

## Review Article

# A Review on: Effect of Nutrients on Brain Function and Development

Faiqa Riaz<sup>1\*</sup>; Ammar Ijaz<sup>2</sup>; Dr Afia Kanwal<sup>3</sup>; Zaineb Riaz<sup>4</sup>; Sara Naqvi<sup>5</sup>; Osama Aziz<sup>6</sup>; Yasmeen Abdul Sattar<sup>7</sup>; Aysha Farooq<sup>8</sup>; Hijab Fatima<sup>9</sup>; Sadaf Tahir<sup>10</sup>

<sup>1</sup>National Institute of Food Science and Technology, University of Agriculture Faisalabad, Pakistan

<sup>2</sup>Faculty of Health and Wellbeing, University of Bolton, United Kingdom

<sup>3</sup>Intertek Food Service (Food inspection Laboratory) UK

<sup>4</sup>Life and Health Sciences, Clinical Nutrition, Pakistan

<sup>5</sup>Research Scholar, Institute of Business Management Sciences, University of Faisalabad, Pakistan

<sup>6</sup>Department of International Public Health, China Medical University Taiwan, Taiwan

<sup>7</sup>Department of Human, Nur International University Lahore, Pakistan

<sup>8</sup>Department of Physiology, Nur International University Lahore, Pakistan

<sup>9</sup>Department of Food and Nutrition, University of Sialkot, Pakistan

<sup>10</sup>Faculty of Nutrition and Home Sciences, Pakistan

\*Corresponding author: Faiqa Riaz

National Institute of Food Science and Technology, University of Agriculture Faisalabad, Pakistan.

Email: faiqariaz786@gmail.com

Received: July 01, 2024

Accepted: July 26, 2024

Published: August 02, 2024

## Introduction

### Nutrition and Brain Development

Nutrition is one of the critical factors that influence brain development, and has a significant impact on the brain's developmental processes and functioning from foetal to adult age [62]. Throughout life, including early development during both the prenatal and postnatal stages, a balanced diet is crucial for mental health and brain development [41,117], including subsequent life stages [117]. In promoting the structural and functional development of the human cognitive function and brain, from conception, nutrition plays a major role during early infancy and continuing into later life [180,185]. Nutrition is vital for the maturation and functional development of the

## Abstract

**Introduction:** Nutrition is one of the critical factors that influence brain development, and has a significant impact on the brain's developmental processes and functioning from foetal to adult age. Newborn human brains utilise 60% of the body's total oxygen, which has an impact on calorie intake. For the anatomical and functional growth of the brain, all nutrients are essential, the ones that aid in energy, carbohydrate, protein, and fat metabolism are especially significant.

**Objectives:** The aim of this review is to boost up memory through diet, to know about the Nutrients for the development of the brain and to ensure Foods that adversely affect normal brain function.

**Methodology:** This literature review consulted multiple databases, focusing on brain health and development, cognitive function, and maternal diet. The review included research from previous decades and analysed around 1,000 articles, with nearly 185 selected. The review assessed the relevance of the content to search terms, evaluating resources based on material quality, topicality, and publication year. The review discussed macronutrients and micronutrients, healthy and unhealthy foods, and maternal diets for foetal brain development.

**Conclusion:** Factors such as maternal diet and macro and micro-nutrient consumption significantly impact brain development and cognitive function. Nutrition is crucial for optimal brain health and preventing cognitive decline. Deficiencies and excesses of certain nutrients affect cognitive function differently. Vitamin A, LC-PUFAs, ketones, protein, zinc, neurotrophins, neuropeptides, choline deficiency, vitamin B, copper, lutein, and zeaxanthin are essential for brain health. Consuming foods like walnuts, dairy, fish, caffeine, and low glycemic index foods can be beneficial for brain health, while junk foods, refined sugar, and saturated fats can be harmful.

**Keywords:** Brain health; Nutrition; Nutrients cognitive function; Micronutrients

Central Nervous System (CNS). Brain development is a carefully controlled process involving cell division, differentiation, migration, and connectivity that depend on overlapping stages. Any disruption to this process can affect brain function [29]. Adequate nutrition is important during pregnancy [105,159] and the first few years of life, because it is during the prenatal and early postnatal period that the brain undergoes rapid growth and development, laying the foundation for cognitive, motor, and socioemotional skills [105]. It is becoming increasingly evident that nutritional status throughout foetal development and in a child's formative years has a significant effect on

neurodevelopment [185]. Nutrition is especially important due to the role that nutrients play in specific metabolic pathways and structural components. For instance, it is widely recognized that a dietary deficiency during critical stages of development can cause permanent changes to the brain. Observational and experimental studies provide mounting evidence that nutrition during intrauterine development can impact cognitive development in offspring later in life [113].

Newborn human brains utilise 60% of the body's total oxygen, which has an impact on calorie intake [67]. Around the world, one-third of children do not develop to their fullest potential by the time they are in preschool. Low-and Middle-Income (LMIC) children are more vulnerable, with sub-Saharan Africa bearing a disproportionate share of the burden of cognitive impairment. It is commonly known that the most important time for brain development is the first 1000 days of life, from conception to age two (McCann et al., 2020). Dietary restriction is known to profoundly influence foetal brain development [103].

### Maternal Diet

The role of maternal nutritional factors in foetal development appeared as important research during the 20<sup>th</sup> century. Maternal nutrition has a direct impact on foetal neurodevelopment, as diet and food choices play a significant role in defining maternal nutritional status [35]. For a healthy pregnancy and successful foetal development, the maternal diet is crucial [143]. Around 22 days after conception, foetal neurodevelopment starts, and it progresses quickly in the second and third trimesters [63].

It's essential to have proper nutrition from the start of pregnancy as it interferes with the neural tube and plate's development. Nutrients like folic acid, copper, and vitamin A play a crucial role in this process. The specific neurodevelopmental processes are also dependent on a number of nutrients. Different parts of the brain engage in each process at various, overlapping times. For instance, myelination of the brainstem auditory pathway starts from week 26 of pregnancy and lasts for at least a year after delivery. The formation of myelin requires fatty acids like Docosahexaenoic Acid (DHA) [143]. As the fetal brain develops quickly, inadequate maternal intake of vital nutrients throughout pregnancy can affect the development of the structure and components of the brain [113].

### Necessary Nutrients for Brain Function

For the anatomical and functional growth of the brain, all nutrients are essential, the ones that aid in energy, carbohydrate, protein, and fat metabolism are especially significant [67]. The three macronutrients that make up the body's main energy sources are carbohydrates, proteins, and fats [117]. Iodine, copper, zinc, and choline, vitamin A, and Long-Chain Polyunsaturated Fatty Acids (LC-PUFAs) are additional nutrients that have significant impacts on brain structure. Through their impact on neurotransmitter concentrations, receptors, and re-uptake systems, nutrients also have an impact on how the brain functions. Nutritional factors that specifically affect neurotransmitter activity include protein, iron, zinc, copper, and choline. Through their impacts on metabolic rate, nutrients also have an impact on the electrophysiologic potential of neurons. Neuronal electrical potential generation is a high-energy activity that depends on functioning mitochondria producing enough ATP. As a result, the developing brain has a high requirement for nutrients that

promote glycolytic and oxidative metabolism [67].

### I. Carbohydrates

In Parenteral Nutrition (PN), glucose serves as the main non-protein energy source and, because it is quickly metabolised, is crucial for the growing brain after birth. As a result of their limited glycogen stores, preterm neonates require an adequate source of exogenous glucose to maintain proper growth and brain development. The neonatal period's demands for glucose change depending on the neonate's specific needs as well as the gestational age. An infusion rate of 3-5 mg/kg/min of glucose is enough for the majority of newborns [153].

### II. Protein

Neonatal protein consumption is essential for the healthy development of the brain and lean body tissue [162]. A diet low in protein during pregnancy is linked to changes in the brain's oxidative state and neurotransmitters. As a result, psychosocial issues start in childhood and persist throughout adulthood [164]. Legumes are nutrient rich sources of protein [118].

### III. Omega-3 Fatty

Lipids make up about 50-60% of the brain's weight, and 35% of those lipids are omega-3 Polyunsaturated Fatty Acids (PUFAs). Over 40% of all omega-3 PUFAs, especially in the grey matter, are made up of Docosahexaenoic Acid (DHA) in neural tissue [50]. The brain lipid composition is unique and exceedingly diverse. The development of the brain is thought to depend on PUFAs from the omega-6 and omega-3 families, which are lipids that must be obtained from food. Beginning during gestation, the brain begins to accommodate both omega-3 and omega-6 PUFAs, a process known as "accretion." The third trimester of pregnancy is when DHA accumulation begins in humans [109].

Omega-3 enhances mental function, protects neurons from degeneration, and preserves them [50]. Omega-3 fatty acids are highly prevalent in marine life and plant-based meals like grains and seeds. Docosahexaenoic Acid (DHA) and Eicosapentaenoic Acid (EPA) occurs naturally in different types of fish, however they can be obtained indirectly from certain seeds and grain. ALA, which is normally transformed into EPA and DHA with the aid of particular enzymes, is the most common type of omega 3-fatty acids found in plant seeds and grains [86].

According to studies, fewer than 20% of people worldwide ingest more than 250 mg/day of n-3 LCPUFAs from seafood. The brain accumulates a significant amount of DHA during the first two years of life, both before and after birth [187]. Human neuroimaging research most recent findings imply that grey matter shrinkage in healthy, middle-aged, and elderly persons is associated with decreased intake of omega-3 PUFAs, without pre-existing neurological conditions, particularly in the areas of the brain such the prefrontal cortex, hippocampus, amygdala, anterior cingulate, and temporal cortex that are frequently linked to mood and psychotic illnesses [114].

### IV. Zinc

Zinc, a necessary trace element, is crucial for brain growth, synaptic plasticity, and overall brain health [141,177]. The cerebral cortex, amygdala, olfactory bulb, and hippocampal neurons are among the regions of the brain that contain free zinc ion (Zn) neurons. The presence of zinc is crucial for adult brain neurogenesis, which has profound effects on the hippocampal structure and function, including memory and learning as well

as emotion and mood control [177]. Recommended daily intake of Zinc for men are 11mg and 8 mg for women [195]. Various illnesses, such as Alzheimer's disease, Parkinson's disease, and mood disorders, have been hypothesised to be influenced by changes in the amount of zinc in the brain [151]. Inadequate zinc during development can also disrupt brain function in the offspring, which might show as altered behaviour, motor and cognitive function, and attention symptoms, e.g. depression, and altered child psychomotor development [99]. Because the body cannot store zinc, it must be consumed regularly through diet to meet physiological requirements [25]. The main sources of zinc include dark green and dark yellow vegetables, shellfish, meat, eggs, cereals, peanuts, dairy products, and whole grains [87].

## V. Choline

It is a necessary nutrient and is crucial for the production of the neurotransmitter acetylcholine, maintaining the integrity of cell membranes, metabolism of methyl groups (which lowers homocysteine), transmission of neural impulses and lipid transport (lipoproteins) [55,81]. Additionally, choline is involved in memory, learning, cognitive function, and sensory processing. It is commonly known that choline aids with brain growth. Diet is the primary way that choline enters the body. Sufficient choline intake is also important during gestation as it contributes to the growth of the brain [81].

## VI. Selenium

As a crucial micronutrient that controls growth, differentiation, and development, selenium (Se) is a trace element. According to available data, Se may be important throughout key stages of brain development. Se is co-translationally integrated into the polypeptide chain as part of the amino acid selenocysteine to produce selenoproteins, unlike other essential trace elements that play biological roles in proteins in the form of cofactors. Selenoproteins, of which 25 have been discovered, are essential for brain function [4]. Food sources of selenium are Brazil nuts and other nuts, grains, veggies, meats, and oil seeds [59].

## VII. B Vitamins

B vitamins, in particular B6, B12, and folate, have an impact on how the central and peripheral nervous systems operate by helping to keep the nervous system healthy and enhancing neurological disorders even when a deficiency is not known to exist [81]. Numerous mental illnesses have been connected to vitamin B deficiency [52]. Thiamine is found in foods including powdered milk, eggs, almonds, oats, oranges, dry pulses, and liver [177].

