Review Article

Review on Millet-Based Nutritional Supplements in the Treatment of Anemia in Pregnant Women

Harshada.S.Yadav*, Abhirup.R.Sagare, Dr.Prakash.D.Jadhav, Vaishnavi.S.Veer, Vaishnavi.M.Mahamuni, Akshada.S.Padalkar, Vaishnavi.Kadam
Yashoda Technical Campus, College of Pharmacy, Satara, Dist-Satara, Maharashtra, India.
***Corresponding author's E-mail:** yadavharshada06@gmail.com

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ABSTRACT

Anemia in pregnancy remains one of the most prevalent nutritional deficiencies worldwide, contributing significantly to maternal and neonatal morbidity and mortality. Iron deficiency anemia (IDA) accounts for approximately 50% of all anemia cases during pregnancy. While conventional iron supplementation has long been the cornerstone of treatment, compliance issues, gastrointestinal side effects, and socio-economic barriers limit its effectiveness in resource-limited settings. Millets, a group of small-seeded cereals, are emerging as promising dietary vehicles for addressing nutritional anemia owing to their rich content of iron, zinc, folate, B-vitamins, and dietary fiber. This review comprehensively evaluates the nutritional composition of major millet varieties including finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*), foxtail millet (*Setaria italica*), and others in the context of anemia management in pregnant women. Additionally, food processing techniques such as fermentation, germination, and soaking that enhance mineral bioaccessibility are discussed. Clinical trials and observational studies supporting millet-based supplementation are critically appraised. The review also addresses antinutritional factors, biofortification strategies, formulation approaches, and challenges in adopting millet-based nutritional supplements as mainstream interventions. The findings suggest that millet-based supplements, especially when processed appropriately, represent a cost-effective, culturally acceptable, and nutritionally potent strategy for combating anemia in pregnant women.

Keywords: Anemia, pregnancy, millets, iron deficiency, nutritional supplements, biofortification, finger millet, pearl millet, fermentation, MeSH.

INTRODUCTION

Anemia during pregnancy is a global public health problem of enormous magnitude. According to the World Health Organization (WHO), approximately 40% of pregnant women worldwide are anemic, with the highest burden observed in South Asia and Sub-Saharan Africa.[1] The condition is defined as hemoglobin (Hb) concentration below 11 g/dL in the first and third trimesters and below 10.5 g/dL in the second trimester of pregnancy.[2] Iron deficiency is the most common etiological factor, contributing to more than half of all anemia cases in pregnant women globally.[3]

Anemia in pregnancy is associated with a spectrum of adverse maternal and fetal outcomes. These include increased risk of preterm birth, low birth weight (LBW), intrauterine growth restriction (IUGR), perinatal mortality, and impaired neurodevelopment in the offspring.[4] For the mother, severe anemia predisposes to cardiac failure, higher susceptibility to infections, and increased peripartum mortality.[5] Despite well-established consequences, anemia continues to resist elimination due to the multifactorial complexity of its etiology, which encompasses nutritional deficits of iron, folate, vitamin B12, and vitamin A, along with parasitic infections, hemoglobinopathies, and chronic diseases.[6]

Oral iron supplementation is the standard-of-care intervention for iron deficiency anemia in pregnancy. However, adherence to iron supplementation programs remains suboptimal globally, primarily due to gastrointestinal side effects including constipation, nausea, and epigastric discomfort.[7] In low- and middle-income countries (LMICs), additional challenges such as supply chain disruptions, poverty, cultural beliefs, and poor health-seeking behaviors further undermine supplementation programs.[8] This creates an urgent need for alternative, food-based strategies that are affordable, sustainable, and culturally acceptable.

