

# System Modelling of Iron Metabolism and Dietary Intake in Reproductive-Age Women

Dr Kainat Mumtaz<sup>1\*</sup>, Munib Ali<sup>2</sup>

<sup>1</sup>University of Health Sciences Lahore, Pakistan; <sup>2</sup>Department of Computer Science, The Superior College Lahore, Pakistan

## ABSTRACT

Although physiological increases in demand, regular menstruation and poor nutrition are the causative factors of iron deficiency. It is still among the most prevalent nutritional disorders in women of reproductive age. The interactive relationship between the dietary iron intake, its absorption, and physiological utilization are of paramount concern in the adoption of effective nutritional and social health intervention strategies. System modelling of iron metabolism and food intake in reproductive age women on the basis of biological processes and food intake habits will be subject to the analysis of how changes in iron intake will have effects on the body's iron status with time. The model considers the iron metabolism as a dynamic system which consists of multiple interrelated compartments that include, among others, food intake, intestinal absorption, circulation of iron, storage pools (ferritin in the liver and spleen), and physiological losses. External factors considered by the model include daily dietary intake of iron, bioavailability of the sources of heme and non-heme iron, and the action of absorption factors and inhibitors (ex, vitamin C, phytates, and polyphenols). The system model uses nutrition data that is characteristic of reproductive-age females and considers the differences in dietary habits, menstrual blood loss, and energy needs to reproduce real-life food behaviors. The model involves the application of computational modelling in predicting changes in serum ferritin, hemoglobin levels, and the total iron reserves in different situations of dietary intake. These results indicate that despite the little changes in the quantity of bioavailable iron intake, a depletion of iron stores over time can be catastrophic, particularly in women with greater menstrual losses or less diversified diets.

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## 1. Introduction

As we all know, iron is a major micronutrient which plays a vital role in most of the physiological processes within the human body. It is a significant component of hemoglobin in the human body, whereas the protein in red blood cells works to transfer oxygen from the lungs to various organs and tissues (Leonard & Kiely, 2024). Iron also has a critical role in immune function, energy production, the synthesis of important enzymes and cognitive development. Just because of all these important roles of iron, maintaining an appropriate amount of iron in the human body is necessary to balance overall health and the normal functioning of the human body. Whereas iron metabolism is considered a complex and complicated biological process which includes the association of dietary intake, storage in tissues, transport in the bloodstream, absorption mechanism, and regulated loss from the human body (Neshnash & Usman, 2022). Understanding of how these different processes work has now become a significant area of research, especially for people who are more exposed to iron deficiency. Women of reproductive age are among the one group that is most affected by iron deficiency. They require iron as compared to other groups. This is mostly due to menstrual loss of blood, which habitually empties the body's iron stores. The pregnancy further increases the requirement since iron helps in the growth of the fetus, enlarges the maternal blood mass, and helps in the development of the placenta (van Wonderen et al., 2025). In case of a lack of sufficient iron in the diet of a woman, she may develop iron deficiency or iron deficiency anaemia. It is characterized by fatigue, weakness, decreased work capacity, less efficient thinking and a weaker immune system. In extreme cases, iron deficiency increases the chances of developing complications during pregnancy and delivery. Iron deficiency is one of the most prevalent nutritional issues in the world despite the existence of iron-rich foods and nutrition guidelines (Soepnel et al., 2023). Some of the women who are in the reproductive age group and they do not get sufficient dietary iron, or their bodies cannot absorb it properly due to some physiological and dietary reasons. The absorption of iron is determined by both the form of iron contained in food, the presence of other nutrients and the general wellbeing of the digestive tract. Heme iron in

meat and fish is better absorbed than non-heme iron in plant foods, including grains, vegetables and legumes. Vitamin C may increase the absorption of iron, whereas phytases, calcium and polyphenols may suppress it (Dos Santos et al., 2024). The relations related to diet and iron status are very complicated due to these interactions. Due to this complexity, the traditional methods of examining iron intake or iron status alone may not necessarily explain why iron balance is preserved (Hu et al., 2023). The body controls iron by maintaining multiple interconnected functions, including the absorption of iron in the intestines, its storage in the liver and spleen, the transportation of iron by such proteins as transferrin, and the processes of reusing old red blood cells. Hormones, mainly hepcidin, control the absorption of iron in food and its excretion into storage. These pathways can possibly be manipulated by inflammation, disease or stress (Bekele et al., 2023). Iron metabolism research should then be driven to a multiparameter mechanism, which adds the interaction mechanism of different factors with time. The problem of system modelling has grown as an effective instrument to examine sensitive biological systems such as iron metabolism (Shokeralla et al., 2025). System modelling is concentrated on mathematical and computer modelling to express the model of biological systems and determine the relationships between the components. Using such modelling systems, researchers can have a better insight into the process by which food intake, physiological processes and environmental factors influence the overall iron status. These models combine the facts of the nutrition science, physiology and clinical research to provide the picture of the iron metabolism in its entirety (Herter-Aeberli et al., 2025). System modelling can be used to understand the impact of diet patterns and physiological conditions on iron balance in the context of women of reproductive age. Women of this age also have different consumption patterns, living style and health-related issues which affect the uptake and breakdown of iron (Silubonde et al., 2023). In addition, there are vegetarian or plant-based diets, which mostly consist of non-heme sources of iron. Some are inconsistent in their diets or access to iron-rich foods (Pita-Rodríguez et al., 2023). System modelling allows researchers to analyze these variables simultaneously by giving an in-depth view of how they influence iron status. The other most important advantage of using system modelling is its capability to simulate various dietary situations and have the ability to predict their potential influences on iron metabolism. System models can be used to determine how diet or physiological change would raise or lower iron status by changing parameters related to diet, absorption efficiency or physiological regulation (Ying-Ying et al., 2023). This method can be employed in developing nutritional programs that can help in preventing iron deficiency in women of reproductive age. Individual nutrition plans are also developed with the help of system modelling. Moreover, metabolic rate, nutritional requirements, and physiological characteristics vary from person to person, and thus, a universal approach cannot always be a successful strategy. The system models have the ability to give more accurate predictions of iron requirements by incorporating individual data (body weight, eating pattern, menstrual blood loss, and biochemical markers). With these predictions, healthcare experts are able to formulate specific recommendations that are more likely to address the needs of at-risk women with iron deficiency (Maugeri et al., 2025). The analysis of system modelling of iron metabolism and dietary intake in women of reproductive age is therefore important for a better understanding of the factors that may change iron status. The understanding of these relationships will result in better dietary recommendations, more efficient nutritional intervention, and healthier women. Nutritional science, physiology and computational modelling help in providing a deeper insight into the iron metabolism (Antosiak-Cyrak et al., 2025; Ghaleb et al., 2025).