### Malnutrition

One of the key factors that can obstruct brain development is malnutrition [164]. Malnutrition presents in 3 forms - undernutrition, micronutrients deficiencies and over nutrition. An imbalance between dietary demands and nutrient intake that results in a cumulative loss of calories, protein, or micronutrients is referred to as paediatric malnutrition, also known as undernutrition and hidden hunger. Poor growth and impaired physical or mental development may be the results of such dietary deficiencies [125].

Malnutrition, including overnutrition and undernutrition, can lead to altered maternal nutrient use [35]. Nutritional deficiencies can affect the growth of the brain, synapse formation,

and cell differentiation. Research on the effects of malnutrition on the Developing brains can be categorised into two types: studies that focus on clinical and physical brain growth and maturation and studies that focus on the development of "brain function," which includes neurological, psychomotor, and intellectual development [164].

### Junk Foods Effects on the Brain

It is believed that the modern diet's food choices have a substantial environmental impact on teenage neurodevelopment. Young people are especially drawn to "junk foods" because they are affordable, nutrient-deficient, and energy-dense. Adolescence is a pivotal phase when exposure to psychostimulants, cannabinoids, and high-fat or high-sugar diets can have pronounced and long-lasting negative impacts on cognition, behaviour, and learning, according to a growing body of research. Diets heavy in fat and sugar, in particular, quickly interfere with cognitive functions involving the hippocampus. Studies conducted on humans also show a link between worse cognitive abilities in the adolescent population and consumption of unhealthy diets, particularly those high in dietary fat [152].

A Western Diet (WD) is linked to decreased cognitive function across the lifespan [183]. Recent research has revealed that American adults consume more saturated fats and added sugars than the 5-10% range advised by the US Departments of Agriculture and Health and Human Services. American adults consume about 12% of their daily energy intake from saturated fats and 13% from added sugars. However, it has been discovered that eating a high-fat diet has a deleterious impact on human memory performance, notably in the hippocampus [175].

### Objectives

1. To boost up memory through diet
2. Nutrients for the development of the brain
3. Foods that adversely affect normal brain function

### Review of Literature

#### Nutrition and Brain Development

One of the significant factors that influence brain development is nutrition [62]. Nutrition is especially important during pregnancy and infancy [143], and plays an essential function in assisting the anatomical and functional evolution of the human brain and cognitive system from conception through early childhood and into old age [113,180,185]. The most crucial time for brain development is generally acknowledged to be the first 1,000 days of life, from conception to age two [49] (McCann et al., 2020). To ensure proper neurodevelopment and lifelong brain function, it is important to have an adequate supply of nutrients during this period [45]. Nutrition influences development of the brain after birth and during the prenatal period as well [49]. In adults, the brain makes up 25% of body weight and consumes 20% of total energy intake; in children, it makes up 5-10% of body weight and controls 50% of metabolic rate [170].

A healthy diet is essential for normal brain development, optimising brain function and preventing cognitive decline [143,148]. Cognitive function refers to a range of brain functions and processes, such as receiving external information, internally processing it, and responding with a behaviour [12]. The Central Nervous System's (CNS) growth and development require proper nutrition [29]. Childhood emotional and behav-

neuronal dysregulation is linked to dietary restriction, poor maternal nutrition status, and early diet [103,110].

Cell differentiation, migration, and connection are all tightly regulated processes during the development of the brain that depend on momentarily overlapping stages. The brain function could be impacted by any disruption to this mechanism [29]. During development, the human brain is formed in the late period of pregnancy and initial postnatal periods [14]. Early in the brain's development, neuronal and glial cells separate from precursor cells and move to take up their final locations. The brain over produces neurons and synaptic connections at this period, and between the ages of 1 and 2 years, the brain reaches its peak synapse creation. Synaptic pruning refers to the removal of redundant synapses and cells by microglia [160]. The primary immune-competent cells of the CNS, microglia, play a significant role in all aspects of brain growth and function [18]. Inflammation of the nervous system and brain development are crucially dependent on microglia [95,160].

The last step Myelin sheaths are formed during the foetal brain's development, creating an insulating layer that enables quick signal transmission. The CNS's stem cells continue to differentiate into neural or glial cells that move into the cerebral white or grey matter even beyond adulthood [52].

60% of the body's overall oxygen and calorie usage occurs in the neonatal human brain [67]. Around the world, one-third of children's do not develop to their fullest potential by the time they are in preschool. Children growing up in Low and Middle-Income Countries (LMICs) are most at risk, and sub-Saharan Africa has one of the highest rates of cognitive deficiency (McCann et al., 2020).

### Maternal Diet

In the 20th century, research on the role of maternal nutritional factors in offspring development became a crucial area of study. An optimal maternal nutrient supply and food choices can directly influence fetal neurodevelopment [35]. Maternal malnutrition during pregnancy can negatively impact placental function, resulting in changes to placental size, shape, and blood flow, which may lessen the fetus's access to nutrition. Later, the foetal nutrition status is disturbed, which has dramatic consequences on organogenesis, growth, and programming and has been linked to both short and long-term effects on development and morbidity [108].

Healthy pregnancy and successful foetal development depend on the food of the mother. Approximately 22 days after conception [143], the brain and spinal cord develop from an ectoderm region referred to as neural plate [181]. Proper nutrition is crucial from the beginning, as vitamins and minerals like copper, folic acid, and vitamin A can affect how the neural plate and neural tube develop. For particular neurodevelopmental processes, a number of nutrients are required. In various parts of the brain, each process happens in distinct, overlapping time periods. By way of illustration, myelination of the brainstem auditory circuit begins from week 26 of pregnancy and lasts for at least a year after birth. Fatty acids such as docosahexaenoic acid (DHA, C22:6 n-3) are necessary for myelination. [143]. Human studies suggest that prenatal inflammation and low consumption of n-3 Polyunsaturated Fatty Acids (PUFAs) can have a negative impact on neurodevelopment, leading to long-lasting consequences on behaviour [95].

As the fetal brain grows quickly, the structure and function-

ing of the developing brain might be impacted by low maternal consumption of essential nutrients during pregnancy [113]. Malnutrition in mothers can alter the brain development of the embryo, leading to changes in developmental tendencies that may impact learning, memory, and social-emotional processes. Deficiencies that occur in the postnatal period can persist throughout adulthood, and may increase the possibility of developing schizophrenia, personality problems, and other psychiatric illnesses including depression [29].

### Nutrients for Brain Function

All nutrients are important for all cells to function [41]. However, certain nutrients are essential for the anatomical and functional growth and development of the brain, and they are especially crucial for the metabolism of fat, protein, and carbohydrates for energy. Iodine, zinc, copper, choline, iron, folate, iodine vitamin A, D, B6, B12, and Long-Chain Polyunsaturated Fatty Acids (LC-PUFAs) are additional nutrients with significant impacts on brain morphology and neurotransmitter function [67,155,192]. Micronutrients are essential dietary components [166] that make up the CNS structure and play major functional roles [71]. Lifelong impairments in brain function may result from failing to provide these essential nutrients throughout the crucial time of brain development [192].

The nutrients have an impact on the metabolic rate, which has an impact on the electrophysiologic potential of neurons. A healthy mitochondrion must produce sufficient amounts of ATP in order for neurons to generate their electrical potential, which is a highly energy-intensive activity. In order to maintain glycolytic and oxidative metabolism, the developing brain is highly dependent on certain nutrients [67].

#### I. Carbohydrates

Despite the adult brain accounting for only 2% of body weight, it requires a significantly higher amount of energy. 20-23% of the body's overall energy needs, mostly in the form of glucose, are met through this action [39]. The brain mostly uses glucose as fuel, the brain also has an alternative fuel for occasions when glucose supply is inadequate, such as extended fasting, starvation, intense exercise, nutritional ketosis, or malnutrition [39,69]. In that it specifically requires ketones (also known as ketone bodies) [39]. Ketones are an important substitute fuel for glucose for the brain during fasting intervals and extended exercise. Due to their increased oxidative efficiency and competition with pyruvate for entry into the citric acid cycle during fasting or calorie restriction, plasma ketones (acetoacetate [AcAc] and  $\beta$ -hydroxybutyrate [BHB]) rise and reduce the need for brain glucose [186].

The principal glucose catabolic pathways, which are crucial for neurons, are likely mostly divided between astrocytes and neurons. The most prevalent glial cells in the brain, astrocytes, carry out a variety of tasks in the Central Nervous System (CNS), including synaptic transmission and synaptogenesis as well as energy storage in the form of glycogen. According to recent research, astrocytic lactate transporters cause molecular alterations important for memory formation and intraneuronal lactate import is required for long-term memory and glycolysis [83].

In addition, there is growing evidence linking the amount of carbohydrates in breast milk to a baby's neurodevelopment. Breast milk carbs have an impact on neurodevelopmental results in addition to somatic growth outcomes [16]. The milk

from a mother is examined to be the ideal resource for infant nutrition [111]. Infant somatic development and breast milk fructose were positively correlated [16]. Carbohydrates, particularly oligosaccharides, are a crucial component in breast milk that aid in the development of the brain. Mature human milk has a carbohydrate content of about 7% [17]. Cereals have been important source of carbohydrates [89].

## II. Protein

Protein intake was positively associated with cognitive function [100]. Neonatal protein consumption is necessary for the proper development of lean body tissue, and particularly the brain [162]. During pregnancy, an inadequate protein intake is linked to changes in the brain's oxidative state and neurotransmitters. As a result, psychosocial issues start in childhood and persist throughout maturity [164].

Neurotrophins are important for brain function in humans [115]. Small proteins called neurotrophins, which are found in the brain and other tissues, control a number of crucial elements of neuronal function, such as neurogenesis, synaptic plasticity, and neuroprotection, as well as programmed cell death [130]. Along with neurotrophins, neuropeptides such as neuropeptide Y are crucial for various pregnancy processes and foetal brain development [158].

The activity of the brain's satiety centers has been found to be influenced by high protein diets [70,196]. It has been demonstrated that a high protein diet affects the function of the brain's satiety centers. Gastric hormones like cholecystokinin and the vagal nerve may interact to send protein signals to the brain [43]. Legumes are nutrient-rich source of protein [118]. Protein is largely obtained from milk and dairy products like cheese and yoghurt [196]. For adults, 0.8 g/kg BW of protein is the Recommended Daily Intake (RDI) [98].

## III. Omega-3 fatty acids

The brain has a distinctive and incredibly complex lipid makeup [109]. The brain's most prevalent fatty acids, Long Chain Polyunsaturated Fatty Acids (LC-PUFAs), are crucial for the formation and growth of the brain [134]. A lipid-based structural component makes up 50-60% of the brain, of which 35% and 30% are omega-3 (PUFAs) [5,14,50]. During development, the buildup of PUFA in the brain is essential [5].

The brain contains a high concentration of the fatty acids docosahexaenoic acid (DHA; n-3 PUFA) and Arachidonic Acid (AA; omega (n)-6 PUFA), which together account for nearly 90% of the brain's PUFAs [109]. DHA, is one of the most studied LCPUFA [34], which is accumulated during the brain growth spurt beginning in the second half of pregnancy, especially in the first two years of life, which are crucial for the development of the central nervous system and other functional organs [96,160,186]. DHA is crucial for brain homeostasis during fetal development [74]. DHA has been reported to affect cognitive functions such as working memory, mental agility, information processing rate and motor neuronal preservation, and protection against neurodegeneration [50].

