-diabetic and heart- protective properties. Iron availability can be further enhanced up to eight-fold through traditional cooking methods like making common rotis or by adding fortificants like folic acid. Ultimately, using germination ragi functions as a practical, functional food that can bridge global important nutritional gaps without requiring major changes to existing established traditional healthy daily local eating habits.^{34,35,36,37}

Macrotyloma uniflorum

Horse gram (*Macrotyloma uniflorum*) sprouts act as a nutritional fortress for blood health by transforming into a bioavailable superfood through germination. This process breaks down anti-nutrients like phytic acid and tannins, significantly enhancing iron absorption and making it a potent treatment for anemia. Rich in bioactive compounds such as ferulic and syringic acids, these sprouts provide essential antioxidant and anti-inflammatory protection for red blood cells. This defensive shield prevents oxidative stress, hemolysis and the formation of damaging Heinz bodies, ensuring cell maintain their proper shape. Furthermore, sprouted horse gram actively stimulates the production of hemoglobin and new red blood cells. By turning this hardy legume into sprouts, one creates a natural enrichment process that strengthens systemic health and shields the body against modern blood disorder effectively while maximizing nutritional density.^{38,39}

Pisum sativum

Pea(*Pisum sativum*) sprouts serve as a promising dietary intervention for iron-deficiency anemia by enhancing iron bioavailability. During germination and early growth, pea seeds exhibit significantly reduced phytic acid levels, which typically inhibit non-heme iron absorption. Consequently, the iron stored as ferritin in sprouted or immature

peas is more readily absorbed by the intestines than that in mature dry peas. Pea sprouts also function as prebiotics, containing oligosaccharides and soluble fibers that modulates gut microbiota and lower intestinal pH. This environment increases the expression of critical transport proteins, DMT-1 and DCYTB, which facilitate iron uptake. Evidence from animal models demonstrates that these nutritional and microbiome-mediated mechanisms lead to significant improvements in hemoglobin level, hepatic iron and overall iron status, making pea sprouts a highly effective functional food.^{40,41,42}

Helianthus annuus

Sunflower (*Helianthus annuus*) sprouts are highly valued functional foods offering significantly amounts of protein, unsaturated fats and vitamin E. The germination process acts as a biological locksmith, utilizing enzymes to release iron and vitamins previously bound within the seed. This biological transformation breaks down complex organic structures, enhancing the bioavailability of minerals and increasing levels of free amino acids and simple sugar. Notably, the iron content rises from 81.13mg/kg to 13.74mg/kg after one week, making sprouts effective for managing anemia. Furthermore, sprouting boosts secondary metabolites like phenolic acids and flavonoids, which provide potent antioxidant, anti-inflammatory and antidiabetic properties. Nutrient synergy from folate, zinc and vitamin C supports red blood cell production, while high tocopherol level shield them from oxidative damage, offering a cost-p effective method to address various nutritional gaps.^{43,44}

Chenopodium quinoa

Quinoa (*Chenopodium quinoa*) sprouts are a potent dietary intervention for anemia management due to their exceptional nutritional density and improved bioavailability. Germination significantly boosts level of iron, calcium and zinc, while simultaneously increasing vitamin C and antioxidant activity. A critical benefit of sprouting is the reduction of antinutritional factors such as phytic acid and tannins while typically inhibit mineral absorption. The elevated vitamin C content further enhances the intake of non-heme iron, supporting effective hemoglobin synthesis and blood health. In experimental studies, diets fortified with quinoa sprouts successfully restored hemoglobin, hematocrit and ferritin levels in anemic subjects. Beyond biochemical improvements, quinoa treatment addresses clinical symptoms like asthenia, weight loss and poor growth. Since toxicological studies confirm it is safe at therapeutic dose, quinoa sprouts offer a nutritionally superior, effective and non-toxic approach for individuals seeking complete natural recovery.^{42,46}

Hordeum vulgare

Barley (*Hordeum vulgare*) sprouts are a functional food that addresses anemia by providing a very dense concentration of iron, folate and vitamin C. the germination process is essential as it activates enzymes that increase vital phytochemicals and nutrients needed for hemoglobin synthesis and erythropoiesis. Furthermore, sprouting reduces antinutritional factors like phytates. Which significantly enhances iron bioavailability and intestinal absorption. Research indicates that germinated barley can measurably improve red blood cell counts and hematocrit values. Notably, the high chlorophyll content shares structural similarities with hemoglobin, potentially stimulating blood formation and oxygen transport. Additionally, barley sprouts offer antioxidant activity to protect red blood cells from oxidative stress. With anti-inflammatory and hepatoprotective properties, these sprouts support iron

metabolism, serving as a cost-effective, valuable plant-based intervention for managing and preventing nutritional deficiencies like anemia.^{47,48}