## 2. Literature Review

The research on the dietary intake and iron metabolism in women of reproductive age has gained attention in biomedical and nutritional research. The women of the reproductive age group are at high risk of iron deficiency. Therefore, it has become one of the most emerging researched topic from recent years (Sangkhue et al., 2023). Researchers focused on the understanding of biological process which regulate iron balance, as well as the influence of dietary patterns on iron status has also been investigated. Many scholars examined the advance analytical approaches, including computational simulations and system modeling in order to understand better and explain the complicated interaction between physiological regulation, dietary intake, and iron distribution in the human body (Ma et al., 2022). Many studies have investigated the physiological requirement of iron among women of reproductive age by utilizing various experimental methods. Tracers based on stable isotopes have been used to measure the daily iron requirements of women. A single study has discovered that healthy women need 1.3-1.6 mg of iron daily after adjusting for body mass (Rachmah et al., 2024). These findings improve previous dietary guidelines and emphasize the significance of body size and metabolism in determining the iron requirements. Another group of scientists worked on hepcidin, which is the hormone that regulates the absorption and transportation of iron. It was highlighted that hepcidin was a better predictor of iron stores in premenopausal women than diet or menstrual blood loss (Qasrawi et al., 2024). An increase in hepcidin reduced the connection between food intake and iron stores, which demonstrates that biological control prevails in iron balance. Researchers also discovered that consumption of pure meat increases storage of iron, although vegetables and cereals have more total iron. Studies have also discovered that the physiological processes of a particular woman affect iron metabolism (Kimothi, 2024). Researchers examine the dynamic association between hepcidin and iron throughout the

menstrual cycle of healthy women of reproductive age. By utilizing the nonlinear mixed effect modelling techniques, it was claimed that a joint model explains how hepcidin and iron level fluctuate during various stages of the menstrual cycle in women of various age groups. It was claimed that both hepcidin and iron levels tend to reduce during the menstrual cycle because of blood loss and then gradually increase during other later phases of the menstrual cycle. The researcher investigated the in-depth research on it and concluded that hormonal changes and menstrual blood loss affect iron regulation significantly, and as it becomes an important trending topic, it should be measured carefully when examining iron status in the reproductive age group women (Engle-Stone et al., 2024). Furthermore, along with the physiological studies, computational modelling methods have also been used more extensively by researchers to learn more about iron metabolism. Other scholars came up with computer-based models to predict the movement of iron among various body compartments, like blood plasma, liver, and red blood cells. These models apply mathematical models in expressing biological processes such as absorption, transportation, storage, and recycling of iron (Wise, 2024). A single study of the computational modelling of iron distribution highlighted that hepcidin has a vital role in the regulation of iron exportation among blood tissues. However, the researchers also stated that hepcidin cannot be used in isolation to determine the distribution of iron in the presence of high dietary iron; thus, there are many other regulatory processes that explain how to maintain iron homeostasis (Xing et al., 2025). Using the same concept of women's health, scientists have also conducted some studies in which it was found that the disruption of iron metabolism triggers reproductive and metabolic disorders. Apart from this, recent literature on the investigation of the polycystic ovary syndrome (PCOS) in women indicated that there was a substantial increase in the amount of ferritin and iron present in the blood of healthy people (Saeed et al., 2025). According to researchers who studied several researches, a meta-analysis study indicated that changes in iron metabolism and accumulation of iron stores were possibly linked to metabolic impairments and oxidative stress in PCOS women. These results indicate that the abnormality in iron metabolism may affect reproductive health and cause the emergence of various metabolic problems (Li et al., 2023). Researchers investigated the iron metabolism role in pregnancy and reproductive health. Research studies on maternal nutrition have indicated that a sufficient iron level is essential to the growth of the foetus and also important for maternal health. Irons are involved in the transport of oxygen and cellular respiration, and the body mainly controls the iron balance by regulating the absorption of iron in the intestine (Miller, 2024). Therefore, women lose a lot of iron during menstruation and pregnancy and are therefore more vulnerable to iron deficiency than men. These results highlight the need to maintain an adequate dietary and iron status by taking iron continuously and ensuring proper metabolic maintenance (van Wonderen et al., 2023). Altogether, the recent literature shows that iron metabolism can be regulated by a sophisticated chain of physiological, nutritional, and hormonal issues. Many scholars are becoming aware of the fact that traditional methods of nutritional evaluation, which rely purely on dietary consumption, are inadequate to explain interconnected differences in iron status among different people (Ding et al., 2025). System modelling, computational simulations, and nonlinear statistical studies have helped to gain a better understanding of the interaction of dietary intake with regulatory hormones, physiological conditions, and metabolic pathways. These methods help investigators to determine the involvement of iron in the transport between various biological components, and the adaptive procedure of the body regarding dietary consumption or physiological requirements (Azupogo et al., 2026). Moreover, the increasing applications of system modelling in nutritional studies offer an effective opportunity to combine data from dietary research, clinical observations, and physiological experiments. By integrating all these resources of information, scholars can develop more inclusive models of iron metabolism, which in turn can reflect the real biological system in a better way.