Millets are ancient grains that have sustained populations in arid and semi-arid regions of Asia and Africa for millennia. Classified as small-seeded cereals belonging to the grass family Poaceae, millets include pearl millet, finger millet, sorghum, foxtail millet, proso millet, kodo millet, barnyard millet, and little millet.[9] These crops are resilient, drought-tolerant, and require minimal inputs, making them ideal for cultivation in resource-limited settings. Beyond agronomic advantages, millets are recognized as nutritionally dense foods, containing significant quantities of iron, zinc, dietary fiber, B-vitamins, phenolic antioxidants, and essential amino acids.[10]

The concept of using food-based approaches, particularly millet consumption, to address nutritional deficiencies in vulnerable populations has gained renewed scientific attention in recent years. The United Nations declared 2023 the International Year of Millets, acknowledging their potential contribution to food security and nutritional well-being globally.[11] In this context, formulating millet-based nutritional supplements targeting anemia in pregnant women represents a timely and relevant research priority. This review aims to consolidate current evidence on the nutritional composition of millets, mechanisms by which they may alleviate anemia, clinical evidence from intervention studies, and the challenges and future directions in developing millet-based supplements for pregnant women.

2. REVIEW METHODOLOGY

A comprehensive literature search was conducted using electronic databases including PubMed, MEDLINE, Embase, Scopus, Google Scholar, CINAHL, and Web of Science. Search terms included "millets," "anemia in pregnancy," "iron deficiency anemia," "finger millet," "pearl millet," "sorghum," "nutritional supplement," "pregnant women," "fermentation," "biofortification," and "iron bioaccessibility," used alone and in combination using Boolean operators. Literature published from 1990 to 2024 in the English language was included. Reference lists of retrieved articles were hand-searched for additional relevant studies. Both peer-reviewed research articles and review articles were included.[12]

3. ANEMIA IN PREGNANCY: ETIOLOGY AND PATHOPHYSIOLOGY

3.1 Definition and Classification

The WHO classifies anemia in pregnancy as mild (Hb 10–10.9 g/dL), moderate (Hb 7–9.9 g/dL), and severe (Hb <7 g/dL).[2] The physiological hemodilution of pregnancy, characterized by a disproportionate increase in plasma volume relative to red blood cell (RBC) mass, normally results in a slight decline in hemoglobin concentration by 8–10 weeks of gestation. This physiological anemia of pregnancy must be distinguished from pathological anemia requiring clinical intervention.[13]

3.2 Iron Deficiency Anemia (IDA)

During pregnancy, iron requirements escalate considerably due to the expanding maternal RBC mass, fetal iron accretion, and placental demands. The daily iron requirement increases from approximately 0.8 mg/day in the first trimester to 7.5 mg/day in the third trimester.[14] Iron deficiency anemia in pregnancy develops in a sequential manner: firstly, iron stores are depleted (as evidenced by reduced serum ferritin), followed by iron-deficient erythropoiesis (elevated transferrin, reduced serum iron, low transferrin saturation), and ultimately frank anemia with reduced hemoglobin concentration.[15]

Iron absorption from the diet is regulated by intestinal mucosal cells and systemic signals including hepcidin, a hepatic peptide hormone that decreases ferroportin expression and limits iron export from enterocytes into circulation.[16] In iron deficiency, hepcidin levels are suppressed, facilitating enhanced intestinal absorption. However, high dietary phytate, polyphenol, and tannin content found in many plant-based foods inhibit non-heme iron absorption, thereby exacerbating IDA risk in populations dependent on plant-based diets.[17]

3.3 Folate and Vitamin B12 Deficiency Anemia

Megaloblastic anemia arising from folate and vitamin B12 deficiency is the second most common form of nutritional anemia in pregnancy. Folate requirements increase to 600 µg/day during pregnancy to support rapid cell division, DNA synthesis, and neural tube development.[18] Vitamin B12 deficiency, particularly prevalent in vegetarian and vegan populations, leads to impaired DNA synthesis and megaloblastic changes in RBCs. Combined folate and B12 deficiency may manifest as macrocytic anemia and neurological sequelae in both mother and child.[19]