DHA, although being a highly unsaturated fatty acid, can act as an antioxidant in a brain that is prone to oxidation. Detoxifying enzymes support DHA's antioxidant defence in brain cells [15]. Parkinson's Disease (PD) and Alzheimer's Disease (AD), among other neurodegenerative diseases, were protected against by DHA [74]. Omega-3 (EPA and DHA), have attracted

great attention for their ability to prevent cognitive decline as a result of the anti-inflammatory and anti-amyloidogenic properties of PUFAs [31]. The physiology of the brain is significantly influenced by omega-6 and omega-3 Polyunsaturated Fatty Acids (PUFA) [19]. The balance of n-6/n-3 PUFAs during prenatal development has an impact on the hippocampus by influencing neurogenesis. The structure of the adult hippocampus may also be affected by the balance of n-6/n-3 PUFA throughout adulthood [156]. Due to the body's inability to synthesize either n-6 or n-3 PUFA endogenously, both are considered essential fatty acids that must be obtained through diet [109,197] while Long-Chain (LC) PUFAs, EPA, and DHA can be synthesized endogenously from their precursor 3 or 06 PUFA or obtained through direct dietary consumption or supplementation [197]. Both n-3 and n-6 PUFAs begin to be incorporated into the brain during pregnancy, a process known as "accretion." In humans, DHA accretion starts at the beginning of the third trimester of pregnancy and continues throughout this trimester [109,150].

While pregnant women are advised to consume enough n-3 fatty acids. By activating PPAR- $\gamma$ , increased n-3 LCPUFA consumption during pregnancy and lactation promotes the development of the developing brain [15]. The prefrontal cortex, hippocampus, amygdala, anterior cingulate, and temporal cortex are among the brain regions frequently linked to mood and psychotic disorders, and recent evidence from human neuroimaging studies suggests that decreased omega-3 PUFA intake is linked to faster grey matter atrophy in healthy, middle-aged, and elderly adults [114]. A higher intake of omega-3 PUFA might be linked to a decrease in AD risk [74].

Diet rich in PUFAs from the omega-6 and omega-3 families are considered crucial for brain development and have been linked to improve memory [109,126]. While ingestion of polyunsaturated fatty acids (DHA) has positive effects in their prevention, high saturated fat intake has been linked to cognitive decline [155].

High concentrations of Omega-3 fatty acids can be found in marine life and plant-based foods like grains and seeds. Plant seeds and grains which are rich in omega-3 fatty acids are found in the form of alpha-linolenic acid (ALA, C18:3 n-3), which is transformed into Eicosapentaenoic Acid (EPA) and DHA by a set of particular enzymes. Fish types contain EPA and DHA directly, whereas they can be found in grains and seeds in an indirect manner [86]. Human milk is a common and natural source of LCPUFA and DHA [34]. The ALA, is also present in addition to soybean and canola oil, in flaxseed oil and walnuts, and the EPA and DHA are found in seafood [58]. Preferable neurocognitive development of the offspring is linked to the ingestion of commercially available fish during pregnancy [27].

A normal Western diet has an increased 20-30:1 n-6 to n-3 PUFA ratio [5]. N-3 LCPUFAs, which comprise DHA and EPA, are mostly obtained from oily fish [90,180]. Previous research have suggested that eating fatty fish and its component n-3 fatty acids improves brain health and neurocognitive development [90]. Less than 20% of the world's population is thought to ingest more than 250 mg/day of seafood-origin n-3 LCPUFA, according to research on the global intake of these fats [187]. The recommended amount of omega-3 fatty acid consumption is 0.6-1.2% of total calorie intake [184]. For the processing of LLC-n3-Fatty acids, astrocytes in the brain are a key location [77].

After weaning, n-3 PUFA supplementation cannot repair the negative effects of PUFA deficit that occur during pregnancy and

breastfeeding on the brain neurogenesis and apoptosis of the adult offspring [57]. Lack of N-3 PUFAs disrupts neurotransmission, neuritogenesis, and synaptic fine-tuning, resulting in a variety of neurobehavioral disorders [95]. Numerous studies show that elderly people's brain health and cognition are improved by LC-n3-FA ingestion through fish or fish oil supplements [77].

#### IV. Vitamin A

Fat-soluble vitamin A is a necessary nutrient that is fat-soluble and can be obtained from both plant- and animal-based sources [133]. The mother needs vitamin A and the compounds that are derived from it during pregnancy for the maintenance of the placenta, and the embryo needs it for the formation and development of many different organs, including the heart, eye, kidney, lung, limbs, spinal cord, and brain. Vitamin A is stored in the placenta and is released to the developing foetus during pregnancy. This storing process helps ensure that retinoids are adequately delivered to protect the developing fetus in situations where mothers don't consume enough [20].

The hippocampus, which is important for learning and memory, as well as the hypothalamus, which is important for maintaining the body's internal physiological equilibrium, all depend on vitamin A [171]. It is well-known that both vitamin A deficiency and excess during prenatal and postnatal life can lead to birth defects, also known as teratogenic effects [201]. Vitamin A deficiency can negatively impact the hypothalamus, which may result in a decreased appetite and growth [171].

Vitamin A cannot be synthesised by the body, it must be consumed through diet [126]. Functional Vitamin A concentrations are highest in liver and fish oils [146]. The liver has around 90% of vitamin A [201]. Glandular meat, red palm oil, milk, egg yolk, carrots, tomatoes, apricots, green vegetables, fortified processed food that may include cereals, condiments and fats are all rich in Vitamin A [54,149]. Breast milk is one of the primary sources of vitamin A for infants [54].

#### V. Zinc

Zinc (Zn) is a crucial trace element that is crucial for brain health, development and synaptic plasticity [141,177]. The hippocampus, cerebral cortex, thalamus, and olfactory cortex have the largest concentrations of it, along with the amygdala and cerebral cortex [92]. Offspring may experience impaired brain performance caused by a lack of zinc during development, which can result in modified behavior, cognitive and motor performance, attentive symptoms, such as depression, and altered child psychomotor development [99]. Both excess and deficiency is associated with cognitive decline. Approximately 150 µmol/L is the average concentration of zinc ions [174].

A crucial step in the CNS's growth is neurogenesis [92]. Zinc's importance for neurogenesis in the adult brain has wide-ranging effects on how the hippocampal region functions in terms of memory and learning as well as emotion and mood regulation. Zinc supplementation (15 or 30 mg/day) was tested in 387 healthy individuals between the ages of 55 and 87 in a study on the relationship between zinc and cognitive function in adults. Each zinc dose taken over a three-month period, the study found, improved spatial working memory. One of the few studies on the relationship between zinc and cognitive function in adults looked at the effects of zinc supplementation (15 or 30 mg/day) in 387 healthy individuals aged 55 to 87 years and found that each dose had a beneficial impact on spatial working memory over the course of three months [177].

A lack of zinc is linked to a number of different mental illnesses. Inadequate levels of zinc affect behaviour, mental health, and brain development since it is essential for neuronal impulses. A number of diseases, including Alzheimer's, Parkinson's, and mood disorders, have been associated to changes in brain zinc levels [151]. There is a higher risk of zinc insufficiency throughout pregnancy and older infancy [112].

To achieve nutritional demands for zinc, which cannot be stored by the body, one must consume it frequently [25]. Dietary Reference Intakes (DRIs), developed by the Food and Nutrition Board (FNB) at the Institute of Medicine of the National Academies, suggest a daily consumption of 8 mg of zinc for women and 11 mg for men. These values can be increased during pregnancy. The vast majority of Zinc intake comes from food [195]. The highest amounts of zinc were found in oyster, fortified breakfast cereals, beef meat, pumpkin and squash seed kernels [61,195].

#### VI. Choline

Choline is one of the vital nutrients necessary for normal brain development and may be the first step in the pathogenesis of the psychotic spectrum [45,65,66]. Choline is recognised to aid in the growth of the brain [81]. Acetylcholine, the neurotransmitter choline, cell membrane integrity, methyl-group metabolism (homocysteine reduction), the transmission of brain impulses, and lipid transport (lipoproteins) are all significant functions of choline [81,55]. Choline also contributes in sensory processing, memory, learning, and neurocognition [81,131]. During pregnancy, it's critical to consume enough choline since it helps with brain growth [81].

Choline deficiency can cause irreversible impairments. Life-long deficiencies in brain function may occur if choline is not provided during the first 1000 days of life [45]. It has been demonstrated that low maternal choline intakes during pregnancy increase the incidence of neural tube abnormalities, a cleft palate and suboptimal brain development among the fetus and in infants [192,193].

Normally, choline is ingested into the body through food [81]. The best sources of choline are liver, wheat germ, milk, eggs, meat, fish, poultry, and dairy products. Choline is also present in some plant foods, such as cruciferous vegetables and some legumes [55,131,192]. Eggs, on the other hand, are a more concentrated source of choline. For pregnant women, 450 mg/day of choline is considered a sufficient dose [13,72], 550 mg per day for nursing mothers [72,131] 550 mg per day for men and 425 mg per day for women [189]. Animal studies have suggested that providing choline supplements during pregnancy can lead to better cognitive outcomes in offspring [78].

#### VII. Selenium

The trace element selenium (Se) is a vital micronutrient that controls growth, development, and differentiation [4]. Selenium seems to have greater effects on brain development in comparison to other microelements [122]. According to the available evidence, Se may be important throughout crucial stages of brain development [4]. Its influence is mediated primarily through selenoproteins [140]. To create selenoproteins, se is co-translationally integrated into the polypeptide chain as a component of the amino acid selenocysteine. There are 25 selenoproteins that have been identified, and they are crucial for brain function [4].

Neurodevelopment and maternal selenium levels have been linked in similar ways [188]. Thus, in connection to prenatal Se levels, impacts on a child's cognitive development have been identified that are favourable, negative, and null (Amoros et al., 2018). In the first two years of life, these levels were favourably correlated with a child's psychomotor development [141]. Age-related cognitive decline, decreased coordination, motor speed, and muscle strength was all linked to low Se levels in humans [200].

Exposure to this element mainly occurs through diet, particularly through seafood and fish and through meat, cereals and eggs [188,190] whereas the selenium level in plant-based diets varies depending on the region of cultivation [188]. Se is also present in breast milk (Amoros et al., 2018). During pregnancy, the requirement for selenium increases. General recommendation of selenium for pregnant women is 60 µg/d [168]. The daily selenium allowance for newborns up to four months old is 10 µg (0.13 µmol), while 15 g (0.19 mol) of recommended intake is for infants between the ages of 4 and 12 [188].

### VIII. B Vitamins

Vitamins of the B group are water-soluble vitamins with many positive effects on the nervous system [106]. B vitamins being necessary for every facet of brain function [85]. The B vitamins B6, folate (B9), and B12 have drawn the most attention in studies examining their effects on brain development [148]. B6, B9, and B12, affect both the peripheral and central nervous systems' functionality by improving neurological conditions and maintaining a healthy nervous system, even when a deficiency is not determined [81]. The Consortium to Establish a Registry for Alzheimer's Disease (CERAD) word acquisition and recall modules were used to examine the relationship between dietary intakes of vitamins B6, B9, and B12 and cognitive function in the elderly [199].

Folate, also known as Vitamin B9 [191] has special importance in pregnancy [191]. Pregnant women should consume at least 400 µg (mcg) folic acid [23], preferably a month before conceiving [108]. Folate is naturally found in many food sources [191]. Leafy greens, seeds, fortified cereals, and folic acid supplements are all natural sources of dietary folate [63]. Recent work promote the consumption of folate-abundant plants along with the addition of foods high in folate, including bread and eggs. Meanwhile, animal liver is a plentiful natural supply of folate but is frequently disregarded [42].

Vitamin B6 (Thiamine) can be consumed in its purest form through fish, liver, pork, fortified cereals, eggs, nuts, oats, oranges, dried beans, yeast, powdered milk, potatoes, dark leafy greens, and chickpeas [63,177]. The main dietary source of vitamin B12 is found in foods including meat, milk, eggs, fish, and shellfish that are sourced from animals [194]. Liver in particular is a very rich source of Vitamin B12, followed by kidney and heart [169]. Compared to non-vegetarians, vegetarians are more susceptible to vitamin B12 insufficiency [194].