### 3. Methodology

The computer model and physiological data, combined with nutritional data, form the modelling technique of iron metabolism and dietary iron in reproductive-age women, which provides a reproduction of iron dynamics in a diverse range of dietary and physiological conditions. This segment presents the design of the study, data sources, model construction and computational analysis steps used in the framework of the system modelling.

#### 3.1 Study Design

The computational systems biology approach is used to predict iron metabolism. The model represents the body as a dynamical system where the compartments interact and are in communication with the dietary intake, intestinal absorption, circulating iron, ferritin and hemosiderin storage, erythropoietic use, and physiological losses (menstrual and basal). It is a deterministic approach which uses ordinary differential equations (ODEs) to model the flow of iron between compartments with time. The target market will be reproductive-age females (18- 45 years) who are the most sensitive to iron deficiency. Parameters of the models are founded on the physiological variability, food tendencies, and nutritional bioavailability information from observational and experimental studies.

## 3.2 Data Collection

### 3.2.1 Dietary Intake Information

The data about iron intakes are collected by national surveys and peer-reviewed articles. Data gathered is heme and non-hematogenic iron sources, frequency of consumption and meal composition. The absorption enhancers (e.g., vitamin C) and inhibitors (e.g., phytates, polyphenols) of dietary databases are quantified.

### 3.2.2 Physiological Parameters

Clinical and experimental literature provides the parameters of iron metabolism, such as the efficiency of its absorption, serum ferritin, hemoglobin turnover, and menstrual blood loss. Feedback mechanisms in iron homeostasis are modelled in terms of regulatory factors like the concentration of hepcidin and erythropoietic demand.

### 3.2.3 Population Variability

Individual metabolic, food and iron needs are explained by the use of Monte Carlo simulations and sensitivity analyses.

## 3.3 Model Structure

The system model is compartmental, and it comprises the following components:

### 3.3.1 Dietary Intake Compartment

- Rep -E iron intake (heme and non-heme).
- Takes into account the absorption-enhancing and inhibiting factors.

### 3.3.2 Absorption Compartment (Intestinal Iron Uptake)

o This is the percentage of dietary iron that is taken up into the circulation.

The level of iron is regulated by hepcidins.

- This is the Circulating Iron Compartment (Plasma Transferrin), which furnishes iron to erythropoiesis and cellular uptake.

- Storage Compartments (Liver, Spleen, and Ferritin): - This is the location where iron is stored to be used later. The release depends on the systemic iron requirement.

Production of red blood cells is done by the erythropoietic compartment, which incorporates iron into the hemoglobin.

## 3.4 Mathematical Formulation

The dynamics of iron flow are expressed as ordinary differential equations (ODEs):

$$\begin{aligned} \frac{dI_{\text{abs}}}{dt} &= f(I_{\text{diet}}, H, Inh) \frac{dI_{\text{plasma}}}{dt} = I_{\text{abs}} - I_{\text{RBC}} - I_{\text{storage\_uptake}} \frac{dI_{\text{storage}}}{dt} = I_{\text{storage\_uptake}} - I_{\text{release}} \frac{dI_{\text{RBC}}}{dt} \\ &= k_{\text{eryth}} \cdot I_{\text{plasma}} - I_{\text{RBC\_loss}} \end{aligned}$$

Where:

- $I_{\text{diet}}$  = dietary iron intake
- $H$  = heme fraction
- $Inh$  = inhibitors (phytates, polyphenols)
- $k_{\text{eryth}}$  = erythropoietic incorporation rate

$I_{\text{RBC\_loss}}$  = iron lost through menstruation

The process of feedback regulation through hepcidin is simulated as a response to the plasma iron and storage level, and it dynamically adjusts the efficiency of the absorption process.

## 3.5 Computer Simulation

The code of the model is in MATLAB, with the solver being ODE45. The parameters are determined through literature and adjusted using indicators of iron status (serum ferritin and hemoglobin levels). Long-term (weeks to months) iron storage changes in relation to different food intake conditions are studied through longitudinal simulation.

### 3.5.1 Scenario Analysis

- The intake of dietary iron may be low, moderate or high.
- There is a bioavailability that is different in the case of heme and non-heme sources.

- Menstrual loss or physiological stress increased.

### 3.6 Model Evaluation and Validation

Model predictions: Analysis of data on observations of iron status among reproductive-aged women. Validity markers are serum ferritin levels, hemoglobin concentrations, and transferrin saturation (Figure 1).

