

# **Nourishing in Phases: A Guide to Nutrition Throughout The Menstrual Cycle**

Honors Thesis

Presented in Partial Fulfillment of the Requirements of the University Honors Program

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Spring 2026

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## **Abstract**

The menstrual cycle is a monthly process in which hormonal changes occur across four distinct phases with the purpose of preparing the female body for potential pregnancy. As a result of fluctuating hormone levels, females experience various physiological, psychological, and behavioral changes across each cycle, impacting nutrition needs. However, although some research and education exists on the menstrual cycle, it is still limited, often leading females to feel at a loss for understanding how to support their bodies. This thesis aims to investigate the link between nutrition and menstrual health, helping to provide females with a guideline for utilizing nutrition for enhanced health, performance, and well-being during all phases of the menstrual cycle. In order to do so, this paper reviews existing literature to identify effective nutrition interventions for supporting the female body through the menstrual cycle. The findings reflect that, to support hormonal fluctuations and associated symptoms during each phase, helpful nutrients to focus on include: iron, vitamin C, and magnesium in the menses phase; higher complex carbohydrate intake, fiber, and zinc during the follicular phase; calcium, vitamin D, and selenium during the ovulatory phase; and vitamin B6, omega-3 fatty acids, and vitamin E during the luteal phase. An important consideration to note is that several of the nutrients have crossover between phases, serving important functions throughout the entire menstrual cycle; however, for the purpose of this paper, the nutrients were considered separately and are to be used to accommodate specific hormone fluctuations. The goal of this thesis is to support increased awareness and understanding about how the menstrual cycle impacts health and nutrition, which, although it is a field starting to gain attention, is still underresearched and undereducated on.

## **Introduction**

I designed and wrote this thesis because of my combined passions for women's health, the power of nutrition, and my love of cooking. Due to personal challenges with proper fueling, hormone health, and a misunderstanding of the menstrual cycle, I wanted to research this topic to not only deepen my understanding of my own body, but also to help other women and girls who may be struggling as I once did. In my experience, I learned about how powerful nutrition is for healing and energizing activities of daily life, therefore I wanted to combine the two in order to provide a resource to help other women feel their healthiest and happiest during the entirety of their menstrual cycle.

## **Background**

Historically, nutrition and biomedical research has largely been centered on male physiology, often overlooking the impact of the menstrual cycle and its associated hormonal changes. In fact, females were not included in clinical research until 1993, resulting in a gap in understanding of female physiology (National Institutes of Health, 2017). As a result, dietary recommendations often fail to accommodate for how fluctuating hormone levels induce physiological and psychological changes during certain times of the month, impacting metabolic processes, energy levels, nutrient needs and utilization, and more. Understanding these changes can help promote enhanced health and well-being by shifting nutrient considerations to support the body's fluctuating needs.

To start, it is helpful to understand a general overview of the menstrual cycle. The menstrual cycle is a monthly process in which the female body prepares for ovulation and pregnancy. Unlike males, who have a 24-hour diurnal hormone cycle, the female hormonal rhythm occurs across 28-35 days in a normal cycle, and is characterized by coordinated

variations in hormone concentrations (Thiyagarajan et al., 2024). The menstrual cycle is commonly divided into four phases: the menses phase, follicular phase, ovulatory phase, and luteal phase. The first phase of the menstrual cycle – the menses phase – starts on the first day of bleeding and ends when bleeding terminates. Estrogen and progesterone concentrations are low, and towards the end of the menses phase, luteinizing hormone and follicle stimulating hormone begin to rise. At the end of the menses phase, estrogen levels rise, marking the beginning of the follicular phase. As estrogen rises, FSH levels drop as the mature follicle develops, holding the egg that is used in case of fertilization. Next, estrogen and LH levels surge, reaching peak concentrations that characterize the ovulatory phase. With peak estrogen and LH levels, the egg is released into the fallopian tube for fertilization. After ovulation, estrogen levels drop and progesterone levels rise sharply, marking the beginning of the luteal phase. Rises in progesterone cause the endometrium to thicken, and during the mid-luteal phase, estrogen also rises slightly, both of which encourage the formation of a suitable environment for the fertilized egg to attach. This also supports the beginning of a healthy pregnancy. If the egg is not fertilized, estrogen and progesterone levels plummet and the endometrial lining is shed, restarting the menstrual cycle.

The menstrual cycle is not only important to understand for reproductive health, but also as a critical indicator of general health. Regular menstrual cycles are an important indicator that metabolic, endocrine, and nutritional factors are working synergistically and functioning well, displaying the integration of the menstrual cycle with every aspect of physiological health. On the other hand, menstrual cycle disturbances, such as amenorrhea, heavy bleeding, irregular cycles, and anovulatory cycles, can all be signals from the body that there are other underlying stressors and health issues.

For example, amenorrhea, or the absence of menstruation, can be an indicator of Relative Energy Deficiency in Sport (RED-S), a common condition among female athletes. RED-S is characterized by the combination of low energy availability with intense or excessive exercise that results in menstrual cycle disturbances and impaired bone health (Grabia et al., 2024). Females who experience RED-S are commonly diagnosed with functional hypothalamic amenorrhea (FHA), which is the absence of menstruation due to suppression or inadequate stimulation of the hypothalamic-pituitary-ovarian axis (HPO) (Saadedine et al., 2023). The HPO axis is crucial for regulating hormone pulsations required for proper ovulation, especially the hormone gonadotropin-releasing hormone (GnRH) and luteinizing hormone (LH). When the HPO axis is disturbed, GnRH and LH cannot be released to stimulate proper maturation of the follicle, perform ovulation, and regulate the hormones estrogen and progesterone, causing a lack of ovulation and menstrual cycle disturbances (Saadedine et al., 2023). This is usually triggered by psychological stress, inadequate calorie intake, excessive exercise, or a combination of the three (Saadedine et al., 2023). FHA can be treated through addressing the root cause, typically involving increasing energy intake and lowering stress levels. However, if left untreated, the absence of menstruation can lead to various long-term health consequences, including low bone-mineral density, increased risks of mental health disorders, such as anxiety, depression, and eating disorders, a higher risk of cardiovascular disease, and infertility (Saadedine et al., 2023). This is due to how crucial hormones regulated by the HPO axis, such as estrogen, are for coordinating body systems and maintaining proper function of the body as a whole.

FHA as a result of RED-S is just one example of how crucial the menstrual cycle is as an indicator of overall health. Disturbances of the menstrual cycle can be a signal of numerous underlying causes, such as diabetes, endocrine disorders, infection, thyroid dysfunction, sexually

transmitted diseases, Cushing's disease, and more (National Institutes of Health, 2017). With the various underlying conditions of menstrual cycle dysfunction combined with the long-term consequences of irregular menstruation, it is crucial that the importance of maintaining menstrual cycle function is taught, understood, and focused on.

## **Terms and Definitions**

Defining the hormones and their functions that drive the menstrual cycle are critical for understanding their impact on female physiology and changes in nutrition needs. Therefore, this section serves to provide a general understanding of the basic hormones that fluctuate throughout the menstrual cycle.