Numerous mental illnesses have been connected to vitamin B deficiency [52] like Parkinson's and Alzheimer's disease [106]. In later life, vitamin B insufficiency and elevated total plasma homocysteine levels have been related to poor cognitive function, cognitive decline, and dementia [60,93]. In both the cognitive-domain and global cognition trials, allocating to B vitamins was linked to a 28.4% and 26.1% decrease in homocysteine plasma concentrations [32]. Evidence shows that vitamin B supplementen-

tation may lowers the homocysteine level that reduce cognitive decline [204]. To prevent neural tube closure problems, which affect about 50% of the population, and to further benefit children's neurodevelopment, folic acid supplementation has been frequently recommended to expectant mothers [131,147].

Studies have shown that a lack of folate is associated with changes in offspring' neurodevelopment, include changes in neurogenesis and neuronal death, changed cortica thickness and cerebral white matter, and decreased overall brain volume. These modifications have been associated with alterations in brain activity in children, including memory, mo function, linguistic abilities, and psychological problems [191].

In particular, the metabolism and transport of glucose are sensitive to the brain. The function of pancreatic beta cells, gluconeogenesis (and lipogenesis), insulin receptor transcription, and hepatic glucose uptake are all significantly regulated by biotin (vitamin B7) [85].

### IX. Vitamin D

During the past decades, numerous studies that demonstrate the relationship between vitamin D and brain health as well as the effects of vitamin D insufficiency on the brain have been reviewed [7]. The nervous system's health and disease are affected by vitamin D and its metabolites in a variety of ways [44]. During foetal development, growth, and senescence, vitamin D may be essential for improving neurocognition; but, in maturity, it may have little (or no) effect [8]. Vitamin D may influence particular neurotransmitters and cortical function [37]. Vitamin D has crucial roles in the brain's calcium signalling, proliferation and differentiation, as well as neurotrophic and neuroprotective activities. It may also change synaptic plasticity and neurotransmission [73].

Vitamin D can impact the brain through different mechanisms, such as regulating neurotrophic growth factors, influencing inflammation, and thrombosis [127]. Numerous research has examined the associations between maternal Vitamin D (VD) insufficiency and the brain health of offspring. The placenta allows vitamin D to pass from the mother to the foetus. thus, the mother is the sole source of vitamin D substrate for her developing child. Studies have suggested that low maternal VD levels could affect neuronal development and lead to the beginning of mental disorders like schizophrenia and autism [138].

It has been shown that vitamin D status affect brain cell differentiation. Numerous clinical brain conditions are connected to vitamin D levels (Eyles, 2020). Dementia, Alzheimer's disease, and Parkinson's disease have all been associated with low vitamin D levels [36]. However, the causality of the association between VD and dementia has not been confirmed [127]. Interestingly, some studies have shown that VD deficiency is linked to reduced hippocampus volumes, which is a brain region that has a crucial role in memory and learning [36]. Worldwide, there is a high prevalence of vitamin D insufficiency [73]. Numerous studies have found a connection between adult vitamin D insufficiency and some neurodegenerative diseases [38].

By exposing skin to sunlight, vitamin D can be produced internally in the body [65,120] and from foods and supplements that include the vitamins D2 and D3 ergocalciferol and cholecalciferol, respectively [120]. The primary nutritional source of vitamin D2 is mushrooms (Janousek et al., 2022), along with fatty fish and eggs, whereas most of vitamin D3 is synthesised within the body [10]. Natural dietary sources of vitamin D3 is

also present in small amounts in the diet of animal origin and include fatty fish, egg yolks, liver oils, dairy products, and supplements [12] (Janousek et al., 2022). In humans, most vitamin D is acquired by vitamin D<sub>3</sub> production in the skin [107]. Vitamin D supplements is readily available and affordable [73] and should be integrated into the care management of older adults with cognitive disorders [8].

## X. Copper

Trace elements such as copper (required in amounts 1 to 100 mg/day by adults) are essential micronutrients [206], for brain health [3]. However, it may be hazardous when administered in excess [91]. Astrocytes are regarded as crucial controllers of copper homeostasis in the brain. Menkes disease, Wilson's disease, and Alzheimer's disease are just a few of the conditions that have been linked to impaired homeostatic systems of copper metabolism in humans [6,161].

Several biological activities require copper, including controlling intracellular signal transduction, balancing catecholamine levels, promoting neuronal myelination, and facilitating efficient synaptic transmission in the central nervous system [6]. Milk, is a dietary source of copper [144]. Food and water are the main sources of copper intake [198]. Sources of copper include dietary categories such nuts and offal, and to a lesser extent grains and fruit [21].

## XI. Lutein and zeaxanthin

Zeaxanthin and lutein operate widely in several brain areas [47]. The carotenoids lutein and zeaxanthin (L+Z) build up in neural tissue and may have positive effects on cognition [26]. Lutein intake is associated with positive outcomes in brain health [121]. Lutein is particularly distributed in gray matter, and has been identified in the prefrontal cortex, the temporal cortex, and the hippocampus. Of particular concern, lutein levels have been associated with memory and general intelligence [202].

L and Z have been suggested to benefit cognitive function and neural outcomes in older adults through dietary intake [119]. For instance, consuming a diet high in carotenoids in late middle age was linked to higher executive functioning, working memory, verbal fluency, and episodic memory 13 years later. By improving cell membrane fluidity, permeability, stability, thickness, and ion exchange, L and Z may also have good impacts on neurocognitive performance [101]. L and Z in neural tissue can have various biological effects, such as antioxidation, anti-inflammation, and structural actions [82].

Since L and Z cannot be synthesised in the body, they must be obtained from diet, specifically through green vegetables, coloured fruits, and other dietary sources [101]. 1-3 mg/day of L and Z are often found in a typical US diet. In addition to egg yolks, common sources of these carotenoids include green leafy vegetables including kale, spinach, broccoli, peas, and lettuce. Einkorn, Khorasan, and durum wheat, maize, and their food items also contain them in rather large concentrations. The ratio of L to Z in green vegetables has been observed to range between 12 and 63, with kale having the highest value, while this ratio ranges between 0.1 and 1.4 in yellow-orange fruits and vegetables [1].

### Relationship between Healthy and Unhealthy Foods and Brain

Walnut diet can enhance memory and cognitive level [2],

Consuming walnuts in your diet might reduce oxidative stress by lowering the production of free radicals and improving antioxidant defence, which will limit oxidative damage to lipids and protein [28]. Walnut extracts could decrease Amyloid- $\beta$  fibrillation and aggregation, indicating their positive impact on memory and cognition [2].

English walnuts are abundant in Linoleic Acid (LA), Alpha Linolenic Acid (ALA), polyphenolics, phytosterols, and micronutrients [2,142] which, regardless of age, have been found to enhance brain health and function. In addition to 4.4 g of saturated (palmitic acid, 16:0) and 8.7 g of monounsaturated (oleic acid, 18:1n-9) fatty acids, each 100 g of walnuts (*Juglans regia*) contains 38 g of LA and 9 g of ALA [142].

The findings suggested that eating more 'healthy' foods such fruit, vegetables, seafood, and whole grains was associated with a lower risk of depression [79]. Healthy eating habits have been demonstrated to be inversely associated to the likelihood of, or risk for, depression in recent systematic studies looking at the connection between nutrition and common mental diseases. Such diets emphasize eating fruit, vegetables, whole grains, nuts, seeds, and seafood while limiting the intake of processed foods. On the other hand, it has been demonstrated that unhealthy diets high in processed, high-fat, high-sugar meals during adolescence and adulthood are positively connected with the prevalent mental disorders, sadness, and anxiety [110].

The benefits of caffeine for the brain are numerous. Only those who are sensitive to caffeine may experience sleep disruption. Caffeine is not dangerous whether used in doses of 200 mg in a single sitting (equivalent to about 2½ cups of coffee) or 400 mg per day (equivalent to about 5 cups of coffee). Long-term coffee use has been associated with reducing the risk of stroke, Parkinson's disease, and Alzheimer's disease as well as preventing cognitive decline [128].

High nutrient intake can have negative impacts on cognition through promoting atherosclerosis, hypertension, and poor glycemic management [184]. A considerable and long-lasting effect on cognition can be produced by calorie intake and diet composition. There is evidence that certain dietary elements may reduce the incidence of age-related cognitive decline and AD, such as antioxidant or vitamin foods, fish, and dietary fats [24].

The research suggests that eating a balanced diet that prioritises consuming fish, fruits, vegetables, nuts, and seeds while limiting the consumption of added sugars will significantly slow and reduce cognitive decline [184]. Diets with a low glycemic index have been shown to improve cognition, memory, and functional capacity, whereas diets high in simple sugars have been connected to attention and concentration problems. The manufacture of neurotransmitters, especially serotonin and catecholamines, requires a steady supply of amino acids in the brain. Reduced memory, thinking, and learning have been linked to low serotonin levels (RM et al., 2018). Low serotonin levels and impaired brain function are both likely to be linked to excessive sugar consumption [135].

Choline, iron, iodine, vitamins B1, B6, B12, D, and folic acid have been shown to enhance cognitive function and have neuroprotective benefits. Antioxidants like vitamins C, E, and A, zinc, selenium, lutein, and zeaxanthin are essential for preventing the oxidative stress that is associated with cognitive decline and for enhancing cognition. However, the current trend of



consuming diets that are low in fruits, vegetables, and water and heavy in refined sugars, saturated fats, and sodium may be detrimental to cognitive function (RM et al., 2018). Toxic trace elements, such as lead, methylmercury, arsenic and manganese have constantly been shown to impair neurodevelopment [88].

Dairy products have been extensively studied and are considered nutrient-dense and health-promoting, providing numerous health benefits to consumers [76]. While it has been suggested that dairy consumption can affect cognition, though, evidence to support this claim is limited and inconsistent [129]. Several countries dietary guidelines have recommended a serving of dairy products, at least one, per day. But even in the United States, a large number of people do not consume the recommended 3 cups of dairy products each day [76].

According to recent research, American adults get 13% of their daily energy from added sugars and 12% of their daily energy from saturated fats, which is much more than the 5-10% that the US Departments of Agriculture and Health and Human Services recommend. Despite this, a high-fat diet has been demonstrated to negatively impact hippocampus-dependent memory function in humans [175].

In the present review, only a few epidemiological research were discussed, regarding the effect of consuming fermented foods on brain function [167]. Fermented foods are regarded as functional foods due to their potential health benefits [11]. Studies suggest that Fermented Papaya Preparation (FPP) has antioxidant and free radical scavenging properties. The extract of yeast-fermented papaya was discovered to enhance both short- and long-term memory. Human studies likewise demonstrated that FPP can enhance memory functions (Kim et al., 2017). Numerous studies have revealed that consuming soybeans that have been fermented such as tempeh does not have a detrimental effect on cognitive performance. In fact, high tofu consumption, a form of soybean curd, has been linked to reduced memory [167].

### Malnutrition

One of the main factors that can prevent proper brain development is malnutrition [164]. Malnutrition is the result of insufficient, excessive, or changed differential percentages of calories, macronutrients, or micronutrients. An urgent worldwide health and socioeconomic burden that is becoming more closely associated with neurodevelopmental problems is malnutrition, particularly in the early years of life [33]. Under and overnutrition in mothers during pregnancy have been shown to negatively affect foetal brain development and child behaviour in studies using both human epidemiologic data and animal models [51].

Malnutrition manifests in three ways: undernutrition, hidden hunger (deficiencies in some micronutrients) and over nutrition. An imbalance between dietary demands and nutrient intake that results in a cumulative loss of calories, protein, or micronutrients is referred to as paediatric malnutrition, also known as undernutrition and hidden hunger. Poor growth and impaired physical or mental development may be the results of such dietary deficiencies [125]. Malnutrition, whether it is in the form of a lack of macronutrients or micronutrients, can have an immediate effect on brain development and operation [185]. Nutritional deficiencies can affect the growth of the brain, synapse formation, and cell differentiation [164].

### Impact of Junk Food on Brain

Fast food is also called Junk food [165]. Young people are especially drawn to "junk foods" since they are affordable and easily accessible while being high in energy and low in nutrients [152]. Junk foods are rich in calories, salt and fats [9,165]. Compressively, the total fat content of junk food can range from 20.8% to 36% [178]. While quickly raising and lowering insulin levels, junk food is changing the structure and function of the human brain [84]. Some examples of junk foods are skated snacked foods, candy, pizza, burgers, sandwich, pastries, hot dogs, gum, samosa, chocolates, most sugary foods, desserts, fried fast food, and fizzy beverages [9,84].