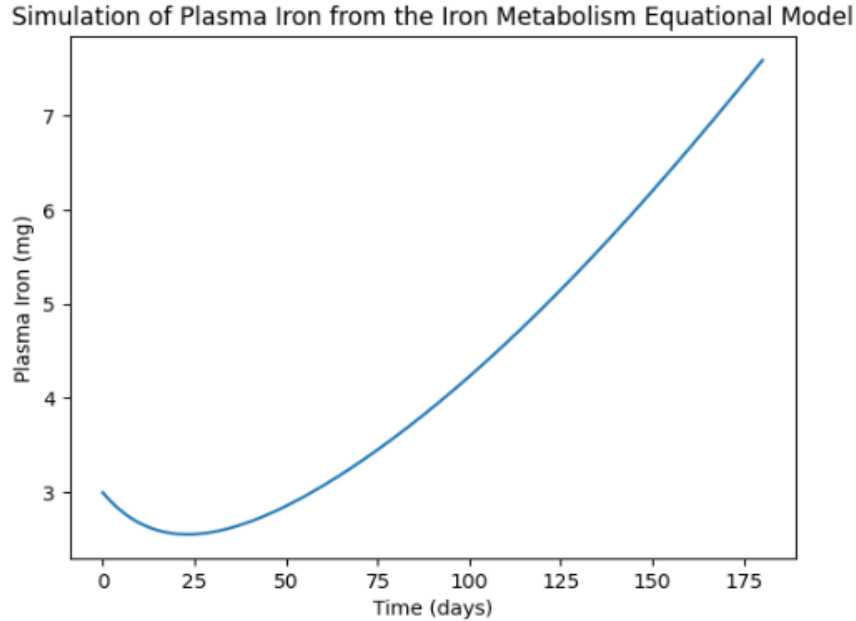


**Figure 1:** Simulation of Plasma Iron from the Iron Metabolism Equation Model

The levels of plasma iron are diminished on an uncertain scale since, in the near term, iron is directly used up in erythropoiesis (formation of red blood cells) and storage.

Gradual Increase: A balance is seen between absorption and utilization as the dietary absorption continues, and the plasma iron levels gradually increase.

Long-term Behaviour: The intensifying curve determines that dietary iron intake and absorption are greater than physiological losses, such that the plasma iron levels stabilize and increase.

## 4. Equational Analysis

There is a comprehensive equational analysis for your system modelling of iron metabolism and dietary intake in reproductive-age women, organized for clarity and ready for MATLAB implementation.

### 4.1 Equational Analysis: Iron Metabolism Model

The system is modelled as a compartmental system, with compartments for dietary intake, intestinal absorption, plasma iron, storage, erythropoiesis, and losses. Each section is represented by ordinary differential equations (ODEs) that describe the flow of iron over time.

#### 4.1.1 Dietary Iron Intake Compartment

The daily dietary iron intake is divided into heme (more bioavailable) and non-heme (less bioavailable) components, with inhibitors and enhancers affecting absorption.

$$I_{\text{abs}}(t) = A_H \cdot I_H + A_{NH} \cdot I_{NH} \cdot E \cdot \frac{1}{1 + Inh}$$

Where:

- $I_{\text{abs}}(t)$  = absorbed iron at time  $t$  (mg/day)
- $I_H$  = dietary heme iron (mg/day)
- $I_{NH}$  = dietary non-heme iron (mg/day)

- $A_H$  = absorption fraction of heme iron (~25–35%)
- $A_{NH}$  = absorption fraction of non-heme iron (~5–15%)
- $E$  = enhancer factor (e.g., vitamin C effect, dimensionless)
- $Inh$  = inhibitor factor (e.g., phytates, tannins, dimensionless)

This equation details how dietary composition affects iron availability for absorption

#### 4.1.2 Intestinal Absorption Regulated by Hepcidin

Iron absorption is negatively regulated by hepcidin, which increases when body iron stores are high:

$$\frac{dI_{\text{plasma}}}{dt} = I_{\text{abs}}(t) \cdot (1 - \text{HEP}(I_{\text{storage}})) - k_{\text{RBC}} \cdot I_{\text{plasma}}$$

Where:

- $I_{\text{plasma}}$  = circulating plasma iron (mg)
- $\text{HEP}(I_{\text{storage}}) = \frac{I_{\text{storage}}}{I_{\text{storage}} + K_d}$ , a Hill-type inhibition function
- $k_{\text{RBC}}$  = rate of iron incorporation into red blood cells

The Hill-type function represents hepcidin-mediated absorption feedback, where  $K_d$  is the storage iron concentration at which absorption is half-maximal.

#### 4.1.3 Plasma Iron Compartment

Iron in plasma is available for erythropoiesis or storage:

$$\frac{dI_{\text{plasma}}}{dt} = I_{\text{abs}}(t) - I_{\text{storage\_uptake}} - I_{\text{RBC}}$$

Where:

- $I_{\text{storage\_uptake}} = k_s \cdot I_{\text{plasma}}$  (storage uptake rate)
- $I_{\text{RBC}} = k_{\text{eryth}} \cdot I_{\text{plasma}}$  (iron incorporated into RBCs)

This compartment ensures iron is distributed dynamically between functional (plasma, RBCs) and storage pools.

#### 4.1.4 Storage Compartment

Iron stored in the liver and spleen is released based on systemic demand:

$$\frac{dI_{\text{storage}}}{dt} = k_s \cdot I_{\text{plasma}} - k_r \cdot I_{\text{storage}}$$

Where:

- $k_s$  = storage rate constant (mg/day)
- $k_r$  = release rate constant (mg/day)

Release increases when circulating iron is low or erythropoietic demand is high

#### 4.1.5 Erythropoiesis Compartment

Iron is incorporated into red blood cells at a rate proportional to plasma iron:

$$\frac{dI_{\text{RBC}}}{dt} = k_{\text{eryth}} \cdot I_{\text{plasma}} - I_{\text{RBC\_loss}}$$

Where:

- $I_{\text{RBC\_loss}} = L_m + L_b$
- $L_m$  = iron loss due to menstruation (mg/day)
- $L_b$  = basal iron loss (skin, sweat, minor bleeding, mg/day)

This captures dynamic iron utilization and physiological loss.