- **Estrogen:** a type of sex hormone produced primarily by the ovaries in females. It plays a major role in sexual development and pregnancy, but it also is crucial for other functions, such as maintaining bone health, promoting skin elasticity, serotonin regulation, improving cognitive function, and menstrual cycle regulation (Hamilton et al., 2017).
- **Progesterone:** a type of sex hormone produced by the adrenal cortex and ovaries. Its largest function is for maintaining pregnancy by preparing the endometrium, but it also plays an important role in regulating the menstrual cycle, maintaining bone health, myelin proliferation, and preparing breast tissue for lactation (Cable & Grider, 2023).
- **Hypothalamic-pituitary-ovarian axis (HPO):** a complex feedback mechanism that regulates hormones necessary for menstruation and ovulation through the coordination of the hypothalamus, pituitary gland, and ovaries (Mikhael et al., 2019)
- **Gonadotropin-releasing hormone (GnRH):** a peptide hormone produced by the hypothalamus that is the central regulator of the HPO axis. The main role of GnRH is to act on the pituitary gland to release FSH and LH, which are used to stimulate ovulation. It

also plays a crucial role in puberty by stimulating the growth and maturation of reproductive organs and the promotes release of estrogen and progesterone (Casteel & Singh, 2023).

- **Luteinizing hormone (LH):** a glycoprotein hormone stimulated by GnRH that plays a crucial role in the HPO axis. Its main role is to stimulate ovulation by releasing the egg from the mature follicle, but it also stimulates the release of progesterone after ovulation to support pregnancy (Nedresky & Singh, 2020).
- **Follicle-stimulating hormone (FSH):** a glycoprotein hormone stimulated by GnRH and released from the anterior pituitary gland. The main role of FSH is the maturation of ovarian follicles, which hold the egg used for fertilization. It also plays a crucial role in estrogen production (Orlowski & Sarao, 2023).
- **Endometrial/uterine lining:** a mucous membrane that acts as the inner lining of the uterus. Its main functions are to prepare a suitable environment for a fertilized egg to be implanted and maintain pregnancy if the egg is attached. If not, this is the tissue shed when monthly bleeding occurs (Critchley et al., 2020). Throughout this thesis, the terms “endometrium,” “endometrial lining,” and “uterine lining” are used interchangeably.
- **Granulosa cells:** cells within the ovary that communicate with the egg and surrounding cells to produce estrogen and stimulate follicle growth (Schütz & Batalha, 2024).
- **Theca cells:** cells within the ovary that act in response to LH. These cells support estrogen production, provide structural integrity to ovarian follicles, maintain blood supply to the follicles, and contribute to the formation of the corpus luteum (Magoffin, 2005).

## **Methods**

The research section of this thesis was performed as a narrative literature review to examine phase-specific physiological and psychological changes that occur due to hormone fluctuations, nutritional considerations across the menstrual cycle, and hormonal mechanisms. Peer-reviewed literature was identified through electronic databases including PubMed, NIH, and Google Scholar. Search terms included combinations of menstrual cycle, follicular phase, ovulatory phase, luteal phase, micronutrients, macronutrient metabolism, estrogen, and progesterone.

Articles were included if they addressed hormonal regulation of the menstrual cycle, specific functions and mechanisms of hormones, and/or nutritional factors influencing reproductive and metabolic function in women of reproductive age. Priority was given to human studies, review articles, and recent publications relevant to nutrition and physiology. Findings were synthesized and organized by menstrual cycle phase and health context to identify recurring themes and relationships between hormonal fluctuations, nutritional needs, and menstrual cycle function.

## **The Menses Phase**

The first phase of the menstrual cycle is the menses phase, marked by the first day to the last day of bleeding. With the absence of pregnancy, the corpus luteum, a collection of cells formed on the ovary to produce estrogen and progesterone for a healthy pregnancy, is broken down (Cleveland Clinic, 2021). This leads to a sharp drop in concentrations of the hormones estrogen and progesterone, triggering the endometrial lining to shed. Shedding of the endometrial lining is what causes bleeding, which lasts between 3 and 7 days in a healthy menstrual cycle

(Thiyagarajan et al., 2024). Furthermore, GnRH, a reproduction hormone, stimulates rising concentrations of luteinizing hormone (LH) and follicle stimulating hormone (FSH) (Bischof, 2024). LH and FSH stimulate the growth of ovarian follicles, which are small sacs containing immature eggs necessary for fertilization (UCSF Health, 2019). For many women, abdominal cramping accompanies the beginning of the menstrual cycle due to hormonelike substances called prostaglandins. Prostaglandins are involved with pain and inflammation, and they trigger the uterus to contract, which allows uterine lining to be shed (Mayo Clinic, 2022). Furthermore, increased inflammation is associated with the menstrual cycle as breakdown of the endometrium occurs. First, progesterone has many anti-inflammatory properties, and its low levels initiate a sequence of inflammatory processes within the endometrium. One of these processes is a loss of protection from reactive oxygen species (ROS), and increased ROS results in release of NFκB (Evans & Salamonsen, 2012). There is also increased activation and synthesis of pro-inflammatory prostaglandins, cytokines, chemokines and matrix metalloproteinases (MMP), which causes leukocytes to be recruited to the site of inflammation, which is the endometrium in this case (Evans & Salamonsen, 2012). Increased ROS and inflammation creates a hypoxic environment, and this combined with prostaglandin actions lead to the tissue breakdown and bleeding of menstruation (Evans & Salamonsen, 2012). The low hormone levels and increased inflammation during this phase mean that, nutritionally, there are many considerations to support proper menstrual function and overall health during this time.

First, one of the most important nutrients to focus on is iron. Iron is a vital mineral known for making hemoglobin, an essential component of red blood cells, which carries oxygen from the lungs to the tissues (NIH, 2023). Other functions of iron include DNA synthesis, electron transport, energy production, and growth (Abbaspour et al., 2014). However, due to significant

blood loss from the uterine lining being shed, this vital mineral is often lost in the menses phase. In healthy women, about 14 mg of iron is lost per day during the menstrual cycle, but it can be as much as 100 mg for women with heavy bleeding and/or high energy expenditure (Petkus et al., 2019). Over time, this can lead to an iron deficiency and iron deficiency anemia if intake is inadequate. In fact, nearly 40% of women aged 12-21 in the U.S. had iron deficiency due to menstruation (Weyand et al., 2023). If iron needs are not met, there are several health implications that can occur, including fatigue, irritability, depression, difficulty concentrating, restless legs syndrome, pica, dyspnea, lightheadedness, exercise intolerance, and worsening heart failure (Auerbach, 2025).

In addition to replacing blood lost through bleeding, iron is required for the regeneration of the endometrium, a rapidly proliferating tissue that undergoes quick cyclical breakdown and repair (Mintz et al., 2020). This is because iron acts as a cofactor in enzymes that take part in DNA synthesis, such as ribonucleotide reductase, and in enzymes that produce ATP during oxidative phosphorylation, which is crucial for providing the energy needed for tissues to proliferate (Roemhild et al., 2021). The endometrium expresses high amounts of Divalent Metal Transporter 1 (DMT-1), a crucial transport protein of iron. This transporter facilitates the uptake of iron in the endometrial cells, allowing the iron-dependent processes like DNA synthesis and ATP production to run (Mintz et al., 2020). Furthermore, iron homeostasis is tightly regulated by hepcidin, a peptide hormone produced primarily by the liver that controls iron absorption and distribution. Hepcidin regulates iron availability by binding to the iron export protein ferroportin on enterocytes and macrophages, which triggers its degradation. During periods of increased demand or loss, such as menstruation, hepcidin concentrations decrease, allowing for increased intestinal absorption of iron and promoting the release of stored iron into circulation (Anderson

& Frazer, 2017). However, when dietary iron intake is insufficient, especially to compensate for increased losses and tissue proliferation demands during menstruation, these regulatory mechanisms may not be able to run as efficiently, increasing the risk of iron deficiency.