A diet of poorer quality, which excludes items like vegetables, fruit, and sources of healthy fats like fish, nuts, and vegetable oils, and includes processed meals, fast food, refined grains, animal fats, and is high in added sugars, can have a negative effect on mental health (Mechlinska et al., 2022). Regular consumption of fast food and junk food may cause nutritional deficiency as well as cognitive and aberrant behaviour development [84]. Even with small effects, continuous use of junk food might increase the symptoms of mental disease [75]. Adolescents consuming high-fat diets, including junk food, may experience cerebral dysfunction, and whether any changes to brain function are irreversible or permanent. Urban adolescents also show evidence of depression associated with junk food consumption [178].

Investigations were also done into the combined effects of using junk food and drinking energy drinks. High caffeine beverages include energy drinks that are advertised to enhance both mental and physical stimulation. Energy drinks mostly consist of caffeine and sugar. The most well-known use for caffeine is as a CNS stimulant [135] (Vandewoude et al., 2016). This causes serotonin and noradrenaline neurons to fire. Energy drinks with caffeine may also activate methylxanthine, which may be associated to psychological conditions like memory, anxiety, or sleep [152].

Currently, the diet is suggested to have a potent influence of the environment on adolescent neurodevelopment [152]. Consuming junk food during pregnancy can cause structural and functional alterations in the brain's reward networks that are long-lasting (Muhlhausler et al., 2017). An increasing body of research has demonstrated that adolescence is a crucial time when exposure to alcohol, psychostimulants, cannabis, and a high-fat or high-sugar diet has pronounced and long-lasting negative consequences on cognition, behaviour, and learning. Especially high sugar and fat content diets rapidly disrupt the memory task reliant on the hippocampus. Studies on humans also show a link between worse cognitive abilities in adolescent populations and consumption of unhealthy diets, particularly those that are excessive in dietary fat [152].

### Methodology

Multiple databases were consulted in order to find sources for this literature review such as Google Scholar, Sci hub and PubMed. The articles used for this study possessed the most current publication dates, extending back only to 2013. Most of the listed references were within the past five years. To develop tenets that remain relevant today, this review includes research from previous decades conducted by a few researchers. This study was based on different keywords including brain, brain development, cognitive function, maternal diet, macronutrient,

micronutrient, healthy foods, unhealthy foods, caffeine, walnuts, junk foods. All of the search phrases used were carefully selected because of their suitability and significance in relation to the aim of this literature review. Around 1,000 articles were checked for this study, and nearly 185 articles were taken into account. Remaining articles were rejected because they were disproportionate to this topic. The initial sources were chosen by reading the article summaries and assessing whether the contents were pertinent to the search terms. The evaluation of the resources was based on three factors: the standard of the material, the topicality, and the year of publication, which ranged from 2013 to the most recent year. In this study different macronutrients and micronutrients were discussed which are crucial for brain health and development. As well as, different healthy and unhealthy foods were explained. In addition maternal diets were also acknowledged which are necessary for foetal brain development.

### Studies on the Recommendations of nutrients for brain Health.

Studies	Key nutrients for brain Health	Recommended Dietary Allowances (RDA)
Chibbar et al., [30]	Carbohydrate	88%
Phillips et al., [139]	Protein	0.8g/kg bodyweight
Bowen et al., [22]	Omega 3 fatty acids	4g/day
Storz & Ronco [172]	Vitamin A	900 /d for men 700 /d for women
Derbyshire et al., [46]	Choline	Non pregnant women: 425 mg/day Pregnant Women: 450 mg/day Lactating women: 550 mg/day
Toth & Csapo 2018	Selenium	55 g/day
Fratoni & Brandi 2015	Vitamin B6	1.9 mg day-1
Kennedy et al., 2016	Vitamin B9	200 & 400 g/d
Fratoni & Brandi 2015	Vitamin B12	2.4mcg day-1
Scilly et al., 2023	Vitamin D	10 g
Elajzar et al., 2023	Copper	900 g/day
Szadkowska et al., 2023	Zinc	4.2 to 14 mg for men 3 to 12 mg for women

### Results and Conclusion

There are a variety of factors that can affect brain development and cognitive function including maternal diet and the consumption of macro and micronutrients. Optimal brain health and the prevention of cognitive decline depend heavily on nutrition. Nutrition should be a priority for pregnant women and infants. We now know that specific nutrients affect brain function and development, Deficiency and excess of certain nutrients differently affect cognitive function. Vitamin A is essential for placental maintenance and foetal brain development. The placenta stores vitamin A to protect the developing foetus in case of maternal insufficient intake LC-PUFAs, particularly DHA is one the most studied that affect cognitive function and offer protection against neurodegeneration. Brain can use ketones because it can serve as an alternative fuel source in certain situations. Adequate protein intake during pregnancy and throughout life is crucial for brain health. Neurogenesis in the brain depends on the presence of zinc and a small protein that is neurotrophins along with neuropeptides play a role in many brain functions. Choline deficiency during pregnancy increases the risk of neural tube defects. Vitamin B especially B6, B12 and B9 have greater importance in brain function and its supplementation reduces cognitive decline. Copper, lutein, zeaxanthin

are all essential for brain health. Moreover, certain foods like walnuts (English walnuts), dairy foods, fish, yeast fermented papaya, caffeine and low glycemic index foods can be beneficial for the brain, while junk foods, refined sugar and saturated fats can be harmful.

### References

1. Abdel-Aal ESM, Akhtar H, Zaheer K, Ali R. Dietary sources of lutein and zeaxanthin carotenoids and their role in eye health, *Nutrients*. 2013; 5: 1169-1185.
2. Adarmanabadi SMHH, Gilavand HK, Taherkhani A, Rafiei SKS, Shahrokhi M Faaliat S, et al. Pharmacotherapeutic potential of walnut (*Juglans spp.*) in nge-related neurological disorders. *IBRO Neuroscience Reports*. 2023; 14: 1-20.
3. Agarwal P, Ayton S, Agrawal S, Dhana K, Bennett DA, Barnes LL, et al. Brain copper may protect from cognitive decline and Alzheimer's disease pathology: a community-based study. *Mol Psychiatry*. 2022; 27: 4307-4313.
4. Ajmone-Cat MA, De Simone R, Tartaglione AM, Di Biase A, Di Benedetto R, D'Archivio M, et al. Critical role of maternal selenium nutrition in neurodevelopment: Effects on offspring behavior and neuroinflammatory profile. *Nutrients*. 2022; 14: 1850.
5. Akerele OA, Cheema SK. Maternal diets high in Omega-3 fatty acids upregulate genes involved in neurotrophin signalling in the fetal brain during pregnancy in C57BL/6 mice. *Neurochemistry International*. 2020; 138: 104778.
6. An Y, Li S, Huang X, Chen X, Shan H, Zhang M. The Role of Copper Homeostasis in Brain Disease. *International journal of molecular sciences*. 2022; 23: 13850.
7. Anjum L, Jaffery SS, Fayyaz M, Samoo Z, Anjum S. The role of vitamin D in brain health: a mini literature review. *Cureus*. 2018; 10: e2960.
8. Annweiler C, Dursun E, Féron F, Gezen-Ak D, Kalueff AV, Littlejohns T, et al. 'Vitamin D and cognition in older adults': updated international recommendations. *Journal of internal medicine*. 2015; 277: 45-57.
9. Arya G, Mishra S. Effect of junk food & beverages on Adolescent's health. *IOSR Journal of nursing and health science*. 2013; 1: 26-32.
10. Arshad R, Sameen A, Murtaza MA, Sharif HR, Dawood S, Ahmed Z, et al. Impact of vitamin D on maternal and fetal health: A review, *Food Science & Nutrition*. 2022; 10: 3230-3240.
11. Aslam H, Green J, Jacka FN, Collier F, Berk M, Pasco J, et al. Fermented foods, the gut and mental health: a mechanistic overview with implications for depression and anxiety. *Nutritional neuroscience*. 2020; 23: 659-671.
12. Aspell N, Lawlor B, O'Sullivan M. Is there a role for vitamin D in supporting cognitive function as we age?. *Proceedings of the Nutrition Society*. 2018; 77: 124-134.
13. Bahnfleth CL, Strupp BJ, Caudill MA, Canfield RL. Prenatal choline supplementation improves child sustained attention: A 7- year follow-up of a randomized. *Neurochem Int*. 2022; 36: e22054.
14. Balogun KA, Cheema SK. The expression of neurotrophins is differentially regulated by omega-3 polyunsaturated fatty acids at weaning and postweaning in C57BL/6 mice cerebral cortex. *Neurochemistry international*. 2014; 66: 33-42.
15. Basak S, Duttaray AK. Maternal PUFAs, placental epigenetics, and their relevance to fetal growth and brain development. *Reproductive Sciences*. 2023; 30: 408-427.