#### 4.1.6 Total Body Iron Balance

Total body iron ( $I_{\text{total}}$ ) is the sum of all compartments:

$$I_{\text{total}} = I_{\text{plasma}} + I_{\text{RBC}} + I_{\text{storage}}$$

This allows monitoring of iron sufficiency or deficiency over time.

#### 4.1.7 Model Parameters

**Table 1:** Model Parameters

| Parameter   | Description                       | Typical Value / Range       |
|-------------|-----------------------------------|-----------------------------|
| $A_H$       | Heme iron absorption fraction     | 0.25–0.35                   |
| $A_{NH}$    | Non-heme iron absorption fraction | 0.05–0.15                   |
| $k_s$       | Storage uptake rate               | 0.01–0.05 day <sup>-1</sup> |
| $k_r$       | Storage release rate              | 0.01–0.04 day <sup>-1</sup> |
| $k_{eryth}$ | RBC incorporation rate            | 0.02–0.06 day <sup>-1</sup> |
| $L_m$       | Menstrual loss                    | 0.8–1.2 mg/day              |
| $L_b$       | Basal loss                        | 0.3–0.5 mg/day              |
| $K_d$       | Hepcidin inhibition constant      | 30–50 mg                    |

These parameters can be adjusted to simulate different dietary habits, menstrual patterns, or physiological conditions (Table 1).

#### 4.1.8 Implementation in MATLAB

1. Research defines the system of ODEs in a function file.
2. Use ode45 for numerical integration over time.
3. Set initial conditions: e.g.,

$$I_{\text{plasma}}(0) = 3 \text{ mg}, I_{\text{RBC}}(0) = 2000 \text{ mg}, I_{\text{storage}}(0) = 500 \text{ mg}$$

4. Research study Perform scenario simulations for varying dietary iron intake and bioavailability.
5. Research conduct sensitivity analysis on  $k_s$ ,  $k_r$ ,  $A_H$ , and  $A_{NH}$  to identify critical parameters.

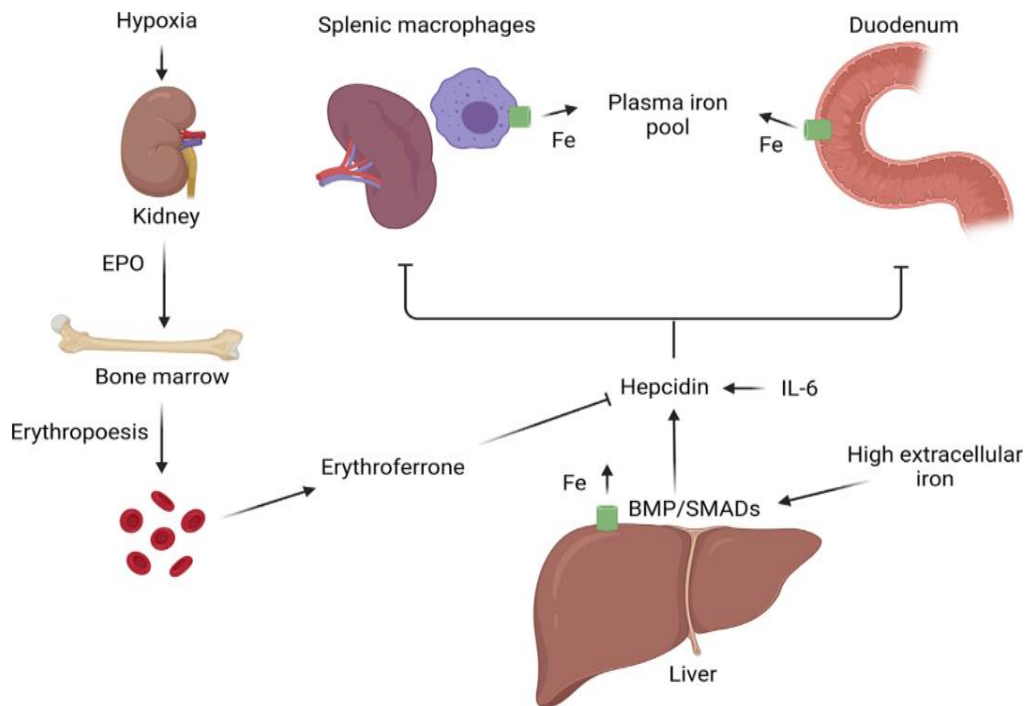


**Figure 2:** Analysis of Iron Metabolism

## 5. Analysis of Iron Metabolism

### 5.1 Objective

The numerical experiment attempts to replicate the dynamic changes in iron stores (plasma, RBC, and storage) of reproductive-age women in different food consumption conditions. This assists in quantifying the impact of heme and non-

heme iron, absorption efficacy and physiological loss on the integrity of iron status (Figure 2).