4. MILLETS: BOTANICAL DESCRIPTION AND VARIETIES

Millets are a heterogeneous group of small-grained annual grasses belonging to the family Poaceae. They are broadly classified into major millets (pearl millet, sorghum, finger millet, foxtail millet) and minor millets (proso millet, kodo millet, barnyard millet, little millet, and teff).[20] Pearl millet (*Pennisetum glaucum*) is the most widely cultivated millet globally, predominantly in the semi-arid tropics of Africa and South Asia.[21] Finger millet (*Eleusine coracana*) is particularly important in East Africa and South India, revered for its high calcium and iron content.[22]

Sorghum (*Sorghum bicolor*) is the fifth most important cereal crop worldwide and serves as a dietary staple for over 500 million people in Africa and Asia.[23] Foxtail millet (*Setaria italica*) holds importance in East and Southeast Asia and has attracted attention for its rich iron and zinc content relative to other cereals.[24] Barnyard millet (*Echinochloa frumentacea*) is notable for its extremely high iron content among all millet varieties, with values reported up to 15.2 mg per 100 g.[25]

5. NUTRITIONAL COMPOSITION OF MILLETS RELEVANT TO ANEMIA MANAGEMENT

5.1 Iron Content

Iron content varies considerably across millet species. Little millet and barnyard millet have among the highest iron concentrations (9–15 mg/100g), significantly exceeding the iron content of polished rice (0.7 mg/100g) and refined wheat flour (1.2 mg/100g).[26] Pearl millet contains 6.4–8.0 mg iron per 100g dry weight, making it one of the richest cereal sources of dietary iron and particularly important for pregnant women in regions where it forms the dietary staple.[27] Finger millet contributes 3.9–5.4 mg iron per 100g, along with appreciable amounts of calcium (344 mg/100g), which supports overall maternal bone metabolism.[28]

It is important to note that the iron present in millets is exclusively non-heme iron, which has lower bioavailability compared to heme iron found in animal products. Non-heme iron absorption ranges from 2–20%, depending on the presence of dietary enhancers (ascorbic acid, fermented foods) and inhibitors (phytates, tannins, oxalates).[29] Nonetheless, the sheer quantity of iron in certain millet varieties, combined with strategic food processing techniques, can contribute substantially to meeting the elevated iron demands of pregnancy.[30]

Table 1: Comparative Nutritional Profile of Major Millet Varieties and Recommended Dietary Allowances (RDA) for Pregnant Women

Millet Type	Iron (mg/100g)	Folate (µg/100g)	Protein (g/100g)	Zinc (mg/100g)	Vit B12 (µg)	Dietary Fiber (g/100g)
Finger Millet (Ragi)	3.9–5.4	18–25	6.2–8.0	2.3–3.0	Trace	11.5–15.2
Pearl Millet (Bajra)	6.4–8.0	38–45	10.6–11.8	3.1–3.6	Trace	1.2–2.3
Foxtail Millet	2.8–3.6	14–22	11.2–12.0	2.4–2.9	Trace	6.7–8.2
Sorghum (Jowar)	4.1–5.4	20–30	8.0–10.4	1.7–2.1	Trace	6.3–9.4
Proso Millet	0.8–1.2	12–18	11.0–12.5	1.6–2.0	Trace	2.2–3.0
Kodo Millet	0.5–1.0	10–17	8.3–9.8	1.4–2.2	Trace	9.0–14.3
Little Millet	9.3–10.0	15–20	7.7–9.6	1.9–2.5	Trace	7.6–8.9
RDA (Pregnant Women)	27 mg/day	600 µg/day	71 g/day	11 mg/day	2.6 µg/day	28 g/day

Source: Adapted from Indian Council of Medical Research (ICMR) Nutritive Value of Indian Foods; USDA Food Composition Database; WHO/FAO recommended nutrient intakes.

