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Iron Deficiency in Female Athletes: A Systematic Review of Health Consequences, Performance Impairments, and Evidence-Based Management Strategies

Subheading: Impact of Iron Deficiency on Female Athletes

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ABSTRACT: Background: In female groups, especially adolescent female endurance athletes, iron deficiency is most vulnerable. This may impair health functions and performance as well. Objectives: To examine the physiological mechanisms, prevalence, and health and performance indicators of iron-deficient female football players. Those examinations are strategized through practical nutritional techniques.

Methods: For this systematic review, PROSPERO registration was done. In this review, various searches such as “PubMed,” “Sport Discus,” “Scopus,” “ProQuest,” “Google Scholar” are used. Many terms, such as blood iron level, food, supplement, exercise, and exercise-induced hormones, are combined using Boolean operators (AND, OR).

Results and Discussion: Menstrual losses, exercise causing hemolysis, GI bleeding, sweating, and inflammation mediated elevations in hepcidin after intense prolonged exercise are some of the variables, responsible to deficiency of iron (ID) and deficiency of iron with anaemia (IDA). For the reason of high intensity prolonged exercise in football sports, female players are more exposed to deficiency of iron and deficiency of iron with anaemia. These responsible elements impede healing, risk of injury, and lower aerobic performance in female athletes. One important, yet sometimes overlooked, element affecting female football players’ health and performance is iron deficiency.

Conclusion: Regular evaluations, diet modification, and tailored supplementation are more crucial for enhancing iron status and attaining improved performance.

1. INTRODUCTION

In most popular sports in the world, Football is one of them. A standard duration of 90 minutes is set for football matches, with an extra 30 minutes, making the total 120 minutes of a match. So, a high degree of physical and physiological fitness is

needed for women's football [Randell et al., 2021]. Women's body size, body composition, and hormonal profile differ from men [Walsh, 2019]. An estimated 253 million people in India are in the adolescent age group at the age of 10-19 years [Jaleel et al., 2024], and they demand adequate nutrition, education, counselling, and guidance to ensure optimal development [Badenhorst et al., 2021]. In sports, approximately 52% in female adolescent athletes have higher iron deficiency and a high prevalence of eating disorders, which affects endurance sports [Raj et al., 2023; Sims et al., 20220]. Female football players are particularly vulnerable due to such factors, including menstrual bleeding, foot strike hemorrhage, sweat losses, excessive stress due to playing football, and inflammation-induced elevations in hepcidin following intense training sessions. These factors may hamper iron absorption and recycling, leading to reduced ferritin levels and inhibiting iron availability. For this reason, variety supplementation regimens are determined to ensure adequate iron status [Smith et al., 2022]. Iron deficiency is global health obstacle in general as well as in the endurance population, leading to decreased haemoglobin level, hematocrit value, and RBC values. Some research [Aggarwal et al., 2020; WHO, 2024] reported the differences in anaemia discovered by haemoglobin level (gm/dl) are about 11.0-11.9 gm/dL (anaemia with mild effect), 8.0-10.9 gm/dL (anaemia with moderate effect), and less than 8.0 gm/dL (anaemia with severe effect) during the adolescent period. This review aims to examine the physiological mechanisms, prevalence, health implications, and performance impacts of iron-deficient female athletes.

2. MATERIALS AND METHODS

2.1 Prospero Registration Protocol

This systematic review has been officially registered in the Systematic Reviews with International Prospective Register. (PROSPERO2026; CRD420261422422).

2.2 Study Design and Reporting Standards

With a focus on female football players specifically, to examine prevalence, causes, physiological process, dietary factors and performance consequences of athletes with iron deficiency, as a systematic review this study was conducted. The recommended reporting items for systematic review (PRISMA) 2020 were referred [Chandler et al., 2019; Page et al., 2021].

2.3 Research Question and Objectives

The primary objective of this thorough analysis was to gather the most recent data on the prevalence, causes, physiological process, dietary factors, and performance effects of the athletes with iron deficiency. A modified version of PICO framework acted as the review's guidance. Female athletes and physically active women were considered in the population (P); where, in the exposure (I/E) included deficiency of iron, deficiency of iron with anaemia, iron loss in exercise-induced, and iron status due to nutritional factors; in comparison (C) included athletes with adequate iron status or, if applicable, different levels of iron-related biomarkers; and the outcomes (O) included the prevalence of iron insufficiency, haematological indicators, physiological process, nutritional factors, performance outcomes, and responses to iron supplementation.

2.4 Literature Search Strategy

For this systematic review Pub Med, Web of Science, and Scopus were used. For this review, the different studies were included, which were from 2000 to 2025. Different Boolean operators like AND, OR and to unite keywords related to diet search approaches were used, iron deficiency, exercise, and hormones. Those keywords are "iron deficiency," "iron-deficiency anemia," "iron status," "female athletes," "female football players," "women athletes," "energy availability," "hepcidin," "exercise-induced iron loss," "energy limitations," "dietary intake," "insufficient dietary iron," "meal time," "acute and heavy training," "dietary iron inhibitors," "heavy periods flow," "sweating," "GI bleeding," "foot strikes hemolysis," and "dietary iron intake," "iron supplementation". Different original review and survey papers, especially on female athletes, were considered.

2.5 Eligibility Criteria

This review also reported biochemical iron profiles as well as performance implications of female athletes, including female footballers. In this review, more attention was given to observational studies, systematic reviews, intervention trials, and longitudinal research. Inclusion of athletes and the physically active population was deliberated. As for revealed facts about hormonal changes caused by exercise, non-athletes were also considered. In the inclusion criteria, peer-reviewed journals between January 2020 and June 2026 were also included. Studies that do not examine iron-related variables or outcomes were

excluded from this study. Also, insufficient methodological details for critical evaluation, unrelated sports participants were excluded.