16. Berger PK, Plows JF, Demerath EW, Fields DA. Carbohydrate composition in breast milk and its effect on infant health. *Current opinion in clinical nutrition and metabolic care*. 2020; 23: 277-281.
17. Berger PK, Plows JF, Jones RB, Alderete TL, Rios C, Pickering TA, et al. Associations of maternal fructose and sugar-sweetened beverage and juice intake during lactation with infant neurodevelopmental outcomes at 24 months. *The American Journal of Clinical Nutrition*. 2020; 112: 1516-1522.
18. Bolton JL, Bilbo SD. Developmental programming of brain and behavior by perinatal diet: focus on inflammatory mechanisms. *Dialogues in clinical neuroscience*. 2022.
19. Borasio F, Syren ML, Turolo S, Agostoni C, Molteni M, Antonietti A, et al. Direct and Indirect Effects of Blood Levels of Omega-3 and Omega-6 Fatty Acids on Reading and Writing (Dis) abilities. *Brain Sciences*. 2022; 12: 169.
20. Bordeleau M, Fernández de Cossio L, Chakravarty MM, Tremblay M. From maternal diet to neurodevelopmental disorders: a story of neuroinflammation. *Frontiers in Cellular Neuroscience*. 2021; 14: 612705.
21. Bost M, Houdart S, Oberli M, Kalonji E, Huneau JF, Margaritis I. Dietary copper and human health: Current evidence and unresolved issues. *Journal of trace elements in medicine and biology*. 2016; 35: 107-115.
22. Bowen KJ, Harris WS, Kris-Etherton PM. Omega-3 fatty acids and cardiovascular disease: are there benefits?. *Current treatment options in cardiovascular medicine*. 2016; 18: 69.
23. Brieger KK, Bakulski KM, Pearce CL, Baylin A, Dou JF, Feinberg JL, et al. The association of prenatal vitamins and folic acid supplement intake with odds of autism spectrum disorder in a high-risk sibling cohort, the Early Autism Risk Longitudinal Investigation (EARLI). *Journal of Autism and Developmental Disorders*. 2022; 52: 2801-2811.
24. Buckinx F, Aubertin-Leheudre M. Nutrition to prevent or treat cognitive impairment in older adults: A GRADE recommendation. *The journal of prevention of Alzheimer's disease*. 2021; 8: 110-116.
25. Camilli MP, Kadri SM, Alvarez MVN, Ribolla PEM, Orsi RO. Zinc supplementation modifies brain tissue transcriptome of *Apis mellifera* honeybees. *BMC genomics*. 2022; 23: 282.
26. Cannavale CN, Keye SA, Rosok L, Martell S, Holthaus TA, Reeser G, et al. Enhancing children's cognitive function and achievement through carotenoid consumption: The Integrated Childhood Ocular Nutrition Study (ICONS) protocol. *Contemporary Clinical Trials*. 2022; 122: 106964.
27. Carlson SE, Colombo J. DHA and Cognitive Development. *The Journal of Nutrition*. 2021; 151: 3265-3266.
28. Chauhan A, Chauhan V. Beneficial effects of walnuts on cognition and brain health. *Nutrients*. 2020; 12: 550.
29. Chertoff M. Protein malnutrition and brain development, *Brain Disorder*. Ther. 2015; 4: 171.
30. Chibbar R, Weiten D, Green KH, Rigaux L, Bernstein CN, Graff LA, et al. A266 Is A Multivitamin Sufficient To Meet Nutritional Requirements In Canadian Adults Following A Gluten-Free Diet?. *Journal of the Canadian Association of Gastroenterology*. 2020; 3: 143.
31. Chu CS, Hung CF, Ponnusamy VK, Chen KC, Chen NC. Higher serum DHA and slower cognitive decline in patients with Alzheimer's disease: two-year follow-up. *Nutrients*. 2022; 14: 1159.
32. Clarke R, Bennett D, Parish S, Lewington S, Skeaff M, Eussen SJ, et al. B-Vitamin Treatment Trialists' Collaboration. Effects of homocysteine lowering with B vitamins on cognitive aging: meta-analysis of 11 trials with cognitive data on 22,000 individuals. *The American journal of clinical nutrition*. 2014; 100: 657-666.
33. Coley EJJ, Hsiao EY. Malnutrition and the microbiome as modifiers of early neurodevelopment. *Trends in Neurosciences*. 2021; 44: 753-764.
34. Comitini F, Peila C, Fanos V, Coscia A. The docosahexanoic acid: From the maternal-fetal dyad to early life toward metabolomics. *Frontiers in pediatrics*. 2020; 8: 538.
35. Cortés-Albornoz MC, Garcia-Guáqueta DP, Velez-van-Meerbeke A, Talero-Gutiérrez C. Maternal nutrition and neurodevelopment: A scoping review. *Nutrients*. 2021; 13: 3530.
36. Croll PH, Boelens M, Vernooij MW, van de Rest O, Zillikens MC, Ikram MA, et al. Associations of vitamin D deficiency with MRI markers of brain health in a community sample. *Clinical Nutrition*. 2021; 40: 72-78.
37. Cui X, Gooch H, Groves NJ, Sah P, Burne TH, Eyles DW, et al. Vitamin D and the brain: key questions for future research. *The Journal of steroid biochemistry and molecular biology*. 2015; 148: 305-309.
38. Cui X, Eyles DW. Vitamin D and the Central Nervous System: Causative and Preventative Mechanisms in Brain Disorders. *Nutrients*. 2022; 14: 4353.
39. Cunnane SC, Courchesne-Loyer A, St-Pierre V, Vandenberghe C, Pierotti T, Fortier M, et al. Can ketones compensate for deteriorating brain glucose uptake during aging? Implications for the risk and treatment of Alzheimer's disease. *Annals of the New York Academy of Sciences*. 2016; 1367: 12-20.
40. Cunnane SC, Courchesne-Loyer A, Vandenberghe C, St-Pierre V, Fortier M, Hennebelle M, et al. Can ketones help rescue brain fuel supply in later life? Implications for cognitive health during aging and the treatment of Alzheimer's disease. *Frontiers in molecular neuroscience*. 2016: 53.
41. Cusick SE, Georgieff MK. Early-life nutrition and neurodevelopment. In *Early Nutrition and Long-Term Health*. Woodhead Publishing. 2022: 127-151.
42. Czarnowska-Kujawska M, Draszanowska A, Gujska E. Effect of Different Cooking Methods on Folate Content in Chicken Liver. *Foods*. 2020; 9: 1431.
43. Davidenko O, Darcel N, Fromentin G, Tome D. Control of protein and energy intake-brain mechanisms. *European journal of clinical nutrition*. 2013; 67: 455-461.
44. Deluca GC, Kimball SM, Kolasinski J, Ramagopalan SV, Ebers GC. Review: the role of vitamin D in nervous system health and disease. *Neuropathology and applied neurobiology*. 2013; 39: 458-484.
45. Derbyshire E, Obeid R. Choline, Neurological Development and Brain Function: A Systematic Review Focusing on the First 1000 Days. *Nutrients*. 2020; 12: 1731.
46. Derbyshire E, Obeid R, Schön C. Habitual choline intakes across the childbearing years: A review, *Nutrients*. 2021; 13: 4390.
47. Demmig-Adams B, López-Pozo M, Stewart JJ, Adams III WW. Zeaxanthin and lutein: Photoprotectors, anti-inflammatories, and brain food. *Molecules*. 2020; 25: 3607.
48. De Jager CA, Kovatcheva A. Summary and discussion: methodologies to assess long-term effects of nutrition on brain function. *Nutrition reviews*. 2010; 68: S53-S58.

49. Diéguez E, Nieto-Ruiz A, Martín-Pérez C, Sepúlveda-Valbuena N, Herrmann F, Jiménez J, et al. Association study between hypothalamic functional connectivity, early nutrition, and glucose levels in healthy children aged 6 years: The COGNIS study follow-up. *Frontiers in Nutrition*. 2022; 9: 935740.
50. Dighriri IM, Alsubaie AM, Hakami FM, Hamithi DM, Alshekh MM, Khoibrani FA, et al. Effects of Omega-3 Polyunsaturated Fatty Acids on Brain Functions: A Systematic Review. *Cureus*. 2022; 14: e30091.
51. Edlow AG, Guedj F, Sverdlow D, Pennings JL, Bianchi DW. Significant effects of maternal diet during pregnancy on the murine fetal brain transcriptome and offspring behavior. *Frontiers in neuroscience*. 2019; 13: 1335.
52. Ekstrand B, Scheers N, Rasmussen MK, Young JF, Ross AB, Landberg R. Brain foods-the role of diet in brain performance and health. *Nutrition reviews*. 2021; 79: 693-708.
53. Eljazzar S, Abu-Hijleh H, Alkhatib D, Sokary S, Ismail S, Al-Jayyousi GF, et al. The Role of Copper Intake in the Development and Management of Type 2 Diabetes: A Systematic Review. *Nutrients*. 2023; 15: 1655.
54. Emekli-Alturfan Ebru. *Fat-Soluble Vitamins. A Guide to Vitamins and Their Effects on Diseases*. 2023: 36.
55. Ernst AM, Gimbel BA, de Water E, Eckerle JK, Radke JP, Georgieff MK, et al. Prenatal and postnatal choline supplementation in fetal alcohol spectrum disorder. *Nutrients*. 2022; 14: 688.
56. Eyles DW. Vitamin D: Brain and behaviour. *JBMR plus*. 2021; 5: e10419.
57. Fan C, Fu H, Dong H, Lu Y, Lu Y, Qi K. Maternal n-3 polyunsaturated fatty acid deprivation during pregnancy and lactation affects neurogenesis and apoptosis in adult offspring: associated with DNA methylation of brain-derived neurotrophic factor transcripts. *Nutrition Research*. 2016; 36: 1013-1021.
58. Fanalli SL, da Silva BPM, Petry B, Santana MHDA, Polizel GHG, Antunes RC, et al. Dietary fatty acids applied to pig production and their relation to the biological processes: A review, *Livestock Science*. 2022; 265: 105092.
59. Farias PM, Marcelino G, Santana LF, de Almeida EB, Guimarães RDCA, Pott A, et al. Minerals in pregnancy and their impact on child growth and development. *Molecules*. 2020; 25: 5630.
60. Ford AH, Almeida OP. Effect of vitamin B supplementation on cognitive function in the elderly: a systematic review and meta-analysis. *Drugs & aging*. 2019; 36: 419-434.
61. Forouzes A, Forouzes F, Foroushani SS, Forouzes A. A new method for calculating zinc content and determining appropriate zinc levels in foods. 2022.
62. Franklyn N, Kesavelu D, Joji P, Verma R, Wadhwa A, Ray C. Impact of Key Nutrients on Brain and Executive Function Development in Infants and Toddlers: A Narrative Review. *Journal of Food and Nutrition Sciences*. 2022; 10: 19-26.
63. Franco CN, Seabrook LJ, Nguyen ST, Leonard JT, Albrecht LV. Simplifying the B Complex: How Vitamins B6 and B9 Modulate One Carbon Metabolism in Cancer and Beyond. *Metabolites*. 2022; 12: 961.
64. Fratoni V, Brandi ML. B vitamins, homocysteine and bone health. *Nutrients*. 2015; 7: 2176-2192.
65. Freedman R, Hunter SK, Law AJ, Clark AM, Roberts A, Hoffman MC. Choline, folic acid, Vitamin D, and fetal brain development in the psychosis spectrum. *Schizophrenia Research*. 2022; 247: 16-25.
66. Freedman R, Hunter SK, Law AJ, Clark AM, Roberts A, Hoffman MC. Choline, folic acid, Vitamin D, and fetal brain development in the psychosis spectrum. *Schizophrenia research*. 2022; 247: 16-25.
67. Georgieff MK, Ramel SE, Cusick SE. Nutritional influences on brain development. *Acta Paediatrica*. 2018; 107: 1310-1321.
68. Georgieff MK. Early Life Nutrition and Brain Development: Breakthroughs, Challenges and New Horizons. *Proceedings of the Nutrition Society*. 2023; 82: 104-112.
69. Giannos P, Prokopidis K, Lidoriki I, Triantafyllidis KK, Kechagias KS, Celoch K, et al. Medium-chain triglycerides may improve memory in non-demented older adults: a systematic review of randomized controlled trials. *BMC Geriatr*. 2022; 22: 817.
70. Gibson MJ, Dawson JA, Wijayatunga NN, Ironuma B, Chatindiara I, Ovalle F, et al. A randomized cross-over trial to determine the effect of a protein vs. Carbohydrate preload on energy balance in ad libitum settings. *Nutrition journal*. 2019; 18: 1-13.
71. Gonzalez HF, Visentin S. Micronutrients and neurodevelopment: An update. *Archivos argentinos de pediatria*. 2016; 114: 570-575.
72. Grafe EL, Wade MM, Hodson CE, Thomas JD, Christie BR. Post-natal choline supplementation rescues deficits in synaptic plasticity following prenatal ethanol exposure. *Nutrients*. 2022; 14: 2004.
73. Groves NJ, McGrath JJ, Burne THJ. Vitamin D as a neurosteroid affecting the developing and adult brain. *Annual review of nutrition*. 2014; 34: 117-141.
74. Hachem M, Nacir H. Emerging role of phospholipids and lysophospholipids for improving brain docosahexaenoic acid as potential preventive and therapeutic strategies for neurological diseases. *International Journal of Molecular Sciences*. 2022; 23: 3969.
75. Hafizurrachman M, Hartono RK. Junk food consumption and symptoms of mental health problems: A meta-analysis for public health awareness. *Kesmas: Jurnal Kesehatan Masyarakat Nasional (National Public Health Journal)*. 2021: 16.
76. Hess JM, Jonnalagadda SS, Slavin JL. Dairy foods: current evidence of their effects on bone, cardiometabolic, cognitive, and digestive health. *Comprehensive Reviews in Food Science and Food Safety*. 2016; 15: 251-268.
77. Huhn S, Kharabian Masouleh S, Stumvoll M, Villringer A, Witte AV. Components of a Mediterranean diet and their impact on cognitive functions in aging. *Frontiers in Aging Neuroscience*. 2015; 7: 132.
78. Irvine N, England-Mason G, Field CJ, Dewey D, Aghajafari F. Prenatal Folate and Choline Levels and Brain and Cognitive Development in Children: A Critical Narrative Review, *Nutrients*. 2022; 14: 364.
79. Jacka FN. Nutritional psychiatry: where to next?. *E Bio Medicine*. 2017; 17: 24-29.
80. Janoušek J, Pilařová V, Macáková K, Nomura A, Veiga-Matos J, Silva DDD, et al. Vitamin D: sources, physiological role, biokinetics, deficiency, therapeutic use, toxicity, and overview of analytical methods for detection of vitamin D and its metabolites. *Critical reviews in clinical laboratory sciences*. 2022; 59: 517-554.
81. Jennings L, Basiri R. Amino Acids, B Vitamins, and Choline May Independently and Collaboratively Influence the Incidence and Core Symptoms of Autism Spectrum Disorder. *Nutrients*. 2022; 14: 2896.