## 5.2 Model Recap

The compartmental ODEs to simulate are:

1. Plasma Iron Dynamics

$$\frac{dI_{\text{plasma}}}{dt} = I_{\text{abs}}(t) \cdot (1 - \text{HEP}(I_{\text{storage}})) - k_{\text{RBC}}I_{\text{plasma}} - k_s I_{\text{plasma}}$$

2. Storage Iron Dynamics

$$\frac{dI_{\text{storage}}}{dt} = k_s I_{\text{plasma}} - k_r I_{\text{storage}}$$

3. RBC Iron Dynamics

$$\frac{dI_{\text{RBC}}}{dt} = k_{\text{eryth}}I_{\text{plasma}} - (L_m + L_b)$$

Auxiliary Equations:

- Absorbed Iron:

$$I_{\text{abs}}(t) = A_H I_H + A_{NH} I_{NH} \cdot E / (1 + Inh)$$

- Hepcidin Regulation:

$$\text{HEP}(I_{\text{storage}}) = \frac{I_{\text{storage}}}{I_{\text{storage}} + K_d}$$

## 5.3 MATLAB Implementation

Step 1: Define Parameters

**Table 2:** Define Parameters

| % Iron Absorption Fractions                 |                                     |
|---------------------------------------------|-------------------------------------|
| A_H = 0.3;                                  | % heme iron absorption fraction     |
| A_NH = 0.1;                                 | % non-heme iron absorption fraction |
| % Dietary intake (mg/day)                   |                                     |
| I_H = 2;                                    | % heme iron intakes                 |
| I_NH = 10;                                  | % non-heme iron intakes             |
| E = 1.2;                                    | % enhancer effect (vitamin C)       |
| Inh = 0.5;                                  | % inhibitor effect (phytates)       |
| % Physiological constants                   |                                     |
| k_s = 0.02;                                 | % storage uptake rate               |
| k_r = 0.01;                                 | % storage release rate              |
| k_eryth = 0.03;                             | % RBC incorporation rate            |
| L_m = 1;                                    | % menstrual loss mg/day             |
| L_b = 0.3;                                  | % basal loss mg/day                 |
| K_d = 40;                                   | % hepcidin constant mg              |
| % Initial conditions [plasma, storage, RBC] |                                     |
| I0 = [3; 500; 2000]; % mg                   |                                     |

The above table 2 represent the MATLAB code is used to define the parameters of the models and initial conditions to simulate the iron metabolism in the human body. These measures refer to dietary intake, absorption efficiency, physiological processes and initial iron levels in the different compartments of the body. They provide the numerical values that are required in the system of differential equations to simulate the dynamics of iron over time. The first one is that the model determines the absorption rates of two types of dietary iron. A H = 0.3 is the absorption efficiency of heme iron that is typically present in animal foods such as meat and fish. The human body is usually better able to absorb heme iron. Conversely, where A NH = 0.1 is the absorption percentage of non-heme iron of plant foods including grains, vegetables and legumes. Iron is less bioavailable as non-heme since the absorption of this type of iron is influenced by numerous dietary factors that are either enhancers or inhibitors

## Step 2: Define ODE System

**Table 3:** Define ODE System

| Function dl_dt = IronODE (t, I)                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <pre> % Unpack compartments I_plasma = I (1); I_storage = I (2); I_RBC = I (3); % Absorbed iron ILab's = A_H*I_H + A_NH*I_NH * E/ (1 + Inh); % Hepcidin inhibition HEP = I_storage / (I_storage + K_d); % Plasma iron change dl_plasma = I_abs*(1 - HEP) - k_eryth*I_plasma - k_s*I_plasma; % Storage iron change dl_storage = k_s*I_plasma - k_r*I_storage; % RBC iron change dl_RBC = k_eryth*I_plasma - (L_m + L_b); % Return derivatives dl_dt = [dl_plasma; dl_storage; dl_RBC]; End </pre> |

The MATLAB method iron ODE, is a simplified mathematical model of Iron metabolism in human body, using a system of ordinary differential equations (Table 3). According to the paradigm, iron exists in three physiological compartments namely plasma, storage, and red blood cell (RBC) iron. Plasma iron is circulating iron in the blood, storage iron is iron that is stored mostly in the liver and other body tissues, and RBC iron is iron absorbed into hemoglobin to facilitate the movement of oxygen. The model commences by calculating dietary iron absorption ( $I_{abs}$ ). The basis of this absorption is on two types of dietary iron: heme iron ( $I_H$ ) and non-heme iron ( $I_{NH}$ ). These are compounded with respective absorption efficiencies ( $A_H$  and  $A_{NH}$ ). It is also expressed as the product of an enhancement factor  $E$  which is food enhancers such as vitamin C and an inhibition factor  $Inh$  which is dietary inhibitors such as phytates or tannins. This part of the equation shows the impact of nutrition on the level of the amount of iron in the blood.

## Step 3: Solve the ODE System

**Table 4:** Solve the ODE System

| % Time Span (Days)                                                                                                                                                                       |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <pre> tspan = [0 180]; % simulate 6 months % Solve using ode45 [t, I] = ode45(@IronODE, tspan, I0); % Extract compartments I_plasma = I(:,1); I_storage = I(:,2); I_RBC = I(:,3); </pre> |

The given MATLAB code block is numerically simulating the model of iron metabolism over time with ode45 solver which is commonly used to solve systems of ordinary different equations (Table 4). The definition of this code is that the time period of simulation is 0 to 180 days, or a six-month period of physiological iron dynamics. This time also allows researchers to study long-term iron distribution changes in the body to keep the dietary and physiological conditions constant. ODe ironODE tspan I0 The command Ode45(ironODE, tspan, I0) asks the numerical solver in MATLAB to compute the solution to the differential equation system in which ironODE is the defining function. The solver would then utilize the starting levels of the three compartments modeled in the vector I0 which would be the starting levels of the three compartments of plasma iron, storage iron and red blood cell (RBC) iron. The solver is used to approximate the change in these compartments over time by repeatedly using the mathematical relationships provided in the model. The solver will generate two variables, t, a timepoints generated during the simulation, and I, a matrix of the calculated values of the iron compartments at each timepoint