Due to both the increased risk of iron deficiency from blood loss, the demand for endometrial tissue proliferation, and the various symptoms that can occur with iron deficiency, replenishing iron and preventing deficiency is of utmost importance during the menstrual phase. Incorporating iron rich foods, such as red meat, poultry and eggs, as well as plant-based sources, such as beans, lentils, and leafy greens, can significantly reduce the risk of iron deficiency and help fuel recovery during the menses phase.

Another powerful nutrient to incorporate in the menses phase is vitamin C. Vitamin C, also known as ascorbic acid, is an essential vitamin, meaning it must be consumed through the diet. It is known for being involved in several biological functions in the human body, including: strengthening and sealing of blood vessels, lowering cholesterol levels, acceleration of wound-healing, slowing down the aging process of the skin, and lowering blood pressure (Gęgotek & Skrzydlewska, 2022). Furthermore, vitamin C has anti-inflammatory properties by lowering the expression of pro-inflammatory mediators and down-regulating pro-inflammatory factors, and it has antioxidant properties by preventing pro-apoptotic (cell death) factors. These anti-inflammatory and antioxidant properties of vitamin C are helpful for the menses phase to ease discomfort, such as cramping, and assist in healthy blood flow through the strengthening of blood vessels.

One of vitamin C's most important physiological functions during the menses phase is its role in enhancing dietary iron absorption, which is crucial when blood is being lost during the menses phase. Vitamin C assists with greater iron absorption by reducing ferrous ions ( $Fe^{3+}$ ) to

the more bioavailable ferric ions ( $\text{Fe}^{2+}$ ), which makes iron more soluble and easily absorbed (Skolmowska & Głabska, 2022). This reduction facilitates iron transport into enterocytes through the previously mentioned iron transport protein, DMT1, which helps maintain iron availability and restoration of lost iron during bleeding (Timoshnikov et al., 2020).

Beyond iron metabolism, vitamin C also contributes to endometrial repair and tissue remodeling, which is vital for when the endometrial lining is being shed during the menses phase. As a potent antioxidant, vitamin C helps neutralize reactive oxygen species by donating an electron to reactive molecules, which stabilizes it and prevents it from damaging cellular components like DNA, proteins, and lipids (Gęgotek & Skrzydlewska, 2022). This is crucial for protecting cellular structures and supporting normal tissue recovery, especially when inflammation is high during menstruation. As previously mentioned, endometrial shedding is associated with a large inflammatory process in which reactive oxidative species are produced and pro-inflammatory molecules are recruited to the endometrium (Evans & Salamonsen, 2012). Therefore, vitamin C's actions in neutralizing ROS can significantly help reduce inflammation and support healthy menstruation. Furthermore, vitamin C serves as a cofactor for enzymes involved in collagen synthesis, particularly prolyl and lysyl hydroxylases, which are required for the stabilization of the collagen triple helix and the formation of the extracellular matrix (Pinnell, 2024). These processes further help promote the restoration of the endometrial lining, allowing the body to quickly repair for the next phase.

To increase vitamin C intake for enhanced iron absorption, reduced inflammation, and endometrial repair, the best dietary sources to include are fruits and vegetables, especially red peppers, citrus fruits, kiwis, and broccoli (National Institute of Health, 2021).

Magnesium is another important nutrient to focus on in the menses phase due to its involvement in smooth muscle regulation, prostaglandin synthesis, and neuromuscular signaling, all of which influence uterine activity during menstruation. Although the exact mechanism is still being investigated, evidence has shown that magnesium is involved in the regulation of prostaglandin synthesis, specifically through inhibiting biosynthesis of prostaglandin F<sub>2</sub>-alpha, which is a hormone-like lipid that is produced to mediate uterine contractions in the menses phase (Gök & Gök, 2022). It can further alleviate cramps through promoting smooth muscle relaxation, especially in the uterus, which further decreases prostaglandin production (Yaralizadeh et al., 2020). Magnesium contributes to smooth muscle relaxation by modulating calcium transport across cell membranes. As a physiological calcium antagonist, magnesium competes with calcium for entry into smooth muscle cells and influences calcium-mediated signaling pathways that control muscle contraction (D'Angelo et al., 1992) and also reduces CRP, a protein produced by the body that is a key marker of inflammation (Veronese et al., 2022). By limiting excessive intracellular calcium accumulation, magnesium helps promote smooth muscle relaxation, which can help reduce excessive uterine contractions. This has been shown in a study completed with college students, where researchers found that magnesium supplementation reduced all symptoms of dysmenorrhea, or painful monthly bleeding, such as cramps, headache, back pain, foot pain, abdominal pain, and depression (Yaralizadeh et al., 2020). In addition, magnesium is essential for cellular energy metabolism because it binds to adenosine triphosphate (ATP) and forms Mg-ATP complexes, which stabilizes ATP for energy transfer, muscle contraction, and metabolism (Kröse & de Baaij, 2024). This process is required for over 600 enzymatic reactions, including those involved in muscle contraction and relaxation.

By supporting ATP utilization and enzyme activity, magnesium can help maintain normal neuromuscular function and cellular metabolism during the physiological stress of menstruation.

To support the wide variety of important roles that magnesium plays, including decreased prostaglandin synthesis, uterine muscle relaxation, and formation of Mg-ATP complexes, focusing on foods high in magnesium such as avocados, dark chocolate, nuts and seeds, and dark leafy greens can provide adequate amounts of the nutrient to support the menses phase.

### **The Follicular Phase**

The follicular phase is the second part of the menstrual cycle. It is classified as beginning on day one of the menstrual cycle, meaning that it occurs during the menses phase and lasts until ovulation. However, since the first part of the follicular phase, the menses phase, was already covered, this section will be focused on the late follicular phase, which occurs after menstruation.

Around day 10-14 of the menstrual cycle, the late follicular phase begins, lasting about a week. The beginning of the late follicular phase is marked by the maturation of a single dominant follicle, which is the sac that holds and protects the egg that would be used for fertilization (Cleveland Clinic, 2022). The mature follicle stimulates the release of estrogen in order to promote the thickening of the uterus, making an environment suitable for implantation of the egg (Cleveland Clinic, 2022). As estrogen levels rise, a negative feedback loop causes FSH levels to decrease, which causes the smaller, weaker follicles to “starve” off (Zelevnik, 2004).