2.6 Study Selection Process

By database search duplicate entries were eliminated after all records. Manual reference screening was put into reference management software. Using the predetermined qualifying criteria, title and abstract were separately checked by two reviewers. Full-text reviews of potentially pertinent studies were conducted. Reviewers' disagreement were settled by discussion, consensus, and if needed, discussion with a third reviewer. To describe the study selection process, in PRISMA, 2020 flow diagram the assessment, review, participation, and final enrolment of studies had been showed.

2.7 Extraction of Data

In accordance with the Cochrane Handbook, a standardize data extraction form developed. To carefully gather data form each included trials, JBI Manual for Evidence Synthesis [Chandler et al., 2019; Evans et al., 2024]. The data collected included the study country, study design, participants' characteristics (e.g., sample size, age, athletic level, sports type).

2.8 Assessment of Quality and Risk of Bias

Employing proven techniques and protocols proper for the research design, two evaluators individually reviewed methodological quality and biasness of risk. Using the revised Cochrane Risk of Bias Tool (RoB 2), randomized controlled trials was evaluated [Sterne et al., 2019]. Using the Newcastle-Ottawa Scale (NOS), observational cohort and case-control studies were assessed [Gualdi-Russo et al., 2026]. Studies were categorized according to their methodological quality.

2.9 Data Synthesis

From Cochrane Handbook and JBI Manual, the data was synthesized. This was for evidence synthesis [Chandler et al., 2019; Evans et al., 2024]. In participant characteristics, iron biomarkers, diagnostic criteria, training status, supplementation practices and outcome measure, major difference was seen. This made unproven quantitative meta-analysis. The results were organized using a narrative thematic approach into several major thematic categories. These include the prevalence of deficiency of iron (ID), deficiency of iron with anaemia (IDA), physiological process of iron depletion, and nutritional factors of iron status, exercise-related iron loss, iron supplementation routine and interventions and performance implications of iron deficiency.

2.10 Statistical Analysis

Because of the major diversity among the studies, a formal meta-analysis was not performed. That is why, no heterogeneity statistics, publication bias analysis, or pooled effect estimates were calculated. The findings were reported descriptively and summarized qualitatively.

2.11 Evidence Certainty

The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) system were used as the guiding principles. By this, the overall strength of the evidence was evaluated. For the assessment of the evidence quality, risk of bias, consistency of results, directness of proof, estimation accuracy, and publication bias were all taken into consideration.

3. RESULTS AND DISCUSSION

3.1 PRISMA Flow Diagram Results

From electronic database such as PubMed, Scopus, Web of Science, and Google Scholar etc., a sum of 1000 records were found through literature search. After identifying records about 1000, about 780 were screened. After title screening, 620 records were eliminated as the records did not fit the specified eligibility requirements. After abstract screening, 160 records were set. From this, 80 records were eliminated as the records were not sufficiently relevant to the review's goal. Then 80 full-text articles were evaluated for eligibility. From these 80 records after full text evaluation, 32 were eliminated because of several reasons such as., lack of focus on iron deficiency or iron metabolism, lack of related outcome measures, populations other than female athletes, publication styles like letters or editorials etc. Ultimately, in the qualitative synthesis of this

systematic review 48 studies were met all inclusion requirements. The PRISMA flow diagram is done for the complete selection process (Figure 1).

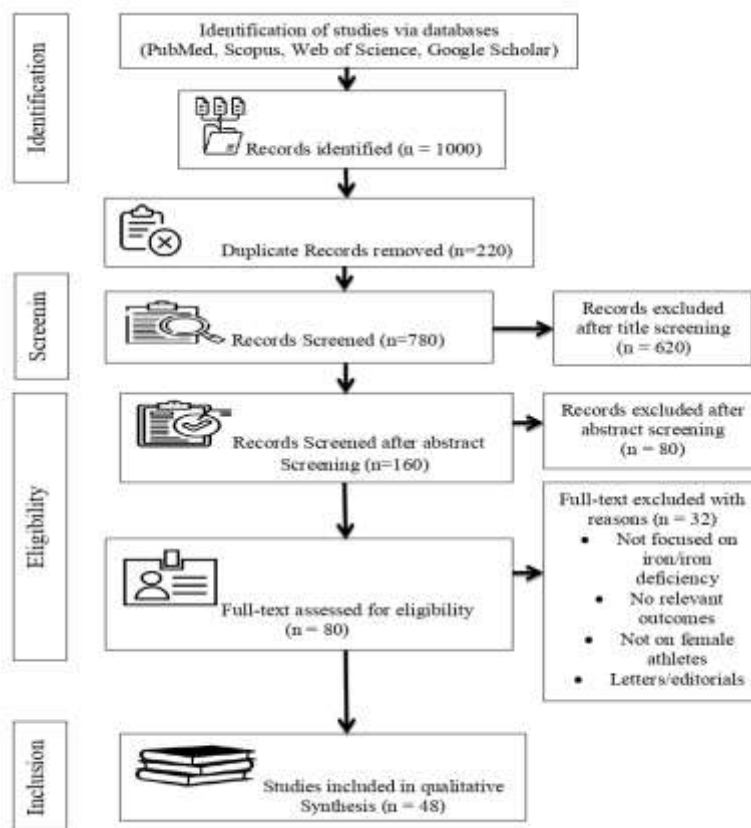


Figure 1: Flowchart showing study selection process

3.2 Risk of Bias Assessment

For observational studies and randomized controlled trials, the Newcastle-Ottawa Scale (NOS) and updated Cochrane Risk of Bias Tool (RoB 2) were used. These two evaluate the methodological quality and biasness of risk of the employed studies. A generally acceptable degree of confidence in the presented findings was indicated by the employed studies overall moderate to high methodological quality. Across all evaluated areas, the majority of randomized controlled trials were considered to have a low-to-moderate biasness of risk. The most frequent issues were insufficient outcome reporting, participant and staff binding, and allocation protection. So, biasness of risk was considered as acceptable for narrative synthesis. However, result should be interpreted for the consideration with methodological variability between studies (Table 1).