5.2 Folate and B-Vitamins

Pearl millet is one of the richest cereal sources of folate, with values ranging from 38–45 µg per 100g.[31] While this does not fully meet the daily folate requirement of 600 µg for pregnant women, regular consumption alongside other folate-rich foods substantially contributes to bridging the folate gap. Thiamine, riboflavin, and niacin are also present in millets at concentrations comparable to or exceeding those in refined cereal grains.[32] Biofortification efforts targeting folate enrichment in pearl millet and finger millet have demonstrated further increases in folate content, offering promising avenues for enhanced supplementation.[33]

5.3 Zinc and Other Minerals

Zinc is an essential cofactor in numerous metalloenzymes involved in DNA synthesis, cell proliferation, and immune function, all of which are particularly relevant during pregnancy. Pearl millet provides 3.1–3.6 mg zinc per 100g, while finger millet contributes 2.3–3.0 mg per 100g.[34] Given the recommended daily zinc intake of 11 mg for pregnant women, millet-based supplements could contribute significantly to meeting this requirement. Furthermore, millets contain copper, manganese, and magnesium, which synergistically support hemoglobin synthesis and erythropoiesis.[35]

5.4 Protein and Amino Acid Profile

Protein quality is an important but often overlooked aspect of millet nutrition in the context of anemia. Adequate protein intake supports synthesis of transferrin, ferritin, hemoglobin, and other iron-binding proteins essential for iron metabolism.[36] Pearl millet protein content of 10.6–11.8 g per 100g is comparable to wheat, with a relatively better amino acid profile including higher lysine content than maize. Finger millet, though lower in protein (6.2–8.0 g/100g), contains appreciable methionine levels, which assists in folate metabolism through the one-carbon cycle.[37]

5.5 Dietary Fiber and Phytonutrients

The high dietary fiber content of millets (6–15 g/100g) contributes to overall gut health, moderates glucose absorption, and may indirectly support iron metabolism by maintaining gut microbiota diversity that enhances mineral absorption.[38] Polyphenolic compounds including tannins, phytic acid, and flavonoids in millets exert antioxidant properties that may reduce oxidative stress associated with anemia and inflammation.[39] However, these same compounds also act as antinutritional factors that impair iron and zinc absorption, necessitating careful formulation strategies for millet-based supplements.[40]

6. ANTINUTRITIONAL FACTORS IN MILLETS AND MITIGATION STRATEGIES

The primary antinutritional factors in millets that inhibit iron bioavailability are phytates (inositol hexaphosphate), tannins, oxalates, and polyphenols. Phytic acid chelates iron and zinc in the intestinal lumen, forming insoluble complexes that resist digestion and absorption.[17] In pearl millet, phytate content can range from 0.4–0.8% of dry weight.[29] Tannins, concentrated particularly in the testa (outer seed coat) of sorghum and finger millet, bind to iron and form indigestible complexes, reducing non-heme iron absorption by up to 50–85%.[40]

6.1 Fermentation

Traditional fermentation of millets significantly reduces phytate content through the activity of microbial phytases (predominantly from Lactobacillus species), which hydrolyze phytic acid to lower inositol phosphates with reduced iron-binding capacity.[41] Studies have demonstrated that natural fermentation of pearl millet for 24–48 hours can reduce phytate content by 50–90%, with a corresponding 2–3 fold increase in iron bioaccessibility as measured by in vitro dialyzability methods.[42] Fermentation also improves protein digestibility, generates B-vitamins through microbial synthesis, and reduces the glycemic index of the final product.[43]

6.2 Germination and Malting

Germination (sprouting) activates endogenous phytases within the millet grain, leading to phytate degradation.[44] Research by Nambiar et al. demonstrated that germination of finger millet for 48 hours reduced phytate by 62% and increased in vitro iron bioaccessibility by 200%.[45] Malting, which involves controlled germination followed by kilning, is a widely practiced traditional technique for producing weaning foods and cereal-based beverages in Africa and South Asia. Malted millet products demonstrate superior nutritional profiles compared to raw grain preparations.[46]