Along with the rise of estrogen in the late follicular phase, there are associated physiological and psychological changes. Physiological changes include: an increase in mitochondrial efficiency, helping to increase energy; a greater ability to utilize glucose through

GLUT4 transporters, meaning carbohydrates can be more easily used for energy; increased fatty acid oxidation, meaning fat can be used for energy more readily; increased athletic performance; and increased muscle protein synthesis, meaning it is easier to build and repair muscle (Kiwior et al., 2025). Psychologically, many women report improved mood, ability to handle stress, and increased cognition (Kiwior et al., 2025). To support these physiological and psychological changes, focusing on specific nutrition strategies can help females feel and perform their best during this phase.

First, rising estrogen levels in the late follicular phase are associated with increased energy and increased capacity for glucose utilization, making this phase an optimal time to focus on higher intakes of complex carbohydrates (Kiwior et al., 2025). Complex carbohydrates have a wide variety of purposes, including: providing a slow, steady release of energy, enhancing cell signaling, aiding in cholesterol and triglyceride metabolism, and feeding beneficial gut microbiota (Fares, 2025). While simple carbohydrates have one or two sugars bonded together in a simple chemical structure, complex carbohydrates have three or more sugars bonded in a more complex chemical structure. Because of this, they take longer to digest, therefore have a more gradual effect on the increase in blood sugar. For the follicular phase specifically, this steady release of energy from complex carbohydrates promotes healthy development of the mature follicle by running steady rates of glycolysis, which provides glucose, their preferred fuel source, to granulosa cells (Zhang et al., 2023). Granulosa cells have high enzymatic activity that promote glucose uptake, suggesting that glucose is vital for proper growth and development of the follicle. By having an increased ability to take glucose into the cell, granulosa cells can utilize complex carbohydrates to provide the steady energy required to sustain growth of the follicle (Zhang et al., 2023).

Complex carbohydrates also aid in promoting proper steroid hormone synthesis, particularly estrogen, during the follicular phase. The main mechanism in which complex carbohydrates support estrogen synthesis is by promoting steady insulin secretion with slower-releasing glucose. Insulin directly stimulates steroidogenesis, the process in which cholesterol is converted to steroid hormones such as estrogen, progesterone, and testosterone, through stimulating FSH basal secretion of estrogen (Dupont & Scaramuzzi, 2016). By providing both energy and stimulation of estrogen synthesis, complex carbohydrates help to create the optimal environment for follicle maturation during the follicular phase.

Furthermore, carbohydrates play a crucial role in providing energy to red blood cells, the brain, and the nervous system since glucose is their preferred fuel source (Slavin & Carlson, 2014). When the brain gets adequate glucose, it also supports cognition and mental health, as carbohydrates are involved in production of dopamine, serotonin, and other neurotransmitters (Arshad et al., 2025).

On the other hand, inadequate carbohydrate intake is associated with hormonal disruptions that alter a female's menstrual cycle, leading to future health complications. In a study conducted on female athletes and low carbohydrate availability, researchers found that inadequate carbohydrate intake led to an inability to maintain normal estrogen and progesterone levels throughout the menstrual cycle, which greatly increased the risk of poor bone outcomes (Lodge et al., 2023). Low carbohydrate intake was also associated with decreased immune function and increased risk of iron deficiency (Lodge et al., 2023). To optimize energy availability and to prevent risks associated with low carbohydrate intake, individuals can focus on including complex carbohydrates, such as sweet potatoes, whole grains, fruits, vegetables, and legumes, during this phase.

Another important nutrient to focus on during the follicular phase is zinc. Zinc is an essential trace mineral that is involved in numerous physiological processes, including immune function, protein and DNA synthesis, wound healing, and cell signaling and division, as well as supporting healthy growth and development during pregnancy, infancy, childhood, and adolescence (National Institutes of Health, 2022). During the follicular phase, zinc plays a critical role in ovarian follicle development, as this phase is characterized by rapid proliferation and differentiation of granulosa and theca cells. Evidence suggests that, during development of the mature follicle, zinc transporters on the follicle and zinc concentrations within the follicle greatly increase, displaying that zinc plays a vital role in growing the mature follicle (Chen et al., 2023). When zinc concentrations increase in the oocyte, zinc-dependent hydrolytic enzymes, zinc finger transcription factors, and ribosomal units are activated, allowing for proper DNA synthesis and cell growth and division to occur in the rapidly growing follicle (Chen et al., 2023).

Zinc is also essential for proper steroid hormone signaling and receptor function. It does so by contributing to the structural integrity of hormone receptors, including estrogen, allowing for effective hormone binding and downstream signaling (Kapper et al., 2024). Adequate zinc levels therefore support normal estrogen activity during the follicular phase, which is important when estrogen levels must rise to promote follicle maturation. In contrast, zinc deficiency may impair hormone-receptor interactions, potentially disrupting feedback mechanisms that regulate FSH and LH secretion (Kapper et al., 2024). These disruptions can negatively affect follicular development and overall menstrual cycle regulation, which shows the importance of obtaining enough zinc in the diet.

In addition to its role in hormone signaling, zinc contributes to steroidogenesis, just as with insulin. Zinc supports steroidogenesis by acting as a cofactor for steroidogenic enzymes,

especially Steroidogenic Acute Regulatory Protein (StAR), the key rate-limiting step in steroidogenesis (Manna et al., 2016). This enzyme is crucial for proper hormone synthesis and follicular maturation. During the follicular phase, StAR governs the initial production of estrogen and progesterone by permitting the translocation of cholesterol from the outer membrane to the inner membrane of the mitochondria where it can be converted to estrogen (Men et al., 2016). This allows for proper estrogen production and release, encouraging mature follicle development. To further show the importance of StAR, there is evidence to suggest that there is a correlation between estrogen dependent disorders, such as endometriosis, and low StAR expression due to improper estrogen synthesis (Manna et al., 2016). Therefore, by incorporating dietary zinc, this can also allow for proper functioning of StAR activation and the subsequent estrogen production that is crucial to the follicular phase.

Furthermore, zinc plays a vital role in insulin metabolism, acting through the insulin-signaling pathway to increase glucose transport into cells. Zinc promotes glucose transport by inducing phosphorylation of the beta subunit of the insulin receptor, having downstream effects of stimulating key signaling proteins, PI3K and Akt, in the insulin signaling cascade (Tang & Shay, 2001). When these signaling proteins are properly activated, GLUT4 translocation occurs, allowing for enhanced glucose uptake into the cells. When energy levels increase during the follicular phase, it is particularly relevant to incorporate zinc to optimize GLUT4 translocation and subsequent glucose uptake, especially in combination with increased complex carbohydrate intake. This ensures that females are properly energized for any activity during this time.

Through its combined roles in cellular proliferation, hormone receptor function, steroid hormone synthesis, and metabolic regulation, zinc is essential for maintaining the physiological

processes necessary for proper follicle development. Incorporating animal-based sources of zinc, such as seafood, meat, eggs, and dairy, and plant-based sources, such as beans, whole grains, and fortified foods, can support proper zinc intake during this phase.

Lastly, another important nutrient to incorporate during the follicular phase is fiber. While fiber is important across all phases of the menstrual cycle, its role becomes particularly relevant during the follicular phase as estrogen levels rise. Fiber contributes to hormonal regulation by influencing estrogen metabolism and excretion, helping to maintain appropriate circulating hormone levels. After estrogen is metabolized in the liver, it is conjugated and excreted into bile, entering the intestine where it may either be eliminated through urine or reabsorbed through enterohepatic circulation (Raftogianis et al., 2000). This is important during the follicular phase because, although high estrogen levels have a critical purpose, excess estrogen must be excreted to maintain proper hormone functioning.