Table 1: Risk of Bias Assessment of Selected Included Studies

Study (Author, Year)	Randomization Process	Deviations from Intended Interventions	Missing Outcome Data	Measurement of Outcome	Selection of Reported Results	Overall Risk of Bias
DellaValle & Haas, 2014	Low Risk	Low Risk	Low Risk	Low Risk	Some Concerns	Low Risk
Burden et al., 2015	Low Risk	Some Concerns	Low Risk	Low Risk	Low Risk	Low Risk
Sim et al.,	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk

2019						
Pengelly et al., 2025	Some Concerns	Low Risk	Low Risk	Low Risk	Some Concerns	Some Concerns
Takahashi et al., 2025	Low Risk	Some Concerns	Low Risk	Low Risk	Low Risk	Some Concerns
Garvican-Lewis et al., 2016	Low Risk	Low Risk	Some Concerns	Low Risk	Low Risk	Some Concerns
Govus et al., 2017	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk	Low Risk
Peeling et al., 2014	Some Concerns	Low Risk	Low Risk	Some Concerns	Low Risk	Some Concerns

3.3 Main Findings

3.3.1 Incidence of Deficiency of Iron (ID) and Deficiency of Iron with Anemia (IDA)

ID and IDA are most prevalent nutritional conditions which affect the health of female athletes. According to the included evidence in this systematic review, female athletes are more likely than both male athletes and non-athletic female because of the combined effect of inadequate dietary intake, menstrual heavy flow, increased training demands, and exercise-induced iron loss [Olszok et al., 2026; Sim et al., 2019]. Deficiency of iron (id) and deficiency of iron with anemia are clearly different. Low haemoglobin level and low serum ferritin level are indicative of iron deficiency anaemia. On the other side, low serum ferritin level alone is a sign of iron insufficiency [Al-Naseem et al., 2021]. In all of the analysed studies, iron insufficiency is more common than iron deficiency anaemia. In student-athletes, approximately 53.9% were found to be hypoferritinemic (Less than 50 mcg/L of ferritin concentration), where showing absolute iron deficiency based approximately 23.0% percent in current definitions. These results strongly recommended the changes in clinical practice guidelines, to enable routine screening for iron deficiency among teenage and collegiate athletes [Thompson et al., 2025]. With rates typically above 40% in elite female competitors, there were notable variations in predominance among sports. The highest incidence of iron deficiency was routinely seen among endurance athletes, including distance runners, cyclists, triathletes, rowers etc. [Marc-Tudor et al., 2021; Olszok et al., 2026]. High training volumes, higher iron turnover, exercise-induced hepcidine responses, gastrointestinal bleeding and foot strike haemolysis all are linked to the increased risk in these athletes [Peeling et al., 2014]. Iron insufficiency was also significant more common in female football players. According to the recent research, between 20 to 35 % of female football players had low iron reserve, especially during intense training and competition [Peña et al., 2023] (Table 2).

Table 2: Incidence of Deficiency of Iron (ID) and Deficiency of Iron with Anemia (IDA)

Reference	Study Population	Study Design / Intervention	Duration	Iron Bioavailability Variables Assessed	Main Findings	Iron-Related Outcome	Relevance to Iron Deficiency in Female Footballers
Olszok et al., 2026	Athletes (various sports)	Narrative Review	Not applicable	Ferritin, hemoglobin, transferrin saturation (TSAT), serum iron,	Subclinical iron deficiency is common among athletes and may impair performance before anemia develops. Early screening and	Subclinical iron deficiency	Explains diagnostic approaches, consequences of low ferritin, and management strategies in

				hepcidin	nutritional management are recommended.		athletes.
Al-Naseem et al., 2021	General population with iron deficiency without anemia	Clinical Review	Not applicable	Ferritin, TSAT, serum iron, hemoglobin, red cell indices	Iron deficiency without anemia can significantly affect health and physical function. Ferritin is an important diagnostic marker and early treatment is warranted.	Iron deficiency without anemia	Supports the concept that performance decrements can occur before anemia develops
Thompson et al., 2025	Collegiate athletes (male and female)	Systematic Review and Meta-analysis	Studies included varied in duration	Ferritin, hemoglobin, TSAT, serum iron	Iron deficiency is highly prevalent among collegiate athletes, particularly females and endurance athletes, highlighting the need for routine monitoring and nutrition-based prevention strategies.	Global prevalence of iron deficiency	Provides prevalence data and identifies female athletes as a high-risk group.
Marc-Tudor et al., 2021	Athletes from multiple sports disciplines	Narrative Review	Not applicable	Hemoglobin, hematocrit, ferritin, erythropoietic markers	Sports anemia and true iron-deficiency anemia should be differentiated. Adequate dietary iron intake and monitoring are essential for athletic performance and recovery.	Sports anemia and iron deficiency	Discusses physiological mechanisms linking iron deficiency to reduced exercise capacity.
Peña et al., 2023	Female football players	Prospective observational study during competitive season	One competitive season	Erythrocyte membrane fatty acid profile (not direct iron bioavailability markers)	Significant seasonal changes occurred in erythrocyte PUFA composition, suggesting dietary and training influences on membrane health. Iron bioavailability was not directly assessed.	Nutritional biomarkers	Useful for athlete nutrition context, but not specifically for iron bioavailability