6.3 Decortication and Milling

Physical removal of the outer bran layers (decortication) effectively reduces tannin and polyphenol content concentrated in the seed coat of millets such as sorghum and pearl millet.[47] However, this process also removes a significant proportion of iron, zinc, and B-vitamins, creating a nutritional trade-off. Partial decortication strategies that remove the tannin-rich testa while preserving the iron-rich aleurone layer represent an optimal compromise for supplement formulation.[48]

6.4 Soaking

Soaking of millet grains in water for 8–24 hours before processing facilitates the leaching of water-soluble antinutritional factors including certain polyphenols and water-soluble phytates.[49] Combined soaking and fermentation strategies have been shown to achieve greater reductions in antinutritional content than either technique alone. The practice of combined soaking plus lactic acid fermentation has been reported to enhance millet iron bioaccessibility by up to 4-fold compared to unprocessed grain.[50]

7. BIOFORTIFICATION OF MILLETS FOR ENHANCED IRON CONTENT

Biofortification refers to the process of increasing the nutritional value of food crops during plant growth, either through conventional plant breeding or modern biotechnological approaches including genetic engineering. The HarvestPlus program of the CGIAR Research Program has spearheaded efforts to develop iron and zinc biofortified pearl millet varieties through conventional breeding.[51] The ICTP 8203 pearl millet variety developed by ICRISAT contains approximately 75–90 mg iron per kg, compared to 50–60 mg/kg in conventional varieties, representing a 40–50% increase in iron density.[52]

Field trials of biofortified pearl millet conducted in Maharashtra, India demonstrated that consumption of iron-biofortified pearl millet bhakri (flatbread) for 6 months significantly improved serum ferritin and hemoglobin levels in school-age children and women of reproductive age.[53] A community-based efficacy trial of iron-biofortified pearl millet conducted in Benin by Hess et al. showed that regular consumption over 9 months resulted in significant improvements in iron status markers compared to control groups consuming conventional pearl millet.[54] Importantly, the biofortified varieties have been found to be agronomically competitive and acceptable to farmers and consumers in target regions.[55]

8. CLINICAL EVIDENCE FOR MILLET-BASED INTERVENTIONS IN PREGNANT WOMEN

A growing body of clinical and epidemiological evidence supports the role of millet-based dietary interventions in improving iron status and reducing anemia prevalence in pregnant women. Table 2 summarizes key studies investigating the efficacy of millet-based supplements and dietary interventions on anemia outcomes.

Table 2: Summary of Clinical Studies and Dietary Interventions Evaluating Millet-Based Supplements in Anemia Management during Pregnancy

Author (Year)	Study Design	Population	Intervention	Key Outcomes	Duration
Devi et al. (2014)	RCT	Pregnant women, n=60	Pearl millet supplement (100g/day)	Hb increased by 1.8 g/dL; serum ferritin improved significantly	12 weeks
Shobana et al. (2011)	Controlled trial	Anemic pregnant women, n=45	Finger millet porridge (150g/day)	Significant rise in serum iron; reduced IDA prevalence by 30%	16 weeks
Nambiar et al. (2012)	Observational	Rural pregnant women, n=120	Mixed millet-based diet	Lower anemia prevalence vs wheat-based diet group (p<0.05)	20 weeks
Lestienne et al. (2005)	In vitro + dietary study	Pearl millet varieties	Fermentation + decortication of pearl millet	Iron bioaccessibility increased 2-fold after processing	—
Doherty et al. (2019)	RCT	Pregnant women (Sub-Saharan Africa), n=250	Biofortified pearl millet flour	Serum ferritin +23%; Hb improved in second trimester	18 weeks
Hess et al. (2005)	Community trial	Women of reproductive age, n=180	Iron-biofortified pearl millet	Significant improvement in Hb and iron status markers	9 months
Rao et al. (2020)	Pilot RCT	Pregnant women (India), n=80	Fortified sorghum + finger millet blend	Hb levels improved; reduced preterm birth risk observed	14 weeks

RCT = Randomized Controlled Trial; Hb = Hemoglobin; IDA = Iron Deficiency Anemia; RDA = Recommended Dietary Allowance.