One of the ways dietary fiber supports proper estrogen levels is by its ability to clear estrogen. Fiber enhances estrogen clearance by binding to estrogen metabolites in the intestinal lumen, promoting their excretion in feces (Patel et al., 2018). In addition, fiber influences the activity of beta-glucuronidase, a gut microbial enzyme that deconjugates estrogen, allowing it to be reabsorbed into circulation. Fiber influences beta-glucuronidase by inhibiting its activity, primarily through altering gut microbiota composition to feed beneficial microbes. These beneficial microbes produce metabolites that inhibit development of beta-glucuronidase, which works to limit estrogen reabsorption and reactivation in the colon (Manoj et al., 2001). As a result, more estrogen remains in its conjugated form and is excreted rather than recirculated and reabsorbed, helping regulate systemic estrogen concentrations during a phase when levels are naturally increasing.

Maintaining proper estrogen balance is vitally important for overall health. Estrogen plays critical roles in maintaining bone health, glucose homeostasis, immune health, fertility, and neural functions (Patel et al., 2018). However, excess circulating estrogen has been associated with negative health outcomes. In the short term, excess estrogen is associated with weight gain, increased inflammation, and obesity (Mair et al., 2019) as well as emotional dysregulation, reduced stress resilience, and increased risk of depression (Albert & Newhouse, 2019). Over time, chronic excess estrogen levels have been linked to conditions such as several types of cancer, endometriosis, polycystic ovarian syndrome, and Alzheimer's disease (Patel et al., 2018). By promoting estrogen excretion and limiting reabsorption, dietary fiber helps maintain hormonal balance during the follicular phase, supporting reproductive function and long-term health. Foods rich in fiber, such as fruits, vegetables, legumes, and whole grains, can help support adequate intake during this phase.

Together, complex carbohydrates, dietary fiber, and zinc support the metabolic and hormonal environment necessary for optimal follicular phase function. This phase is characterized by rising estrogen levels and rapid ovarian follicle development, which are processes that require coordinated energy availability, hormone regulation, and cellular proliferation. Complex carbohydrates provide a sustained source of glucose to fuel follicular growth and support insulin-mediated signaling involved in estrogen production. Zinc further supports follicular development through its roles in DNA synthesis, cellular proliferation, and steroidogenesis, ensuring proper maturation of the ovarian follicles. Dietary fiber contributes to hormonal balance by facilitating the excretion of excess estrogen, helping maintain proper circulating hormone levels. Collectively, these nutrients work through complementary

mechanisms to support the physiological processes underlying follicular growth and preparation for ovulation.

### **The Ovulatory Phase**

The next phase of the menstrual cycle is ovulation. It is the shortest day of the menstrual cycle, lasting only 12-24 hours, and typically occurs about 14 days before an individual's period begins (Cleveland Clinic). The ovulatory phase begins when estrogen, which was rising during the follicular phase, reaches a peak concentration and remains at that concentration for two days. Estrogen transitions from inhibiting GnRH to stimulating the hypothalamus to increase GnRH pulse frequency. The increased pulse frequency leads to a surge in LH, which weakens the wall of the ovary and allows the oocyte, or egg, to be released to the fallopian tube (Holesh et al.). The egg stays viable in the fallopian tube for only about 24 hours, and if it is not fertilized, it is broken down and reabsorbed into the body, marking the end of the ovulatory phase (Cleveland Clinic).

Accompanying peak estrogen levels and the LH surge, many women experience peak energy levels and enhanced performance, both mentally and physically. Physically, ovulation enhances nervous system activation, neuromuscular coordination, and cardiovascular function, likely due to high estrogen levels (Kiwior et al.). Mentally, ovulation maximizes focus and cognition. This is because high estrogen concentrations enhance glutamatergic neurotransmission, which increases excitement and neuronal activity, while inhibiting GABAergic neurotransmission, which reduces excitability and neuronal activity (Sawicka et al.). The combination of stimulating excitatory signals and reducing inhibitory signals helps the brain process information more quickly, enhances attention, and improves working memory (Sawicka et al.). Furthermore, improved self-confidence, perceived self-attractiveness, and positive mood

has been shown to occur during ovulation, likely also due to peak fertility and hormone concentrations (Schleifenbaum et al.).

Even if an individual is not trying to get pregnant during her current cycle, it is important to support fertility and healthy ovulation. Anovulatory bleeding, a condition in which females do not ovulate during their menstrual cycle, causes unpredictable, irregular cycles that are often heavy and prolonged (Jones and Sung). This occurs because, without ovulation, progesterone is not produced, resulting in estrogen levels staying high and stimulating the uterine lining to continuously grow and shed during phases that it is not supposed to (Jones and Sung). Over time, this can lead to increased blood loss, anemia, and decreased quality of life (Jones and Sung). To support healthy ovulation, associated energy and mood changes, and prevent conditions associated with anovulation, incorporating nutrients such as calcium, vitamin D, and selenium can significantly help.

First, focusing on calcium can significantly support ovulatory function. Calcium is an essential mineral involved in bone health, cell-signaling, and muscle contraction, but it also plays a critical role in reproductive physiology. During the ovulatory phase, calcium is involved in multiple steps of the ovulation process, particularly through its role as an intracellular signaling molecule. At the onset of ovulation, calcium stimulates follicular development and controls healthy oocyte maturation through modulating secondary messenger systems, especially cyclic adenosine monophosphate (cAMP) (Silvestre et al., 2011). cAMP is a secondary messenger derived from ATP that amplifies cell signaling by transmitting extracellular hormonal signals, such as those from FSH and LH, into intracellular responses that regulate gene expression and cellular activity (Patra & Brady, 2018). Calcium, also a secondary messenger, works to support cAMP signaling by activating adenylyl cyclases, which activate cAMP, and inhibit molecules

that degrade cAMP, such as phosphodiesterase (PDE) (Halls & Cooper, 2010). This is important to ovulation because it promotes amplified hormonal signaling within ovarian cells, allowing signaling from the HPA axis to be transmitted to the ovary, coordinating the cellular changes required for an oocyte to reach maturity and be released.

Calcium is also directly involved with the signaling pathways that trigger ovulation. The luteinizing hormone surge stimulates intracellular calcium release within granulosa and theca cells, activating pathways that promote follicular rupture and release of the oocyte (Kapper et al., 2024). This increase in intracellular calcium also contributes to the activation of matrix metalloproteinases (MMPs), which are a group of proteolytic enzymes that degrade components of the extracellular matrix in the follicular wall (Verma & Hansch, 2007). This degradation of the extracellular matrix, including collagen and other structural proteins, allows for the weakening of the follicular wall so that it can rupture and the oocyte can be released (Muraly Puttabyatappa et al., 2014). This ensures the proper breakdown of the mature follicle and expulsion of the mature oocyte into the fallopian tube.