3.3.2 Physiological Mechanisms of Iron Depletion

In athletes who are subjected to high training volume and competitive demands, the risk of iron shortage is often increased by both systems working together. The hepcidin response is caused by exercise is one of the extensively studied process. The primary regulator of iron homeostasis is controlled by hepcidin. It has been stated that acute endurance and high intensity training increases the circulation of hepcidine level, which is high usually three to six hours after exercise [Peeling et al., 2014]. Increased hepcidin contributes to the gradual depletion of iron reserves by decreasing iron absorption and availability for erythropoiesis. Hepcidin levels may be persistently raised in athletes, who train often or for long period of time, making more vulnerable to iron shortage [Fensham et al., 2023].

Table 3: Nutritional Determinants of Iron Status in Female Athletes

Reference	Study Population	Dietary Factor Investigated	Study Design / Intervention	Iron Bioavailability Variables Assessed	Nutritional Determinant outcomes	Main Findings
Sim et al., 2019	Athletes (particularly female and endurance athletes)	Dietary iron intake, heme vs. non-heme iron, vitamin C, calcium, polyphenols, phytates, iron supplementation	Narrative Review	Ferritin, Hemoglobin, Serum Iron, Transferrin Saturation, Soluble Transferrin Receptor (sTfR), Hepcidin	Low consumption of heme iron foods, Insufficient vitamin C intake, High intake of absorption inhibitors (tea, coffee, phytates, calcium), Exercise-induced hepcidin response affecting iron absorption	Female athletes are at high risk of iron deficiency. Iron absorption is influenced by dietary enhancers (vitamin C) and inhibitors (calcium, phytates, polyphenols). Exercise-induced hepcidin may reduce iron absorption.
Alaunyte et al., 2015	Female athletes	Dietary iron intake, iron-rich foods, iron supplementation, vitamin C co-ingestion	Review Article	Ferritin, Hemoglobin, Serum Iron	Low dietary iron intake, Low consumption of heme iron foods, Insufficient vitamin C intake	Dietary interventions emphasizing iron-rich foods and vitamin C can improve iron status. Iron supplementation is effective when dietary measures alone are insufficient.
Ackerman et al., 2019	Male and female athletes with Relative Energy Deficiency in Sport (RED-S) risk	Low energy availability (LEA) as a nutritional determinant	Cross-sectional observational study	Not direct iron biomarkers; LEA surrogate measures	Low energy availability (LEA), Menstrual dysfunction associated with LEA	Low energy availability was associated with adverse health and performance outcomes. Chronic LEA may indirectly compromise iron status through inadequate dietary intake and menstrual disturbances.
Logue et al.,	Athletes from various	Energy intake, dietary patterns,	Systematic	Not primarily iron biomarkers; nutritional	Restrictive eating patterns/disordered eating, Low	LEA is prevalent among athletes and is associated with inadequate

2018	sports	nutrient inadequacy	Review	adequacy indicators	energy availability (LEA)	micronutrient intake, including iron. Female athletes are particularly vulnerable due to increased physiological iron requirements.
Nebl et al., 2019	Vegan, lacto-ovo-vegetarian, and omnivorous recreational runners	Vegetarian and vegan dietary patterns affecting iron intake and absorption	Cross-sectional comparative study	Hemoglobin, Ferritin (where reported), Dietary Iron Intake	Vegetarian/Vegan dietary patterns	Plant-based diets may provide adequate total iron but predominantly non-heme iron, which has lower bioavailability. Proper dietary planning is necessary to maintain iron status in female athletes following vegetarian diets.
Milman, 2020	General population (focus on iron absorption physiology)	Dietary enhancers and inhibitors of iron absorption	Narrative Review	Intestinal iron absorption mechanisms	Phytate-rich diets, Tea and coffee consumption, High calcium intake	Vitamin C, meat factors, and organic acids enhance iron absorption, whereas phytates, calcium, polyphenols, tea, coffee, and some fibers inhibit absorption. These dietary factors are important determinants of iron status.

In female athletes, the most significant contributing factor of iron deficiency is menstrual heavy bleeding. Heavy menstrual bleeding is linked to low serum ferritin level, a greater chance of IDA and ID [Petkus et al., 2017]. So, iron deficiencies in female athletes are more physiologically challenges condition as compared to male athletic populations. Reduced iron status is also a result of haemolysis caused by exercise. Foot strike haemolysis is the term for the mechanical destruction of erythrocytes caused by repeated foot contact during running and field based sports [Lowe et al., 2024]. Chronic exposure may lead to iron shortage even if a large portion of the released iron is recycled. Additionally, through decreased splanchnic blood flow, increased intestinal permeability, and mucosal injury, prolonged or intense exercise can cause gastrointestinal bleeding, which can lead to further iron losses [Sim et al., 2019]. Furthermore, high intensity training raises the inflammatory marker i.e., interleukin -6 (IL-6), which promotes hepcidin in liver and interferes the normal iron metabolism [Larsuphrom & Latunde-Dada, 2021].