Table 1: Summary of anti-anemic potential of grain and sprouts

S. N	Grain name	Common name	Key phytochemical	Major minerals contents	Summary	Reference
1	<i>Vigna radiata</i>	Mung bean	Flavonoids, sterols, organic acids	Iron, Zinc	Sprouting boosts antioxidants, iron bioavailability, restoring Hemoglobin and RBCs with erythropoiesis and oxidative protection	10-12
2	<i>Cicer arietinum</i>	Chickpea	Phenolics, flavonoids, folate	Iron, zinc, calcium, magnesium	Germination activates phytase, reducing phytic acid and enhancing iron absorption	13-15
3	<i>Lens culinaris</i>	Lentil	Reduced phytates, low polyphenols	Iron, calcium	Fortification and dephytinization dramatically improves iron bioavailability and anemia prevention	16-17
4	<i>Medicago sativa</i>	Alfalfa	Phenolics flavonoids, vitamins C and K, GABA	Iron, calcium	Improves serum iron, transferrin saturation and Hemoglobin with strong antioxidant protection	18-19
5	<i>Phaseolus vulgaris</i>	Common bean	Rutin, caffeic acid, phenolic acids	Iron, zinc	Sprouting lowers phytates and enhance erythropoiesis while protecting RBC membranes	20-23
6	<i>Glycine max</i>	Soyabean	Phytoferritin, isoflavones, antioxidants	Iron (ferritin-bound)	Ferritin-bound iron improves absorption and restores hemoglobin efficiently	24-27
7	<i>Trigonella foenum-graecum</i>	Fenugreek	Flavonoids, polyphenols, amino acids (lysine, tryptophan)	Iron	Sprouts enhance iron bioavailability, stimulate erythropoiesis and reduce oxidative hemolysis	28-30
8	<i>Triticum aestivum</i>	Wheat	Chlorophyll, flavonoids, enzymes	Iron, folate	High chlorophyll and iron content stimulate hematopoiesis and improve Hemoglobin levels	31-33
9	<i>Eleusine coracana</i>	Finger millet (Ragi)	Polyphenols, flavonoids	Iron, calcium	Germination reduces tannins/phytates, increasing iron bioaccessibility several-fold	34-37
10	<i>Macrotyloma uniflorum</i>	Horse gram	Phenolic acids flavonoids	Iron, calcium	Sprouting enhance iron absorption and protects RBCs from oxidative damage	38-39
11	<i>Pisum sativum</i>	Pea	Ferritin, polyphenols, prebiotic oligosaccharides	Iron	Reduced phytates and microbiome modulation enhance iron uptake and Hemoglobin synthesis	40-42
12	<i>Helianthus annuus</i>	Sunflower	Phenolic acids, flavonoids, tocopherols	Iron, zinc	Germination increases iron content and antioxidant protection of erythrocytes	43-44
13	<i>Chenopodium quinoa</i>	Quinoa (Rajgira)	Saponin-reduced phenolics, carotenoids,	Iron. Zinc, calcium	Sprouting improves mineral bioavailability and restores hemoglobin and ferritin in anemia models	45-46

			vitamin C			
14	<i>Hordeum vulgare</i> L.	Barley	Phenolic acid, flavoids, tocopherols, chlorophyll, vitamin C	Iron, folates, magnesium	Sprouting enhance phytochemical content, reduces phytates, improving iron bioavailability, stimulates erythropoiesis and protects erythrocytes from oxidative stress leading to improved hemoglobin and hematological parameters	47-48

IV. Conclusion

Sprouts are nutritionally enhanced functional foods with significant potential in the prevention and management of anemia. Germination improves iron bioavailability by reducing antinutritional factor such as phytic acid, increasing vitamin C, ferritin and antioxidant compound. Evidence from cereals, legumes and pseudocereals shows that sprouts enhance hemoglobin levels, stimulates erythropoiesis and protect red blood cells from oxidative damage. Their additional antioxidant and metabolic benefits further support overall hematological health, due to their low cost, sustainability and culture acceptability. Sprouts represent an effective dietary and public health strategy for combating anemia. In this review we demonstrated fourteen legumes and cereals effectiveness for managing anemia.

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