82. Johnson EJ. Role of lutein and zeaxanthin in visual and cognitive function throughout the lifespan. *Nutrition reviews*. 2014; 72: 605-612.
83. Katayama S, Nakamura S. Emerging roles of bioactive peptides on brain health promotion. *International Journal of Food Science & Technology*. 2019; 54: 1949-1955.
84. Kaur R, Preet KB, RKV KU. Fast Food and Junk Food Culture, Nutritional Status and Cognitive and Abnormal Behaviour among Teens. *International Research Journal of Social Sciences*. 2014; 3: 46-49.
85. Kennedy DO. B vitamins and the brain: mechanisms, dose and efficacy-a review. *Nutrients*. 2016; 8: 68.
86. Khalid W, Gill P, Arshad MS, Ali A, Ranjha MMAN, Mukhtar S, et al. Functional behavior of DHA and EPA in the formation of babies brain at different stages of age, and protect from different brain-related diseases. *International Journal of Food Properties*. 2022; 25: 1021-1044.
87. Khayat S, Fanaei H, Ghanbarzahi A. Minerals in pregnancy article. *Journal of Clinical and Diagnostic Research: JCDR*. 2017; 11: QE01-QE05.
88. Kippler M, Bottai M, Georgiou V, Koutra K, Chalkiadaki G, Kampouri M, et al. Impact of prenatal exposure to cadmium on cognitive development at preschool age and the importance of selenium and iodine. *European journal of epidemiology*. 2016; 31: 1123-1134.
89. Kim B, Hong VM, Yang J, Hyun H, Im JJ, Hwang J, et al. A review of fermented foods with beneficial effects on brain and cognitive function. *Preventive nutrition and food science*. 2016; 21: 297-309.
90. Kouvari M, D'cunha NM, Travica N, Sergi D, Zec M, Marx W, et al. Metabolic syndrome, cognitive impairment and the role of diet: a narrative review. *Nutrients*. 2022; 14: 333.
91. Kumar J, Sathua KB, Flora SJS. Chronic copper exposure elicit neurotoxic responses in rat brain: Assessment of 8-hydroxy-2-deoxyguanosine activity, oxidative stress and neurobehavioral parameters. *Cellular and Molecular Biology*. 2019; 65: 27-35.
92. Kumar V, Kumar A, Singh K, Avasthi K, Kim JJ. Neurobiology of zinc and its role in neurogenesis. *European Journal of Nutrition*. 2021; 60: 55-64.
93. Kwok T, Wu Y, Lee J, Lee R, Yung CY, Choi G, et al. A randomized placebo-controlled trial of using B vitamins to prevent cognitive decline in older mild cognitive impairment patients. *Clinical Nutrition*. 2020; 39: 2399-2405.
94. Lees B, Meredith LR, Kirkland AE, Bryant BE, Squeglia LM. Effect of alcohol use on the adolescent brain and behavior. *Pharmacology Biochemistry and Behavior*. 2020; 192: 172906.
95. Leyrolle Q, Decoeur F, Briere G, Amadiou C, Quadros ARADA, Voytyuk I, et al. Maternal dietary omega-3 deficiency worsens the deleterious effects of prenatal inflammation on the gut-brain axis in the offspring across lifetime. *Neuropsychopharmacology*. 2021; 46: 579-602.
96. Leyrolle Q, Decoeur F, Dejean C, Brière G, Leon S, Bakoyiannis L, et al. N. 3 PUFA deficiency disrupts oligodendrocyte maturation and myelin integrity during brain development. *Glia*. 2022; 70: 50-70.
97. Liao K, McCandliss BD, Carlson SE, Colombo J, Shaddy DJ, Kerling EH, et al. Event related potential differences in children supplemented with long- chain polyunsaturated fatty acids during infancy. *Developmental science*. 2017; 20: e12455.
98. Lim JJ, Liu Y, Lu LW, Barnett D, Sequeira IR, Poppitt SD. Does a Higher Protein Diet Promote Satiety and Weight Loss Independent of Carbohydrate Content? An 8- Week Low-Energy Diet (LED) Intervention. *Nutrients*. 2022; 14: 538.
99. Liu X, Adamo AM, Oteiza PL. Di-2-ethylhexyl phthalate affects zinc metabolism and neurogenesis in the developing rat brain. *Archives of Biochemistry and Biophysics*. 2022; 727: 109351.
100. Li Y, Li S, Wang W, Zhang D. Association between dietary protein intake and cognitive function in adults aged 60 years and older. *The journal of nutrition, health & aging*. 2020; 24: 223-229.
101. Lindbergh CA, Renzi-Hammond LM, Hammond BR, Terry DP, Mewborn CM, Puente AN, et al. Lutein and zeaxanthin influence brain function in older adults: a randomised controlled trial. *Journal of the International Neuropsychological Society*. 2018; 24: 77-90.
102. Loughman M. Exercise is brain food: the effects of physical activity on cognitive function. *Developmental neurorehabilitation*. 2008; 11: 236-40.
103. Mohajeri MH. Nutrition for Brain Development. *Nutrients*. 2022; 14:1419.
104. Lv S, Qin R, Jiang Y, Lv H, Lu Q, Tao S, et al. Association of maternal dietary patterns during gestation and offspring neurodevelopment. *Nutrients*. 2022; 14: 730.
105. Mahmassani HA, Switkowski KM, Scott TM, Johnson EJ, Rifas-Shiman SL, Oken E, et al. Maternal diet quality during pregnancy and child cognition and behavior in a US cohort. *The American Journal of Clinical Nutrition*. 2022; 115: 128-141.
106. Mandić M, Mitić K, Nedeljković P, Perić M, Božić B, Lunić T, et al. Vitamin B complex and experimental autoimmune Encephalomyelitis-Attenuation of the clinical signs and gut microbiota dysbiosis. *Nutrients*. 2022; 14: 1273.
107. Marek K, Cichon N, Saluk-Bijak J, Bijak M, Miller E. The Role of Vitamin D in Stroke Prevention and the Effects of Its Supplementation for Post-Stroke Rehabilitation: A Narrative Review. *Nutrients*. 2022; 14: 2761.
108. Marques AH, O'Connor TG, Roth C, Susser E, Bjørke-Monsen AL. The influence of maternal prenatal and early childhood nutrition and maternal prenatal stress on offspring immune system development and neurodevelopmental disorders. *Frontiers in neuroscience*. 2013; 7: 120.
109. Martinat M, Rossitto M, Di Miceli M, Layé S. Perinatal dietary polyunsaturated fatty acids in brain development, role in neurodevelopmental disorders. *Nutrients*. 2021; 13: 1185.
110. Marx W, Moseley G, Berk M, Jacka F. Nutritional psychiatry: the present state of the evidence. *Proceedings of the Nutrition Society*. 2017; 76: 427-436.
111. Martin CR, Ling PR, Blackburn GL. Review of infant feeding: key features of breast milk and infant formula. *Nutrients*. 2016; 8: 279.
112. Mattei D, Pietrobelli A. Micronutrients and brain development. *Current nutrition reports*. 2019; 8: 99-107.
113. McGarel C, Pentieva K, Strain JJ, McNulty H. Emerging roles for folate and related B-vitamins in brain health across the lifecycle. *Proceedings of the Nutrition Society*. 2015; 74: 46-55.
114. McNamara RK, Almeida DM. Omega-3 polyunsaturated fatty acid deficiency and progressive neuropathology in psychiatric disorders: a review of translational evidence and candidate mechanisms. *Harvard review of psychiatry*. 2019; 27: 94-107.

115. McPhee GM, Downey LA, Stough C. Neurotrophins as a reliable biomarker for brain function, structure and cognition: A systematic review and meta-analysis. *Neurobiology of learning and memory*. 2020; 175: 107298.
116. Mechlińska A, Włodarczyk A, Gruchała-Niedoszytko M, Małgorzewicz S, Cubala WJ. Dietary Patterns of Treatment-Resistant Depression Patients. *Nutrients*. 2022; 14: 3766.
117. Melzer TM, Manosso LM, Yau SY, Gil-Mohapel J, Brocardo PS. In pursuit of healthy aging: effects of nutrition on brain function. *International journal of molecular sciences*. 2021; 22: 5026.
118. Messina M, Sievenpiper JL, Williamson P, Kiel J, Erdman Jr JW. Perspective: soy-based meat and dairy alternatives, despite classification as ultra-processed foods, deliver high-quality nutrition on par with unprocessed or minimally processed animal-based counterparts. *Advances in Nutrition*. 2022; 13: 726-738.
119. Mewborn CM, Lindbergh CA, Hammond BR, Renzi-Hammond LM, Miller LS. The effects of lutein and zeaxanthin supplementation on brain morphology in older adults: A randomised, controlled trial. *Journal of Aging Research*. 2019; 2019: 3709402.
120. Meza-Meza MR, Muñoz-Valle JF, Ruiz-Ballesteros AI, Vizmanos-Lamotte B, Parra-Rojas I, Martínez-López E, et al. Association of High Calcitriol Serum Levels and Its Hydroxylation Efficiency Ratio with Disease Risk in SLE Patients with Vitamin D Deficiency. *Journal of Immunology Research*. 2021; 2021: 2808613.
121. Miranda-Dominguez O, Ramirez JS, Mitchell AJ, Perrone A, Earl E, Carpenter S, et al. Carotenoids improve the development of cerebral cortical networks in formula-fed infant macaques. *Scientific reports*. 2022; 12: 15220.
122. Močenić I, Kolić I, Nišević JR, Belančić A, Tratnik JS, Mazej D, et al. Prenatal selenium status, neonatal cerebellum measures and child neurodevelopment at the age of 18 months. *Environmental research*. 2019; 176: 108529.
123. Mohajeri MH. Nutrition for Brain Development. *Nutrients*. 2022; 14: 1419.
124. Mühlhäusler BS, Adam CL, McMillen IC. Maternal nutrition and the programming of obesity: the brain. *Organogenesis*. 2008; 4: 144-152.
125. Murray RD, Kerr KW, Brunton C, Williams JA, DeWitt T, Wulf KL. A first step towards eliminating malnutrition: A proposal for universal nutrition screening in pediatric practice. *Nutrition and Dietary Supplements*. 2021; 13: 17-24.
126. Muth AK, Park SQ. The impact of dietary macronutrient intake on cognitive function and the brain. *Clinical Nutrition*. 2021; 40: 3999-4010.
127. Navale SS, Mulugeta A, Zhou A, Llewellyn DJ, Hyppönen E. Vitamin D and brain health: an observational and Mendelian randomization study. *The American Journal of Clinical Nutrition*. 2022; 116: 531-540.
128. Nehlig A. Effects of coffee/caffeine on brain health and disease: What should I tell my patients?. *Practical neurology*. 2016; 16: 89-95.
129. Ni J, Nishi SK, Babio N, Martínez-González MA, Corella D, Castañer O, et al. Dairy Product Consumption and Changes in Cognitive Performance: Two Year Analysis of the PREDIMED- Plus Cohort. *Molecular nutrition & food research*. 2022; 66: 2101058.
130. Nordvall G, Forsell P, Sandin J. Neurotrophin-targeted therapeutics: a gateway to cognition and more?. *Drug Discovery Today*. 2022; 27: 103318.
131. Obeid R, Derbyshire E, Schön C. Association between Maternal Choline, Fetal Brain Development, and Child Neurocognition: Systematic Review and Meta-Analysis of Human Studies. *Advances in Nutrition*. 2022; 13: 2445-2457.
132. Obeid R, Holzgreve W, Pietrzik K. Folate-, Cholinund Vitamin-B12-Supplementierung für präkonzeptionelle und schwangere Frauen [Folate, Choline, and Vitamin B12 Supplementation for Preconception and Pregnant Women]. *Therapeutische Umschau. Revue therapeutique*. 2022; 79: 541-548.
133. Olsen T, Blomhoff R. Retinol, retinoic acid, and retinol-binding protein 4 are differentially associated with cardiovascular disease, type 2 diabetes, and obesity: an overview of human studies. *Advances in Nutrition*. 2020; 11: 644-666.
134. Ostadrahimi A, Salehi-Pourmehr H, Mohammad-Alizadeh-Charandabi S, Heidarabady S, Farshbaf-Khalili A. The effect of perinatal fish oil supplementation on neurodevelopment and growth of infants: a randomized controlled trial. *European journal of nutrition*. 2018; 57: 2387-2397.
135. Park S, Lee Y, Lee JH. Association between energy drink intake, sleep, stress, and suicidality in Korean adolescents: energy drink use in isolation or in combination with junk food consumption. *Nutrition journal*. 2016; 15: 87.
136. Park S, Rim SJ, Lee JH. Associations between dietary behaviours and perceived physical and mental health status among Korean adolescents. *Nutrition & Dietetics*. 2018; 75: 488-493.
137. Park JS, Kim SY, Lee SC, Jeong YR, Roy VC, Rizkyana AD, et al. Edible oil extracted from anchovies using supercritical CO<sub>2</sub>: Availability of fat-soluble vitamins and comparison with commercial oils. *Journal of Food Processing and Preservation*. 2021; 45: e15441.
138. Pet MA, Brouwer-Brolsma EM. The impact of maternal vitamin D status on offspring brain development and function: a systematic review. *Advances in nutrition*. 2016; 7: 665-678.
139. Phillips SM, Paddon-Jones D, Layman DK. Optimizing adult protein intake during catabolic health conditions. *Advances in Nutrition*. 2020; 11: S1058-S1069.
140. Pitts MW, Hoffmann PR, Schomburg L. Selenium and selenoproteins in brain development, function, and disease. *Frontiers in Neuroscience*. 2022; 15: 1856.
141. Polanska K, Hanke W, Krol A, Gromadzinska J, Kuras R, Janasik B, et al. Micronutrients during pregnancy and child psychomotor development: Opposite effects of Zinc and Selenium. *Environmental research*. 2017; 158: 583-589.
142. Poulouse SM, Miller MG, Shukitt-Hale B. Role of walnuts in maintaining brain health with age. *The Journal of nutrition*. 2014; 144: 561S-566S.
143. Prado EL, Dewey KG. Nutrition and brain development in early life. *Nutrition reviews*. 2014; 72: 267-284.
144. Puchkova LV, Babich PS, Zatulovskaia YA, Ilyechova EY, Di Sole F. Copper Metabolism of Newborns Is Adapted to Milk Ceruloplasmin as a Nutritive Source of Copper: Overview of the Current Data. *Nutrients*. 2018; 10: 1591.
145. Radd-Vagenas S, Duffy SL, Naismith SL, Brew BJ, Flood VM, Fatarone Singh MA. Effect of the Mediterranean diet on cognition and brain morphology and function: a systematic review of randomized controlled trials. *The American journal of clinical nutrition*. 2018; 107: 389-404.
146. Rafeeq H, Ahmad S, Tareen MBK, Shahzad KA, Bashir A, Jabeen R, et al. Biochemistry of fat soluble vitamins, sources, biochemical functions and toxicity. *Haya: The Saudi Journal of Life Sciences*. 2020: 188-196.