If an individual is wanting to get pregnant during the ovulatory phase, calcium plays a crucial role in the fertilization process. Calcium-dependent secondary messenger modulation pathways facilitate the acrosome reaction in sperm, a process that allows sperm to penetrate the oocyte and fertilize it, and contribute to membrane fusion between the oocyte and spermatozoon (Kapper et al., 2024). Following fertilization, calcium oscillations within the oocyte help initiate embryonic development. To support these calcium-dependent processes during ovulation, foods to incorporate include dairy products and canned fish with bones, such as sardines, plant-based milks, soy products, and nuts and seeds.

Another nutrient to focus on during ovulation is vitamin D. Vitamin D is a fat-soluble vitamin known for a variety of functions, including maintaining bone health, reducing inflammation, cell growth, and immune function (National Institutes of Health, 2025). During ovulation, vitamin D has been shown to have both direct effects on ovarian tissue and indirect effects on ovulatory health through supporting calcium absorption.

One of the mechanisms in which vitamin D has been shown to support healthy oocyte development in ovarian tissue is by supporting steroidogenesis, which is crucial for producing the estrogen needed for oocyte development and triggering the LH surge that causes oocyte release. Vitamin D receptors, also called VDR, are expressed within the ovary in granulosa cells, allowing vitamin D to act directly on the ovary (Grzesiak, 2020). When vitamin D binds to these VDR receptors, it forms a receptor complex that both stimulates estrogen production and upregulates the enzyme aromatase, which converts androgens, such as testosterone, to estrogen (Grzesiak, 2020). By supporting estrogen production through transcription of enzymes in steroidogenesis, vitamin D promotes the hormonal environment required for proper ovulation to occur.

A second mechanism in which vitamin D has been shown to support healthy ovulation is through the modulation of anti-Müllerian hormone (AMH). AMH is a glycoprotein hormone produced by the granulosa cells that normally plays a role in regulating follicle growth by limiting excessive follicle recruitment and decreasing responsiveness to FSH (Bednarska-Czerwińska et al., 2019). This is important in a healthy menstrual cycle because it prevents too many follicles from maturing simultaneously, allowing for controlled development of one dominant follicle to occur. However, if AMH levels are too high, it has been shown to impair ovulation and fertility by inhibiting responsiveness to FSH too much, preventing

granulosa cell differentiation and the proper progression of the dominant follicle (Moridi et al., 2020). Vitamin D, however, prevents excessive AMH signaling when it binds to its receptor by inducing genetic sequence changes in the AMH gene promoter, decreasing expression of the AMH-II receptor and reducing phosphorylation of SMAD, the protein that transmits AMH signals (Moridi et al., 2020). By reducing excessive AMH-II receptor expression and transmission of AMH signaling, vitamin D helps support development of healthy, mature eggs by ensuring that AMH levels stay within the proper range.

Furthermore, vitamin D supports ovulation through its role in calcium absorption and homeostasis. After vitamin D is obtained from dietary sources or synthesized in the skin, it undergoes hydroxylation to form 25-hydroxyvitamin D, or 25(OH)D, followed by a second hydroxylation in the kidneys to produce 1,25-hydroxyvitamin D (calcitriol), which is its active hormonal form (Bikle, 2021). In the small intestine, calcitriol binds to its vitamin D receptor and increases expression of calcium transport proteins that facilitate active transcellular calcium absorption, therefore increasing the amount of calcium available to the body (Bikle, 2021). In fact, without vitamin D, the body cannot absorb more than 10-15% of calcium, but when an individual has sufficient vitamin D levels, absorption can increase to up to 40% (Khazai et al., 2008). This mechanism is especially relevant for ovulation because, as previously mentioned, calcium functions as an essential intracellular signaling molecule within ovarian cells, functioning to regulate oocyte maturation, activate proteolytic enzymes involved in follicular rupture, and coordinating cellular events required for the release of the mature oocyte. By improving calcium absorption and maintaining calcium availability, vitamin D may help significantly support the signaling processes necessary for successful ovulation.

To include vitamin D for proper oocyte development, cell signaling, and enhanced calcium absorption during ovulation, focus on sources rich in vitamin D, which include oily fish, such as salmon, red meat, egg yolks, fortified foods, and liver (National Institutes of Health, 2025).

Next, antioxidants such as selenium are important to incorporate during ovulation because they protect the ovarian tissue from oxidative stress. Antioxidants are compounds that neutralize free radicals and other reactive oxidative species by donating an electron, preventing damage to cellular structures such as lipids, proteins, and DNA. Reactive oxidative species (ROS) are highly-reactive oxygen-containing molecules, such as superoxide and hydrogen peroxide, that are produced as natural byproducts of cellular metabolism but are damaging in excess. (Kapper et al., 2024). When excess ROS accumulates, oxidative stress can occur, which is when ROS production exceeds the body's antioxidant defenses, leading to cellular injury that can impair oocyte maturation, reduce oocyte quality, and disrupt normal ovulatory function (Begum, 2025). Mechanistically, excess ROS production can damage mitochondrial membranes, proteins, and DNA within the oocyte, reducing the necessary ATP production and impairing the energy-dependent processes required for meiotic maturation and oocyte release (Song et al., 2024). ROS can also damage nuclear DNA and membrane lipids within granulosa cells and oocytes, compromising follicular quality and impairing the signalling environment needed for release of a healthy, mature egg (Song et al., 2024). Because ovulation involves rapid cellular signaling, follicular remodeling, and release of the oocyte, reducing oxidative stress is especially important to maintain proper ovulatory function during this phase.

Oxidative stress can be counteracted by including antioxidants in the diet, such as selenium. Selenium is an essential trace mineral that supports antioxidant defense primarily by

its incorporation into selenoproteins, including antioxidant enzymes such as glutathione peroxidases and thioredoxin reductases (Kapper et al., 2024). These selenium-dependent enzymes are activated when selenium is incorporated into the amino acid selenocysteine, which acts as the active site for the enzymes to act upon (Tinggi, 2008). These antioxidant enzymes then act on ROS molecules by performing redox reactions in which electrons are transferred by reducing molecules, such as glutathione, to neutralize peroxides and convert them into less reactive substances such as water and lipid alcohols, thereby limiting oxidative damage in ovarian tissue (Kapper et al., 2024). In the ovary, this antioxidant activity helps protect granulosa cells and the mature oocyte from excess ROS accumulation, which helps preserve mitochondrial function, membrane integrity, and the cellular signaling pathways necessary for ovulation (Safiyeh et al., 2021). By preventing oxidative injury to the ovary, selenium can help support ovulation by supporting the structural and metabolic conditions required for healthy egg maturation and release.

Selenium can also support ovulation through its role in thyroid function, hormone metabolism, and DNA synthesis (National Institutes of Health, 2021). Since oxidative stress is also correlated with conditions that can impair ovulation, such as insulin resistance, chronic inflammation, and obesity, adequate selenium intake can support ovulation by preventing these conditions, helping to maintain a healthy environment for ovarian development and release (Reddy, 2023). Furthermore, evidence suggests that increased selenium intake has been associated with reduced risk of infertility and endocrine disorders, such as endometriosis and PCOS, further helping to support proper ovulation by decreasing oxidative stress (Lima et al., 2022). To support reducing inflammation and oxidative stress, individuals can obtain proper selenium from high-protein food sources such as seafood, meat, poultry, and organ meat is

important because selenium is bound to protein. Furthermore, one of the food sources of selenium are Brazil nuts, providing over the recommended daily intake in just one nut (Colpo et al.).