3.3.3 Nutritional Determinants on Iron Status

Maintaining sufficient iron shortage and preventing iron shortage depends on a number of factors, including dietary iron consumptions, iron bioavailability, energy availability, dietary constraints and food choice. According to a number of studies [Petkus et al., 2017; Sim et al., 2019], female athletes, especially those play endurance, are often fall short of recommended iron intake levels due to restrictive eating habits and attempts to meet particular body consumption goals. Iron status is significantly influenced by the source of dietary iron. Non haem iron form plant based meals is less easily absorbed than haem iron, which is present in animal food products. Compared to athletes who primarily rely on plant based iron sources, those who consume haem iron containing diets have greater serum ferritin level and a lower prevalence of iron deficiency [Alaunyte et al., 2015]. Iron depletion may therefore be more likely if iron-rich animal products are not consumed in sufficient amounts. Iron and other vital minerals are frequently consumed in insufficient amounts by female athletes who have low calorie intake in comparison to training needs. A significant correlation have been shown between poor energy availability, lower ferritin level and higher risk of iron shortage, especially in athletes with sports related energy deficiency, is also called RED-S

[Ackerman et al., 2019; Logue et al., 2018]. For the reason of their potential to affect iron status, vegetarian and vegan eating habits have drawn more attention. As a result, compared to omnivore's athletes, vegetarian and vegan female athletes often have lower ferritin level and a greater chance of iron insufficiency [Nebl et al., 2019]. Dietary bioavailability of iron is enhanced by vitamin C, organic acids, and animal protein (haem iron) and non-haem iron from factory sources, including legumes, green lush vegetables, whole grains, and fortified cereals, while iron absorption is inhibited by phytates, polyphenols, calcium, and certain gastrointestinal conditions [Milman, 2020; Sim et al., 2019] (Table 3).

3.3.4 Iron Deficiency with Exercise-Related Risk Factors

In female athletes, iron insufficiency is caused by variables connected to exercise according to the data included in this systematic review. Iron metabolism is influenced by a number of factors that might hasten the depletion of iron reserves, including training volume, exercise intensity, sport-specific demands, seasonal workload variations, and competition schedule. Impaired iron status was always associated to high intensity training volume. For the reason of increased iron turnover, several processes are responsible. Additionally, in iron metabolism hepcidin is crucial regulator. This hepcidine is temporarily elevated by intense training which decline iron absorption and restricts iron availability [Fensham et al., 2023; Ishibashi et al., 2020]. The independent impact of training stress on iron homeostasis was demonstrated by several studies. Distance runners, cyclists, triathletes, and rower are example of female endurance athletes that have consistently greater rates of iron insufficiency than athletes who play team sports [Pengelly et al., 2025]. Greater cumulative training volumes and the extended physiological demands of endurance exercise seem to make people more vulnerable to iron deficiency. On the other hand, despite typically lower prevalence rates in team sports, female football players were nonetheless at significant risk because of their frequent training sessions, high intensity workouts, and packed schedule. There were also frequent reports of seasonal changes in iron status. During pre-season conditioning and competitive phases, when training loads were at their highest, iron reserves generally decreased, but partial recovery of iron status was regularly seen during off-season times with lower workloads. Iron deficiency risk is also increased by recuperation efforts and competition schedules. Iron absorption and iron stores repair may be hampered by repeated inflammatory reactions and prolonged hepcidin increases brought on by frequent contests with short recovery periods [McCarthy et al., 2026].

Table 4: Effects of Iron Supplementation on Iron Status and Performance in Athletes

Reference	Study Population	Dietary Factor Investigated	Study Design / Intervention	Duration	Iron Bioavailability Variables Assessed	Main Findings
Burden et al., 2015	Iron-deficient non-anemic (IDNA) endurance athletes	Oral iron supplementation	Systematic Review and Meta-analysis	Included studies varied (4–12 weeks)	Ferritin, Hemoglobin, Transferrin Saturation, Serum Iron	Iron supplementation improved iron stores, particularly ferritin levels, in IDNA athletes. Performance benefits were more evident in athletes with lower baseline iron status.
Steinbicker & Pantopoulos, 2025	General population and clinical patients	Oral versus intravenous iron therapy	Narrative Review / Book Chapter	N/A	Ferritin, Hemoglobin, Transferrin Saturation, Hepcidin	Oral iron effectively replenishes iron stores in mild-to-moderate deficiency, while intravenous iron may be more appropriate for severe deficiency or poor oral absorption.
Rubeor et al., 2018	Iron-deficient non-anemic	Oral iron supplementation	Systematic Review	Included studies varied	Ferritin, Hemoglobin, Serum Iron	Iron supplementation consistently improved ferritin concentrations. Improvements in athletic

	athletes					performance were observed mainly in athletes with iron deficiency but without anemia.
Šmid et al., 2024	Athletes from multiple sports	Oral iron supplementation	Systematic Review, Meta-analysis and Meta-regression of RCTs	Included RCTs ranged from 2–24 weeks	Ferritin, Hemoglobin, Transferrin Saturation, Serum Iron, Soluble Transferrin Receptor (sTfR)	Oral iron supplementation significantly increased ferritin and improved overall iron status. The greatest improvements occurred in athletes with low baseline ferritin and longer supplementation durations.
Dellavalle & Haas, 2014	Iron-depleted female rowers	Oral iron supplementation	Randomized Controlled Trial	6 weeks	Ferritin, Hemoglobin, Soluble Transferrin Receptor (sTfR)	Iron supplementation improved iron status and energetic efficiency during exercise, even in the absence of anemia.
Burden et al., 2015	Elite athletes with iron deficiency	Intravenous iron administration	Randomized Controlled Trial	4 weeks	Ferritin, Hepcidin, Hemoglobin, Serum Iron	Intravenous iron markedly increased ferritin levels and improved iron metabolism markers. Aerobic capacity improvements were limited and mainly observed in iron-deficient athletes.
Sim et al., 2019	Athletes, particularly female and endurance athletes	Oral iron supplementation, dietary iron intake, iron absorption strategies	Narrative Review	N/A	Ferritin, Hemoglobin, Serum Iron, TSAT, Hepcidin, sTfR	Oral iron supplementation is effective for restoring iron stores in athletes. Timing of supplementation and management of exercise-induced hepcidin responses are important for maximizing absorption.
Pengelly et al., 2025	Female athletes	Iron supplementation (primarily oral), dietary iron interventions	Systematic Review	Included studies varied (4–24 weeks)	Ferritin, Hemoglobin, Serum Iron, TSAT, sTfR	Iron supplementation significantly improved ferritin and iron status markers in female athletes. Benefits on performance were most apparent in iron-deficient athletes and those with low ferritin concentrations.