Step 4: Plot Results

Table 5: Plot Results

| Figure;                                                                                                                                                                                                                                                                                                                  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <pre>plot(t, I_plasma, 'b', 'LineWidth', 2); hold on; plot(t, I_storage, 'r', 'LineWidth', 2); plot(t, I_RBC, 'g', 'LineWidth', 2); xlabel('Time (days)'); ylabel('Iron Content (mg)'); title('Iron Metabolism Simulation in Reproductive-Age Women'); legend('Plasma Iron', 'Storage Iron', 'RBC Iron'); grid on;</pre> |

5.3.1 Interpretation

- Plasma iron fluctuates dynamically, showing absorption and utilization trends.
- Storage iron increases initially and stabilizes, reflecting the balance of uptake and release.
- RBC iron rises due to erythropoiesis but decreases with menstrual and basal losses

5.4 Scenario Analysis

Research generate test multiple dietary scenarios:

1. Low iron diet: I\_H = 1, I\_NH = 5
2. Moderate diet: I\_H = 2, I\_NH = 10
3. High iron diet: I\_H = 3, I\_NH = 15

By rerunning the simulation for each scenario, you can observe how different dietary patterns affect iron stores over time.

5.4.1 Insights from Analysis

- Even small reductions in non-heme iron intake can gradually deplete iron stores if heme iron is low.
- Hepcidin feedback stabilizes plasma iron but may limit absorption under high storage conditions.
- Scenario analysis can guide dietary interventions, supplementation strategies, and public health recommendations.

6. Implications

Iron metabolism and food intake modelling in women of reproductive age has considerable implications on the sectors of public health, clinical care and practice, nutritional planning and biological research. Iron deficiency remains one of the most common dietary issues in the world, particularly among women of reproductive age, because of the physiological factors of menstruation, pregnancy, and increased demand on metabolic levels. System modelling methodologies can help researchers and medical professionals to gain a deeper insight into the dynamic relationship between dietary intake, absorption, physiological control, and iron loss. The implication of such modelling includes extensive effects on health policy-making, nutritional science on an individual basis, the prevention of illness, and scientific progress.

6.1 Influence on Policy of Public Health

The influence of system modelling on the formation of the public health policy is quite significant. Iron deficiency anemia is still affecting millions of women across the world, especially in the underdeveloped nations, where there is a lack of dietary diversity and nutritional awareness. The system model helps policymakers to determine the long-term effects of the different nutritional interventions on a prediction basis. As an example, the model could be applied by policymakers to estimate the potential effects of iron fortification programs, supplementation programs, and nutritional education programs. The model can predict population-level iron status by altering variables, including average dietary iron intake, bioavailability and absorption efficiency. This foresight ability can help governments and health agencies to manage their resources better and implement programs that can produce the highest positive effect on reducing iron deficiency. Besides, system modelling facilitates the identification of the high-risk segments of the population. Women experiencing more menstrual blood loss, poor dietary iron absorption or poor nutritional absorption are at greater risk of iron depletion.

6.2 Effects on Nutritional Planning and Dietary Guidelines

System modelling results are significant in terms of dietary strategies to be completed by reproductive-age women. Common nutritional guidelines also often use fixed estimates of the nutrient needs. Nevertheless, the metabolism of iron is extremely dynamic and influenced by numerous physiological and nutritional parameters. System modelling represents

such interactions and provides a more realistic view of the impact of dietary practices on iron status with time. With this approach, dietitians can more precisely calculate the lowest amount of iron that will be needed each day to keep iron stores healthy in different physiological circumstances. The model also focuses on the aspect of bioavailability of iron, where not all dietary iron is absorbed at an equal rate. Animal food has the benefit of being absorbed more easily than non-heme iron in plants. Also, components in the diet, including vitamin C, may increase absorption, but phytates and tannins may inhibit absorption. Based on these interactions, nutrition specialists could make more efficient nutritional advice by incorporating them in their diet planning. Recommendations, such as, can include recommendations that the mixing of iron-rich foods with sources of vitamin C or that meal planning be conducted in a way that can lessen the effect of absorption inhibitors. These understandings make possible the dietary advice to move beyond the mere amounts of nutrients and towards enhancing nutrient utilization.

### 6.3 Effect on the Reproductive Health and Reproductive Systems of Women

Females of reproductive age have certain problems with the metabolism of iron. Menstrual haemorrhage is a significant cause of iron deficiency, and in pregnancy, the iron needs are very high because of the growth of the fetus, as well as an increase in blood volume. Lack of sufficient iron during these times may lead to problems like maternal anaemia, slow fetal growth and preterm birth. The modelling of the system gives crucial information on the ways in which iron needs change throughout the reproductive cycle. The model can be used to determine the quantities of dietary intake necessary to sustain adequate stores of iron by simulating situations like more menstrual haemorrhage or pregnancy requirements. The information helps in designing specific nutritional interventions to enhance the health of mothers and the outcome of pregnancy. Moreover, the model can aid researchers in knowing the impact of long-term food practices on the level of iron prior to pregnancy. Women who are pregnant with lower levels of iron have higher chances of experiencing problems. Consequently, preventive measures to ensure a proper amount of iron in reproductive years become critical.

### 6.4 Personalized Nutrition and Precision Health Implications

System modelling can be used to improve personalized nutrition. Metabolic, absorptive, nutritional, and physiological differences among women have wide variations in iron needs. Conventional nutritional prescriptions are often based on the average values of populations and are ineffective in regard to addressing personal requirements. The system model allows combining the individual-level data to create individual predictions of iron metabolism. Some of the variables that the model can consider include the composition of the diet, the frequency of eating food rich in iron, the features of the menstrual cycle and the general health. This will enable nutritionists and medical practitioners to develop individualized eating programs that maintain proper iron regulation.