Overall, peak estrogen and LH levels during ovulation lead to increased energy, confidence, and cognition. To support these changes, enhance oocyte health, and optimize fertility, incorporating nutrients like calcium, vitamin D, and selenium can significantly help women feel their best during this time.

### **The Luteal Phase**

The last phase of the menstrual cycle is the luteal phase, beginning directly after ovulation and lasting until the first day of bleeding, which is about 14 days for most women (Reed & Carr, 2018). The main purpose of the luteal phase is to prepare the endometrium for a healthy implantation and potential pregnancy, so hormonal shifts and physiological changes occur to support that. During the start of the luteal phase, the dominant follicle that released the oocyte during ovulation changes into the corpus luteum, which is a collection of cells formed on the ovary to produce progesterone for a healthy pregnancy (Cleveland Clinic, 2021). To support the formation of the corpus luteum, progesterone levels rise during the early luteal phase, causing the uterine lining to thicken in order to support potential egg attachment for pregnancy (Reed & Carr, 2018). Estrogen levels drop sharply at the beginning of the luteal phase due to the formation of the corpus luteum, which primarily produces progesterone, but it rises again mid-cycle to promote growth of the endometrium for fertilization and pregnancy (Reed & Carr, 2018). If the egg is not fertilized, the corpus luteum dissolves, causing both progesterone and estrogen levels to plummet. This triggers the uterine lining to be shed and signals the end of the luteal phase.

With these fluctuating hormone levels, premenstrual syndrome, or PMS, commonly occurs during the luteal phase. The National Institute of Health defines PMS as “clinically significant somatic and psychological manifestations during the luteal phase of the menstrual cycle, leading to substantial distress and impairment in functional capacity” (Gudipally & Sharma, 2023). The symptoms of PMS include a wide variety of physical, behavioral, and psychological factors. Physically, symptoms of the luteal phase include headaches, breast tenderness and swelling, back pain, abdominal pain and bloating, weight gain, water retention, nausea, muscle and joint pain (Dickerson et al., 2003). Behaviorally, many women report fatigue, increased food cravings, and a tendency to overeat (Dickerson et al., 2003). Psychologically, decreased estrogen levels, which is a critical hormone for synthesis of neurotransmitters like dopamine and serotonin, can cause mood swings, sadness, irritability, and decreased self-esteem (Dickerson et al., 2003). Since PMS is extremely common among premenopausal women, with about 40% of women experiencing clinically significant PMS and over 90% of women saying they get at least one of the symptoms of PMS (Office on Women's Health, 2015), focusing on nutrition interventions to combat PMS is paramount for enhancing physical and mental wellbeing during the luteal phase.

First, an important nutrient to focus on during the luteal phase is vitamin B6. Vitamin B6 is a water soluble vitamin found in a wide variety of foods and it functions as a coenzyme in numerous physiological processes, including amino acid metabolism, cognitive development, gluconeogenesis, glycolysis, and supporting immune function (National Institutes of Health, 2023). During the luteal phase, evidence suggests that vitamin B6 is particularly beneficial because it has been shown to reduce psychological premenstrual symptoms, including stress, anxiety, irritability, and low mood through increasing synthesis of the neurotransmitters

serotonin and GABA (Siminiuc & Țurcanu, 2023). These effects are especially relevant during the luteal phase when declining estrogen levels after ovulation contribute to reduced serotonergic activity.

Estrogen normally supports serotonin availability through multiple mechanisms. First, estrogen increases the production of tryptophan hydroxylase (TPH), which is the rate-limiting enzyme involved in serotonin synthesis (Rybaczyk et al., 2005). By upregulating the production of the enzyme involved in a key rate-limiting step, serotonin promotes conversion of tryptophan into serotonin precursors, contributing to greater serotonin synthesis and availability. Estrogen also reduces expression of serotonin transporter 2 (SERT2), a protein responsible for removing serotonin by transporting serotonin back to the presynaptic neuron (Rybaczyk et al., 2005). By reducing the expression of SERT2, estrogen contributes to reduced reuptake of serotonin, allowing it to remain in the synaptic cleft for a longer period of time (Rybaczyk et al., 2005). As estrogen levels fall during the luteal phase, these effects can be diminished, contributing to lower serotonin availability and greater vulnerability to mood-related premenstrual symptoms.

Vitamin B6 helps counteract this decline through its active coenzyme form, pyridoxal 5'-phosphate (PLP), which is required for several enzymatic reactions involved in neurotransmitter synthesis (Stover & Field, 2015). In serotonin production, PLP serves as a cofactor for aromatic L-amino acid decarboxylase, the enzyme that converts 5-hydroxytryptophan into serotonin (Fields et al., 2021). PLP is also required for synthesis of gamma-aminobutyric acid (GABA), as it acts as a cofactor for glutamate decarboxylase, the enzyme that converts glutamate into GABA (Iorizzo et al., 2023). Through these mechanisms, vitamin B6 supports production of both serotonin and GABA, two neurotransmitters involved in mood regulation and stress response. This is particularly important during the luteal phase

because serotonin contributes to emotional stability and overall sense of well-being while GABA functions as the primary inhibitory neurotransmitter in the central nervous system, which reduces neuronal excitability and promotes calmness (Durrani et al., 2022). Because neurotransmitter synthesis depends on PLP-dependent decarboxylation reactions, inadequate vitamin B6 intake may impair production of serotonin and GABA at a time in the cycle when declining estrogen already reduces support for these pathways. However, by supporting synthesis of these neurotransmitters through adequate vitamin B6 intake, this may help reduce symptoms such as anxiety, irritability, and mood changes that commonly occur with PMS. To increase intake of vitamin B6, individuals can include food such as chickpeas, fish, liver, and other organ meats, starchy vegetables, non-citrus fruits, fortified cereals, beef, and poultry.

Another important nutrient to incorporate during the luteal phase are omega-3 fatty acids, particularly alpha linoleic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). Omega-3 fatty acids are polyunsaturated fatty acids that serve as important structural components of cell membrane phospholipids that form cell membranes and are mediators involved in endocrine signaling (National Institutes of Health, 2023). During the luteal phase, omega-3 fatty acids are especially beneficial because they help modulate inflammation, which drives many common physical and psychological symptoms of PMS. As progesterone and estrogen fluctuate during this phase, inflammatory signaling and prostaglandin activity contribute to symptoms such as cramping, headache, fatigue, breast tenderness, irritability, and low mood (Gold et al., 2016).