3.3.5 Iron Supplementation Effects on Athletic Iron Status

Iron supplementation has been demonstrated to enhance iron status of low iron status female athletes with. Oral iron supplementation is the most often used in intervention. Different studies typically stated that to supply 40-200 mg of

elemental iron daily ferrous fumarate, ferrous sulphate, or ferrous bisglycinate [Burden et al., 2015; Sim et al., 2019]. Particularly, athletes with low baseline ferritin levels raise serum ferritin level after 6-16 weeks of supplementation. Ferritin levels frequently increased by 30% to 100% suggesting that iron stores have been successfully restored [Burden et al., 2015; Dellavalle & Haas, 2014]. Athletes with non-anaemic iron deficiency mostly showed increased iron stores without significant haemoglobin alterations. On the other side, improvements in haemoglobin levels were often restricted to athletes in iron-deficiency anaemia. Intravenous (IV) iron treatment has become a viable option for those athletes who have severe iron shortage, poor tolerance to oral supplements [Burden et al., 2015; Steinbicker et al., 2025]. Based on studies [Rubeor et al., 2018], ferritin level increased quickly and significantly after IV treatment than oral supplements. After supplementation, haemoglobin level, transferrin saturation, serum ferritin, and serum iron level all showed improvements, though serum ferritin was the most sensitive indication [Šmid et al., 2024]. Based on the recent findings [Pengelly et al., 2025], replenishing iron stores may also improve iron availability and control by normalizing exercise-induced hepcidin responses (Table 4).

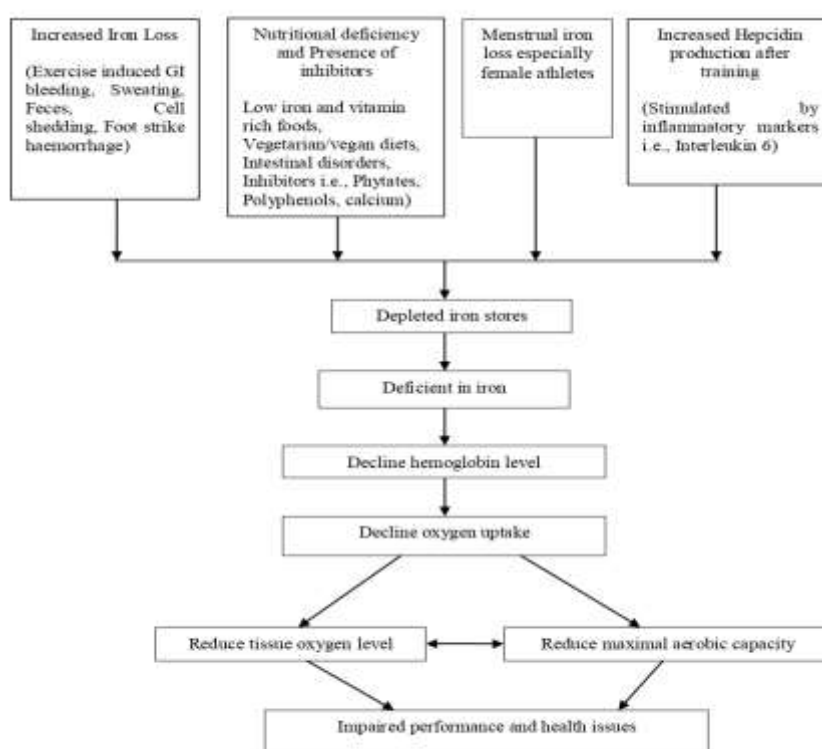


Figure 2: Mechanisms Linking Iron Deficiency, Endurance Performance and Health

Table 5: Performance Implications of Iron Deficiency in Athletes

Reference	Study Population	Dietary Factor Investigated	Study Design / Intervention	Duration	Iron Bioavailability Variables Assessed	Performance Consequences of Iron Deficiency
Dellavalle & Haas, 2014	Iron-depleted female rowers	Oral iron supplementation	Randomized, double-blind, placebo-controlled	6 weeks	Serum ferritin, hemoglobin, soluble transferrin receptor (sTfR), body	Iron supplementation significantly improved iron status and energetic efficiency during submaximal exercise. Improvements occurred even in the absence of anemia, suggesting