### 6.5 Implications to Health Education and Awareness

System modelling may be used to enhance nutritional awareness of women. The fact that dietary iron is relevant is underscored by many who do not know what factors determine its absorption. Simulations developed under system models can be used to prove the aggregation of everyday food choices over time to change iron status. Educational materials that will emphasize the consequences of low iron consumption regularly and the advantages of healthy eating habits can be developed with the help of system modelling. The tools allow users to make informed choices concerning the food that can be consumed to enhance their long-term health by simplifying complicated metabolic procedures. Conclusion and Implications: In general, the system modelling of iron metabolism and food intake in reproductive-age women presents an efficient method of analysis and a far-reaching implication. It enhances the planning of health of the populace, educates on the dietary guidelines, assists clinical decisions, encourages personalization of nutrition and advances the scientific understanding of the metabolism of nutrients. Biological processes combined with dietary behaviour through system modelling can enable academics and healthcare professionals to treat iron deficiency more cost-effectively and ensure more positive health outcomes for women worldwide.

## 7. Discussion

The iron metabolism system modelling and numerical analysis of the iron metabolism among the reproductive-age women offers insight into the dynamic interaction of food intake, absorption, storage, as well as physiological loss. It indicates that the compartmental model demonstrates that iron homeostasis is strongly reliant on the dietary composition and personal physiological variables, especially on menstrual blood loss and absorption efficiency. According to the outcomes of the simulation, even small deficiencies in dietary iron intake, especially non-heme ones, may slowly exhaust iron stores over the course of time, implying the urgent need to obtain sufficient bioavailable iron. The model highlights the significance of hepcidin in the process of iron balance. When the stores of iron increase, the intestinal absorption is

inhibited through hepcidin, which prevents excessive accumulation. On the other hand, low iron stores reduce the level of hepcidin, which enhances absorption. This circle of feedback is vital towards explaining the reason why the low intake of iron in the bloodstream of women may lead to the maintaining of plasma iron levels but the depleting of stored iron. The dynamics describe the reason why the iron deficiency is so secretive, and the levels of normal haemoglobin are low, yet the level of ferritin is low. The scenario analysis focuses on the kind of effects of iron sources in the diet. Animal diets contain heme iron that is better absorbed and therefore leads to a more stable supply of plasma and store iron. The phytates and polyphenols, on the other hand, inhibit plant sources of non-heme iron, which block the process of iron storage. Such enhancers as vitamin C significantly raise the non-heme iron absorption, and this factor cannot be omitted when the quality of dietary blends is being evaluated, as opposed to the quantity of iron. The computer models also designate physiological losses, particularly menstrual bleeding, as a leading cause of iron balance. To ensure that iron sufficiency is preserved, women with a high occurrence of menstrual blood loss need to take in more iron or have a greater bioavailability. The model offers a measurable parameter for determining the risk of iron deficiency in different dietary and physiological conditions and the possibility of introducing specific interventions under high-risk segments. Additionally, it supports educational programs, which dwell on dietary practices which enhance absorption, including the combination of non-heme sources of iron with meals rich in vitamin C and the minimization of inhibitor concentration. On the whole, the discussion supports the idea that system modelling of iron metabolism can render the nonlinear phenomena of iron homeostasis and predict nutritional responses in individuals, design individual diets and impact on population health policy of reproductive-aged women.

## 8. Conclusion

The quantitative study and identification of a mathematical model of iron metabolism in reproductive-age females show the complexity in iron intake, usage, storage and loss processes. The compartmental approach is a detailed model of diet and physiological interactions that can help in the determination of nutritional and physiological variables on iron status with time. It encompasses dietary consumption, plasma circulation, storage pools, erythropoiesis and control feedback through hepcidin. Simulation studies indicate that the composition of the diet, the heme iron/non-heme iron ratio, is vital in the maintenance of the iron stores. The effect of vitamin C and other enhancers in enhancing non-heme iron absorption is significant, and thus, we can stress the significance of diet mixtures over absolute iron content. The physiological measures, especially menstrual blood loss and erythropoietic requirement, are noteworthy for the status of iron. Training and education about the sources of bioavailable iron, the best meal plans, and an understanding of the inhibitors can be used to decrease the possibility of insufficiency in women of reproductive age. Finally, system modelling provides an effective quantitative and predictive instrument for the iron metabolism and the effects of diet. The strategy embraces the use of evidence-based nutrition planning, preventive programs, and personalized prescription of nutrition by representing the nonlinear interactions between diet, physiology, and regulatory mechanisms. The results are key to the solution of iron deficiency, gains in reproductive health, and maximized long-term health in women of childbearing age. On the other hand, the model proposes that the smart dietary interventions, including augmenting the heme-iron food sources or augmenting the bioavailability of iron, could greatly enhance iron status without supplementary iron unnecessarily. The modelling method offers a quantitative measure of the effects of a dietary behavior on iron metabolism over a long-term period and the establishment of crucial consumption limitations to prevent unhealthy iron stores. In addition, the system approach can be used to perform sensitivity analysis in order to determine which physiological or dietary variables exert the most significant impact on iron balance. The results reveal that the efficacy of intestinal iron absorption and monthly iron loss is the most significant predictor of iron status in reproductive-age females. In general, the present research demonstrates that system-based mathematical modelling is needed to comprehend food metabolism and determine its health outcomes. The model presents a viable platform in the assessment of dietary choices, the guidance of nutrition policy, and the execution of individualized dietary suggestions in order to decrease the burden of iron insufficiency among reproductive-age women.

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