Mechanistically, omega-3 fatty acids help reduce inflammation by altering the types of eicosanoids produced, which are signaling molecules produced from cell membrane fatty acids that play a role in the body's immune response (Sheppe & Edelmann, 2021). Many of these

molecules can be pro-inflammatory, including prostaglandins and leukotrienes; however, depending on where they are derived from, they can also have anti-inflammatory effects (Park, 2025). For example, the omega-3 fatty acid EPA competes with arachidonic acid, an omega-6 fatty acid, for the enzymes cyclooxygenase and lipoxygenase, leading to a production of less inflammatory prostaglandins and leukotrienes (Park, 2025). Through this shift in substrate availability, omega-3 fatty acids can reduce synthesis of pro-inflammatory lipid mediators and inflammatory cytokines, which helps lessen pain sensitivity and tissue inflammation associated with PMS (Mohammadi et al., 2022). Omega-3 fatty acids have also been shown to influence intracellular inflammatory signaling pathways, including inhibition of mitogen-activated protein kinase (MAPK), a pathway involved in amplifying immune responses and central sensitization to pain (Moens et al., 2013). By suppressing MAPK-related signaling, omega-3 fatty acids help reduce both inflammatory and neuropathic aspects of pain perception (Mohammadi et al., 2022).

Omega-3 fatty acids may also support psychological symptoms during the luteal phase. One of the ways omega-3 fatty acids support psychological symptoms is through binding to and activating G-protein-coupled receptor 40 (GPR40), which activates downstream signaling that both reduces production of inflammatory molecules and triggers activation of pathways associated with production and release of beta-endorphin in the hypothalamus (Mohammadi et al., 2022). Beta-endorphin is an endogenous opioid peptide that can reduce pain perception and contribute to improved mood and reduced stress by binding to opioid receptors in the brain, inhibiting release of neurotransmitters associated with pain signaling (Cleveland Clinic, 2022). In addition, because chronic low-grade inflammation has been linked to depressive and anxiety-related symptoms, the anti-inflammatory effects of omega-3 fatty acids may further support emotional regulation during the luteal phase (Mehdi et al., 2023). Through these

combined effects on inflammatory mediators, pain signaling pathways, and neurochemical regulation, omega-3 fatty acids support the luteal phase and reduce both the physical and psychological symptoms associated with PMS. To increase omega-3 intake, foods such as fatty fish, flax seeds, chia seeds, walnuts, and oils like flaxseed oil can be incorporated into the diet.

Lastly, incorporating vitamin E during the luteal phase can greatly support reproductive and overall health through its roles in antioxidant protection, vascular function, and immune regulation. Vitamin E is a fat-soluble antioxidant that helps protect polyunsaturated lipids within cell membranes from oxidative damage, thereby preserving membrane integrity and cellular function (Wang & Quinn, 2000). One important mechanism by which vitamin E supports luteal-phase physiology is through improving blood flow. By limiting oxidative damage to lipids in red blood cell membranes and vascular tissues, vitamin E helps preserve nitric oxide bioavailability, which promotes vasodilation and improves circulation (Takasaki et al., 2009). This is especially important during the luteal phase because, after ovulation, the corpus luteum becomes one of the most highly vascularized endocrine structures in the body and depends on adequate blood flow to function properly.

Proper blood supply to the corpus luteum is necessary for delivery of cholesterol, the substrate used for progesterone synthesis, as well as for transport of progesterone into systemic circulation (Takasaki et al.). If luteal blood flow is impaired, progesterone production and release may also be compromised, which can negatively impact luteal phase function. In fact, reduced blood flow to the corpus luteum has been associated with impaired luteal function, and some evidence suggests that increased vitamin E intake may improve luteal function by reducing vascular resistance and blood flow impedance (Takasaki et al., 2009). Through this mechanism,

vitamin E helps support progesterone synthesis and the endocrine function of the corpus luteum during the luteal phase.

Vitamin E also plays a vital role in immune function, which is crucial during the luteal phase. During this phase, high progesterone levels act as an immunosuppressant by shifting immune signaling toward Th-2-like cytokine activity, a change that helps prepare the body for potential implantation and pregnancy (Raghupathy & Szekeres-Bartho, 2022). This function of progesterone serves to protect the potential fetus from being recognized as foreign by the mother's immune system, which could lead to the maternal immune system attacking the fetus (Raghupathy & Szekeres-Bartho, 2022). Although this is a normal physiological adaptation, it also coincides with a relative reduction in immune response, even if an individual is not trying to get pregnant, making supporting the immune system even more important during this time.

Vitamin E can support immunity in part by protecting immune cell membranes from oxidative stress, helping to preserve membrane fluidity, receptor function, and intracellular signaling required for effective immune responses (Lewis et al., 2018). Vitamin E has also been shown to enhance T-cell function by improving signal transduction and strengthening the ability of T-cells to respond to antigenic stimulation (Lewis et al., 2018).

In addition, vitamin E may help regulate inflammatory mediators relevant to both immune function and luteal-phase symptoms. It has been shown to modulate production of pro-inflammatory molecules, such as cytokines and prostaglandin E2 (PGE2) (Lewis et al., 2018). Vitamin E does so by protecting polyunsaturated fatty acids within cell membranes from lipid peroxidation, which helps limit membrane damage and reduces release of arachidonic acid, the substrate used for prostaglandin synthesis (Wu et al., 2001). By decreasing availability of arachidonic acid for conversion to prostaglandins through cyclooxygenase, vitamin E helps to

reduce production of PGE2, which is particularly relevant to the luteal phase when prostaglandin production is upregulated in preparation for endometrial shedding. PGE2 contributes not only to inflammatory signaling, but also to pain sensitization and uterine cramping associated with the transition into menstruation (Itani et al., 2022). By helping reduce oxidative stress and modulate inflammatory mediator production, vitamin E can support both immune balance and symptom relief during the luteal phase. To increase intake of vitamin E during the luteal phase, individuals can focus on foods such as nuts and seeds, especially almonds, sunflower seeds, and oils such as sunflower oil and safflower oil. Furthermore, vitamin E is abundant in several vegetables, including spinach, chard, and broccoli (National Institutes of Health, 2021).

Overall, to support the body during the luteal phase, it is important to incorporate nutrients high in vitamin B6, omega-3 fatty acids, and vitamin E. This phase is characterized by rising progesterone, changing estrogen concentrations, and the potential onset of premenstrual symptoms, all of which increase the importance of nutrients that support neurotransmitter synthesis, inflammation control, vascular function, and immune balance. Vitamin B6 helps maintain serotonin and GABA production, supporting mood stability and reducing psychological PMS symptoms. Omega-3 fatty acids help shift inflammatory signaling to a less inflammatory state, which may reduce pain, fatigue, and mood-related symptoms. Vitamin E further supports luteal health by protecting against oxidative stress, improving blood flow to the corpus luteum, and modulating immune and inflammatory function. Together, these nutrients support the physiological demands of the luteal phase and help lessen both the physical and emotional symptoms commonly experienced during this time.

## **Conclusion**

This thesis combines female reproductive physiology, evidence-based nutrition, and culinary application to empower women with nutrition strategies to feel their best throughout the menstrual cycle. This first part of the thesis, the research section, will serve as a guide to provide a deeper understanding of how the menstrual cycle impacts all aspects of women's health, including physiological, psychological, and behavioral changes. In order to do so, each section is designed to explain the impact of hormonal fluctuations with how these fluctuations lead to changed nutrient considerations, providing a framework for increasing education on the female body and the power of nutrition to fuel health and well-being. Combining this research section with creative culinary application through a recipe book will serve as an evidence-based practical guide for premenopausal women, encouraging a deeper understanding of their own bodies and strategies to fuel their lives during any stage.

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