			controlled trial		iron stores	that iron depletion can impair exercise economy and endurance performance.
Peeling et al., 2014	Trained athletes (male and female)	Exercise-induced regulation of iron metabolism rather than dietary intervention	Observational study examining post-exercise hepcidin response	Acute (single exercise bout)	Ferritin, serum iron, hepcidin, IL-6	Athletes with higher ferritin concentrations exhibited a greater post-exercise hepcidin response. Elevated hepcidin may reduce iron absorption and recycling, potentially contributing to iron deficiency and impaired training adaptation over time.
Alaunyte et al., 2015	Female athletes	Dietary iron intake, iron-rich foods, vitamin C, iron supplementation	Narrative Review	N/A	Ferritin, hemoglobin, serum iron	Iron deficiency negatively affects aerobic capacity, endurance, and work efficiency. Dietary strategies and supplementation can improve iron status and support exercise performance.
Burden et al., 2015	Iron-deficient non-anemic (IDNA) endurance athletes	Iron treatment (primarily oral supplementation)	Systematic Review and Meta-analysis	Included studies ranged approximately 4–12 weeks	Ferritin, hemoglobin, serum iron, transferrin saturation	Iron treatment improved iron stores and was associated with improved endurance performance, particularly in athletes with low ferritin concentrations. Benefits were most evident before anemia developed.
Solberg & Reikvam, 2023	Athletes from various sports	Iron status and iron supplementation	Narrative Review	N/A	Ferritin, hemoglobin, transferrin saturation, serum iron	Iron deficiency impairs oxygen transport, mitochondrial energy production, endurance capacity, recovery, and cognitive function. Female and endurance athletes are particularly vulnerable. Early detection and treatment are important for maintaining performance.
McKay et al., 2021	Athletes of varying performance calibers (elite to recreational)	Not a dietary study; athlete classification framework	Methodological Framework Paper	N/A	Not applicable	Provides a standardized framework for classifying athletic caliber in sports science studies, facilitating interpretation of performance outcomes across iron-related research.
Manna, 2020	Indian female athletes	Iron status assessment	Cross-sectional study	Single assessment	Hemoglobin, ferritin, hematological indices	A substantial proportion of Indian female athletes exhibited iron deficiency and low iron stores. Poor iron status was associated with reduced physical performance and increased fatigue risk.

McKay et al., 2022	Athletes and sports science research participants	Iron status assessment methodologies	Methodological Review	N/A	Ferritin, hemoglobin, serum iron, transferrin saturation, hepcidin, sTfR	Accurate assessment of iron biomarkers is essential for understanding the relationship between iron status and athletic performance. Standardized methodology improves interpretation of performance effects associated with iron deficiency.
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3.3.6 Performance Implications of Iron Deficiency

Deficiency of iron is linked to several sports specific circumstances in female athletes. Those circumstances are decline aerobic capacity, performance, recovery, training adaptation. Especially in female endurance athletes, low blood ferritin level have been linked to decreased exercise efficiency, endurance capacity and maximum oxygen uptake (VO_{2max}) [Solberg & Reikvam, 2023]. Athletes with low iron stores are often reported feeling exhausted and delaying recovery. Because reduced iron availability may hinder mitochondrial ATP synthesis and oxygen transport, leading to increased perceived effort [Alaunyte et al., 2015]. A number of intervention trials showed that by given supplementation to restore iron status decreased tiredness and enhanced subjective well-being [Burden et al., 2015; Dellavalle & Haas, 2014]. Physiological adaptation to exercise may also be hampered by iron shortage. RBC production, mitochondrial biogenesis, and remodelling of skeletal muscle all are depend on sufficient iron availability. Particularly, during periods of increasing training intensity, chronic iron deficiency may lessen training-induced improvements in aerobic capacity and performance [McKay et al., 2021]. Raised hepcidin levels brought on by exercise may further restrict iron availability, limiting adaptive responses and training the risk of long term shortage [Peeling et al., 2014]. The deficiency of iron effect differs depending on the demands of the sport. **Figure 2** shows how iron deficiency linked with endurance performance and health. Particularly, during periods of increasing training intensity, chronic iron deficiency may lessen training-induced improvements in aerobic capacity and performance [Manna, 2020; McKay et al., 2022] (Table 5).

3.4 Discussion

Due to their greater vulnerability to deficiency of iron and its possible health and athletic performance effects, female football players received special attention. The results show that female athletes had a notable majority of insufficiency of iron. Deficiency of iron with anaemia, on other hand, is less prevalent but is linked to more serious physiological problems and worse performance [Manna, 2020]. Different literature shows that due to their elevated physiological iron requirements and high training demands, female football players and endurance athletes seem to be more vulnerable to iron shortage. Monthly blood loss, insufficient intake of iron in dietary form, and iron losses brought on by exercise all increase this risk [Singha et al., 2026]. Based on latest studies, it has been shown that about 9-60% of female athletes affect in ID, while numbers vary greatly between studies and populations [Pengelly et al., 2025]. As per reported, deficit of iron erythropoiesis is more often than in non-athletic women, accounted the iron status of blood profile. It is most critical evaluation to differentiate of ID and IDA. To detect reduced iron availability of athletes is not only depending on insufficient haemoglobin level, as iron store may short before haemoglobin drops [Singha et al., 2026]. Requirement of iron is not just limited in haemoglobin synthesis and oxygen transport, it is equal important in several activities such as oxidative phosphorylation, cellular energy metabolism, myoglobin function etc. Thus, even before acute anaemia develops, tissue level deficiency of iron is the physiological issue [Alaunyte et al., 2015]. Therefore, the available data point to a trend in which by gradual iron store depletion may follow haematological problems, which in severe cases of athletes may ultimately lead to IDA. Furthermore, the relationship between ferritin level and performance is not always linear, where differences among studies shows that low ferritin level should be taken in together with haemoglobin, transferrin saturation, dietary intake, menstrual loss, training load, and athletic demand instead of isolated marker.