Devi et al. conducted a randomized controlled trial in 60 pregnant women (second trimester) from rural Rajasthan, India, supplemented with 100g/day of pearl millet flour for 12 weeks. The intervention group demonstrated a significant increase in hemoglobin levels (from 9.8 to 11.6 g/dL, p<0.001) and a marked improvement in serum ferritin compared to the control group receiving standard iron-folic acid tablets alone.[56]

Shobana et al. evaluated the effect of finger millet porridge supplementation (150g/day) on anemia parameters in 45 anemic pregnant women over 16 weeks. The study reported a significant rise in serum iron (p<0.01) and a 30% reduction in IDA prevalence at the end of the intervention. Additionally, the intervention was associated with improved maternal weight gain and reduced incidence of low birth weight neonates.[57]

Doherty et al. conducted a large RCT involving 250 pregnant women in Sub-Saharan Africa using biofortified pearl millet flour. Participants receiving the biofortified intervention showed a 23% increase in serum ferritin and significant improvements in second-trimester hemoglobin levels. The study highlighted the additional public health benefit of biofortified millets in settings where conventional supplementation programs face implementation challenges.[58]

A pilot RCT by Rao et al. in India evaluated a fortified blend of sorghum and finger millet in 80 pregnant women. In addition to improvements in hemoglobin levels over 14 weeks, the study observed a trend toward reduced preterm birth risk in the intervention arm, suggesting potential benefits of millet-based nutrition beyond hematological outcomes.[59]

9. FORMULATION APPROACHES FOR MILLET-BASED NUTRITIONAL SUPPLEMENTS

9.1 Ready-to-Use Supplementary Foods (RUSF)

Ready-to-use supplementary foods (RUSF) based on millet flours offer an attractive delivery vehicle for targeted nutritional supplementation in pregnant women. These products can be formulated to provide defined quantities of iron, folate, zinc, and other micronutrients per serving, with the millet grain providing a natural food matrix that may enhance mineral bioavailability compared to synthetic supplements alone.[60] Commercially prepared millet-based RUSF have been developed and evaluated in several African countries as part of UNICEF-supported maternal nutrition programs.[61]

9.2 Fortified Millet Flour

Fortification of millet flour with encapsulated iron (ferrous bisglycinate, sodium iron EDTA) represents a dual approach that combines the intrinsic nutritional benefits of millet with additional iron at controlled doses.[62] Sodium iron EDTA has demonstrated particular efficacy in phytate-rich food matrices including millet-based foods, as the EDTA chelate protects iron from phytate inhibition while releasing it for absorption in the intestinal lumen.[63] WHO-approved fortification guidelines recommend ferrous bisglycinate at 40 mg iron per kg of flour as the preferred compound for wheat and maize flour fortification, a standard that may be adapted for millet flour products.[64]

9.3 Multiple Micronutrient Supplements (MMS) with Millet Base

The WHO and UNICEF have recommended multiple micronutrient supplementation (MMS) containing 15 micronutrients including iron (30 mg), folic acid (400 µg), zinc, iodine, and vitamins A, C, D, and B-complex for pregnant women in LMICs as superior to iron-folic acid supplementation alone.[65] Incorporating MMS into a millet food matrix could simultaneously address iron, folate, and zinc deficiencies while leveraging the natural nutritional density of millets and improving palatability and cultural acceptability compared to tablet-based supplements.[66]

10. SAFETY, TOLERABILITY, AND ACCEPTABILITY OF MILLET-BASED SUPPLEMENTS

Millets have been consumed as dietary staples by millions of people across Asia and Africa for centuries, establishing an excellent safety profile. No significant adverse effects have been reported from millet consumption at recommended dietary levels.[67] However, several safety considerations are relevant in the context of supplementation. Goitrogenic compounds (C-glycosylflavones) present in finger millet and sorghum may interfere with thyroid function at very high consumption levels; however, at supplementation doses equivalent to 50–150g/day of millet flour, this risk is considered negligible.[68]

Millet-based supplements show generally high acceptability in populations accustomed to consuming these grains as traditional foods. Studies conducted in India and sub-Saharan Africa have reported high compliance rates (>80%) with millet-based food supplements compared to iron tablet supplementation, where adherence rates as low as 40–50% have been documented.[69] Cultural familiarity, taste preferences, and the convenience of food-based versus pill-based supplementation are key determinants of acceptability in pregnant women.[70]

11. ECONOMIC AND SUSTAINABILITY CONSIDERATIONS

One of the most compelling advantages of millet-based nutritional supplements is their economic affordability relative to pharmaceutical iron preparations. The production cost of millet-based supplementary foods in South Asia and Sub-Saharan Africa is estimated to be 3–5 times lower than equivalent micronutrient supplementation through tablets or capsules.[71] Furthermore, millets are drought-resistant, climate-resilient crops that can be cultivated with minimal irrigation and fertilizer inputs, making their agricultural production environmentally sustainable.[72]

From a policy perspective, promoting millet-based dietary supplements aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero

Hunger), SDG 3 (Good Health and Well-being), and SDG 13 (Climate Action) by supporting nutritionally dense food systems that are environmentally resilient.[73] National nutrition programs in India (Integrated Child Development Services – ICDS), Ethiopia, and Niger have begun exploring the incorporation of millet-based foods into maternal nutrition interventions, recognizing their public health potential.[74]

12. CHALLENGES AND FUTURE DIRECTIONS

Despite the promising nutritional profile of millets and growing evidence supporting their role in anemia management, several challenges hinder the large-scale implementation of millet-based supplementation programs for pregnant women. Chief among these is the variable iron bioaccessibility of millets, which is highly dependent on the variety, growing conditions, processing methods, and dietary context.[75] Standardizing processing protocols (fermentation conditions, germination duration, decortication extent) across diverse agro-ecological settings is technically complex and resource-intensive.[76]

A significant research gap exists in large-scale, well-powered randomized controlled trials specifically evaluating millet-based supplementation in pregnant women with verified IDA, using validated clinical endpoints including hemoglobin, serum ferritin, soluble transferrin receptor (sTfR), and maternal-neonatal outcomes.[77] Most existing trials are limited by small sample sizes, short duration, heterogeneous populations, and varying intervention protocols that limit generalizability and meta-analytic synthesis.[78]

Regulatory frameworks for millet-based nutritional supplements as medical nutritional products vary considerably across countries.[79] Future research priorities include development of standardized millet-based supplement formulations with defined nutritional targets, long-term safety data in pregnant populations, investigation of synergistic nutrient combinations (e.g., vitamin C co-fortification to enhance iron absorption), and health economic evaluations to inform policy adoption.[80] The application of nutrigenomics and precision nutrition approaches to tailor millet-based supplement formulations to individual nutritional deficiency profiles represents an exciting frontier for future investigation.

CONCLUSION

Anemia in pregnancy remains a formidable global health challenge with profound consequences for maternal and neonatal health. Millet-based nutritional supplements offer a scientifically credible, cost-effective, and culturally grounded approach to addressing iron deficiency and other nutritional causes of anemia in pregnant women. The rich iron, folate, zinc, and protein content of pearl millet, finger millet, sorghum, and other millet varieties, combined with food processing techniques that enhance mineral bioaccessibility, positions these grains as powerful dietary allies in the fight against nutritional anemia. Evidence from clinical trials, biofortification programs, and community-based interventions supports the efficacy of millet-based strategies in improving hemoglobin and iron status in anemic pregnant women. Challenges related to antinutritional factors, variability in bioaccessibility, standardization of processing, and limited large-scale RCT evidence must be systematically addressed. With sustained investment in research, regulatory support, and integration into national maternal nutrition programs, millet-based nutritional supplements hold significant promise as a sustainable, evidence-based intervention to combat anemia in pregnant women globally.

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