In female athletes, by the interaction of physiological iron requirements, dietary intake, iron loss due to exercise, menstrual blood loss etc. is related with the incidence of ID. As regular monthly blood loss is happened, that is why premenopausal women faced major dietary iron requirement than men. As high training volume is shown in female athletes, this increased

grater iron demands. This is further from adverse balance between iron requirements and iron availability [Alaunyte et al., 2015]. Iron depletion is caused by a number of exercise-related causes, such as increased hepcidin, foot-strike hemolysis, gastrointestinal haemorrhage, and iron loss through perspiration [Fensham et al., 2023]. In addition, due to exercise, hepcidin which is a key regulator of iron metabolism rises 3-6 hours after exercise. This may reduce intestinal iron absorption as well as iron recycling, thereby limit iron availability [Singha et al., 2026]. Nutritional factors like low calorie intake, restricted diets, vegetarian or vegan diet where restricted haem iron etc. may increase the risk. Heavy menstrual bleeding and high training volume are also recognized risk factors for iron deficiency. Therefore, in female athletes iron insufficiency is a complex recognized factor, involving impaired absorption, increased utilization, inadequate dietary intake, and iron losses.

Depending on the level of depletion and presence of anaemia is appeared the performance consequences of iron deficiency (ID). Deficiency of iron with anaemia is more vulnerable for impairing oxygen delivery because it is the reason of reduced haemoglobin level. On the other hand, deficiency of iron without anaemia also responsible for impair of performance because iron dependent cellular functions can be disrupted before haemoglobin declines. Based on systematic review where reported 23 studies involved 669 high-level female athletes from 16 sports. In that review, ID is linked with about 3-4% reduction in performance [Pengelly et al., 2025]. While results for strength and power were less reliable, low iron stores in non-anaemic athletes is the reason for reduced maximal aerobic capacity, fatigue, impaired training quality, and further difficult to take workloads. However, most studies were small and employed a variety of diagnostic criteria. Furthermore, athletes differed in their sports, training background, and histories, so the causal relationship should be interpreted in caution. Female football players deserves special care because repeated high intensity running, strength, power, and workloads etc. involved in football. In prior studies, both ID and IDA have documented in elite female soccer players [Landahl et al., 2005]. However, not all athletes with iron deficiency have measurable performance impairment. Nutritional, psychological, physiological, training related factors etc. all are affecting in individual response and performance.

The review's conclusion has major consequences for care, screening and prevention. For female athletes with frequent menstrual loss, high training volumes, endurance based sports, prior ID, low energy availability, restricted dietary practice etc. a preventive instead of symptom driven approach may be appropriate. Blood iron biomarkers such as haemoglobin, serum ferritin, transferrin saturation etc. are combinable assessed for the detection of ID and IDA. Current general recommendations place strong emphasis on regular monitoring of iron status in female athletes. Moreover, should keep into account such factors like dietary changes, menstrual loss, disordered eating or low energy availability etc. [Bangsbo et al., 2025]. Inadequate energy intake, insufficient dietary intake, poor iron availability and inhibiting or enhancing factors etc., all should be addressed and maintained individualized nutritional management. The timing of tea, coffee, calcium rich foods and other inhibiting foods etc. should be taken into account and maintained regular consumption of iron rich foods with vitamin C rich foods for better iron absorption. Evidence from dietary interventions in female runners suggests that food-based approaches can improve iron status and may represent a useful component of prevention and management [Alaunyte et al., 2014]. Iron supplementation, however, should be targeted to athletes with documented or clinically suspected deficiency and undertaken under appropriate medical or sports-nutrition supervision. Endurance performance and maximal aerobic capacity in ID and IDA female athletes have been said in the current systematic review, but has been considered among studies of dose, route, duration and response [Pengelly et al., 2025]. Athletes whose have adequate iron level, should not use supplementation as it form adverse GI effects and other risks. These results justify in iron-replete athletes. Rather, care need to take for identifying the root cause, correcting dietary inadequacy, increasing iron stores and always monitor haematological reactions.

4. LIMITATIONS

A significant restriction in the research are inconsistent definitions of iron insufficiency, varying ferritin cut-offs value, and insufficient reporting of confounding variables such as menstrual status, food consumption, and energy availability constitute. Particularly in adolescent age groups, specifically in Indian female footballers, due to growth and training demands, few studies have examined iron deficiency.

5. CONCLUSION

The health and performance among female athletes, especially Indian adolescent girls, are seriously harmed by Iron deficiency. Menstrual loss, exercise-induced iron loss, insufficient food intake, and elevated physiological demands are the

major risk factors for iron shortage. Importantly, even in the lack of anemia, preclinical iron shortage can affect training quality. It could also have a detrimental impact on athlete retention and recovery. The prevention and treatment on deficiency of iron depend on the execution of a customized iron-rich meal plan, nutrition education, and routine evaluation of iron biomarkers. Iron supplements can enhance good sports performance and assist restore iron status when needed. Upcoming research should prioritise on extended-term nutritional interventions, standardized iron assessment, and individualized iron-folic acid supplementation to improve iron status, menstrual health, recovery, and performance among adolescent female football players, particularly in India.

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Author Contributions

Pratee Singh: Investigation, Data collection and formal analysis,

Gurjeet Kaur Chawla: Experimental design, Supervision,

Indranil Manna: Experimental design, Writing – original draft, Supervision.

Conflict Of Interest: The authors declare that there is no conflict of interest.

Ethics Statement: Ethical approval was not required for this systematic review as from prior studies the data has been synthesized and also no human participants were involved. This systematic review has been officially registered in the Systematic Reviews with International Prospective Register. (PROSPERO2026; CRD420261422422). Available from <https://www.crd.york.ac.uk/PROSPERO/view/CRD420261422422>

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