147. Rahat B, Hamid A, Bagga R, Kaur J. Folic acid levels during pregnancy regulate trophoblast invasive behavior and the possible development of preeclampsia. *Frontiers in Nutrition*. 2022; 9: 847136.
148. Rahman MM, Islam MR, Emran TB. Impact of nutrition in brain function and development: Potential brain foods. *International Journal of Surgery*. 2022; 106: 106908.
149. Ravisankar P, Reddy AA, Nagalakshmi B, Koushik OS, Kumar BV, Anvith PS. The comprehensive review on fat soluble vitamins. *IOSR Journal of Pharmacy*. 2015; 5: 12-28.
150. Rees A, Sirois S, Wearden A. Prenatal maternal docosahexaenoic acid intake and infant information processing at 4.5 mo and 9mo: A longitudinal study. *PLoS One*. 2019; 14: e0210984.
151. Rezazadegan M, Shahdadian F, Soheilipour M, Tarrahi MJ, Amrani R. Zinc nutritional status, mood states and quality of life in diarrhea-predominant irritable bowel syndrome: a case-control study. *Scientific Reports*. 2022; 12: 1-8.
152. Reichelt AC, Rank MM. The impact of junk foods on the adolescent brain. *Birth defects research*. 2017; 109: 1649-1658.
153. Rizzo V, Capozza M, Panza R, Laforgia N, Baldassarre ME. Macronutrients and Micronutrients in Parenteral Nutrition for Preterm Newborns: A Narrative Review. *Nutrients*. 2022; 14: 1530.
154. Martinez Garcia, RM, Jimenez Ortega AI, Lopez Sobaler AM, Ortega RM. Nutrition strategies that improve cognitive function. *Nutricion hospitalaria*. 2018; 35: 16-19.
155. Roberts M, Tolar-Peterson T, Reynolds A, Wall C, Reeder N, Rico Mendez G. The effects of nutritional interventions on the cognitive development of preschool-age children: A systematic review. *Nutrients*. 2022; 14: 532.
156. Rodriguez-Iglesias N, Nadjar A, Sierra A, Valero J. Susceptibility of Female Mice to the Dietary Omega-3/Omega-6 Fatty-Acid Ratio: Effects on Adult Hippocampal Neurogenesis and Glia. *International Journal of Molecular Sciences*. 2022; 23: 3399.
157. Royer A, Sharman T. Copper Toxicity. In *StatPearls*. StatPearls Publishing. 2022.
158. Sahay A, Kale A, Joshi S. Role of neurotrophins in pregnancy and offspring brain development. *Neuropeptides*. 2020; 83: 102075.
159. Santander Ballestin S, Giménez Campos MI, Ballestin Ballestin J, Luesma Bartolomé MJ. Is supplementation with micronutrients still necessary during pregnancy? A review. *Nutrients*. 2021; 13: 3134.
160. Sass L, Bjarnadóttir E, Stokholm J, Chawes B, Vinding RK, Mora-Jensen ARC, et al. Fish Oil Supplementation in Pregnancy and Neurodevelopment in Childhood-A Randomized Clinical Trial. *Child Development*. 2021; 92: 1624-1635.
161. Scheiber IF, Mercer JF, Dringen R. Metabolism and functions of copper in brain. *Progress in neurobiology*. 2014; 116: 33-57.
162. Schneider N, Garcia-Rodenas CL. Early nutritional interventions for brain and cognitive development in preterm infants: a review of the literature. *Nutrients*. 2017; 9: 187.
163. Scully H, Laird EJ, Healy M, Crowley V, Walsh JB, McCarroll K. Vitamin D: determinants of status, indications for testing and knowledge in a convenience sample of Irish adults. *British Journal of Nutrition*. 2023; 1144-1154.
164. Sethi P, Prajapati A, Mishra T, Chaudhary T, Kumar S. Effects of Malnutrition on Brain Development. In *Nutrition and Psychiatric Disorders*. Springer, Singapore. 2022: 75-88.
165. Sharma V. Adolescents knowledge regarding harmful effects of junk food. *IOSR J Nurs Health Sci*. 2013; 1: 01-4.
166. Shergill-Bonner R. Micronutrients. *Paediatrics and Child Health*. 2017; 27: 357-362.
167. Sivamaruthi BS, Kesika P, Chaiyasut C. Impact of fermented foods on human cognitive function-A review of outcome of clinical trials. *Scientia pharmaceutica*. 2018; 86: 22.
168. Skróder HM, Hamadani JD, Tofail F, Persson LA, Vahter ME, Kippler MJ. Selenium status in pregnancy influences children's cognitive function at 1.5 years of age. *Clinical nutrition*. 2015; 34: 923-930.
169. Sobczyńska-Malefora A, Delvin E, McCaddon A, Ahmadi KR, Harrington DJ. Vitamin B12 status in health and disease: a critical review. Diagnosis of deficiency and insufficiency-clinical and laboratory pitfalls. *Critical reviews in clinical laboratory sciences*. 2021; 58: 399-429.
170. Sree SR, Suneetha J, Kumari BA, Kavitha V. Brain booster foods for children. *Int. J. Chem. Stud*. 2020; 8: 379-382.
171. Stoney PN, McCaffery P. A Vitamin on the Mind: New Discoveries on Control of the Brain by Vitamin A. *World review of nutrition and dietetics*. 2016; 115: 98-108.
172. Storz MA, Ronco AL. Nutrient intake in low-carbohydrate diets in comparison to the 2020-2025 Dietary Guidelines for Americans: A cross-sectional study. *British Journal of Nutrition*. 2023; 129: 1023-1036.
173. Sultan S, Taimuri U, Basnan SA, Ai-Orabi WK, Awadallah A, Al-mowald F, et al. Low vitamin D and its association with cognitive impairment and dementia. *Journal of aging research*. 2020; 2020: 6097820.
174. Sun R, Wang J, Feng J, Cao B. Zinc in cognitive impairment and aging. *Biomolecules*. 2022; 12: 1000.
175. Spencer SJ, Korosi A, Laye S, Shukitt-Hale B, Barrientos RM. Food for thought: how nutrition impacts cognition and emotion. *Npj Science of Food*. 2017; 1: 1-8.
176. Szadkowska L, Kostka T, Wlazel RN, Kroc L, Jegier A, Guligowska A. Dietary Zinc Is Associated with Cardiac Function in the Older Adult Population. *Antioxidants*. 2023; 12: 265.
177. Szot M, Karpecka-Gałka E, Drózd R, Frączek B. Can Nutrients and Dietary Supplements Potentially Improve Cognitive Performance Also in Esports?. In *Healthcare*. MDPI. 2022; 10: 186.
178. Tarantino G, Cataldi M, Citro V. Could Alcohol Abuse and Dependence on Junk. 2022.
179. Foods Inducing Obesity and/or Illicit Drug Use Represent Danger to Liver in Young People with Altered Psychological/Relational Spheres or Emotional Problems?. *International Journal of Molecular Sciences*. 23: 10406.
180. Teisen MN, Vuholm S, Niclasen J, Aristizabal-Henao JJ, Stark KD, Geertsen SS, et al. Effects of oily fish intake on cognitive and socioemotional function in healthy 8-9-year-old children: The FiSK Junior randomized trial. *The American Journal of Clinical Nutrition*. 2020; 112: 74-83.
181. Ten Donkelaar HJ, Lammens M, Hori A, ten Donkelaar HJ, Yamada S, Shiota K, et al. Overview of the development of the human brain and spinal cord *Clinical neuroembryology: development and developmental disorders of the human central nervous system*. 2014: 1-52.
182. Tóth RJ, Csapó J. The role of selenium in nutrition-A review. *Acta Universitatis Sapientiae, Alimentaria*. 2018; 11: 128-144.

183. Tsan L, Décarie-Spain L, Noble EE, Kanoski SE. Western diet consumption during development: setting the stage for neurocognitive dysfunction. *Frontiers in Neuroscience*. 2021; 15: 632312.
184. Tucker KL. Nutrient intake, nutritional status, and cognitive function with age. *Annals of the New York Academy of Sciences*. 2016; 1367: 38-49.
185. Vaivada T, Ahsan H, Zaman M, Miller SP, Bhutta ZA. 1.4. 7 Nutrition, brain development, and mental health. *Pediatric Nutrition in Practice*. 2022; 124: 122-132.
186. Vandenbergh C, St-Pierre V, Fortier M, Castellano C-A, Cuenoud B, Cunnane SC. Medium Chain Triglycerides Modulate the Ketogenic Effect of a Metabolic Switch. *Front Nutr*. 2020; 7: 3.
187. Dael PV. Role of n-3 long-chain polyunsaturated fatty acids in human nutrition and health: review of recent studies and recommendations. *Nutrition Research and Practice*. 2021; 15: 137-159.
188. Varsi K, Bolann B, Torsvik I, Rosvold Eik TC, Højl PJ, Bjørke-Monsen AL. Impact of maternal selenium status on infant outcome during the first 6 months of life. *Nutrients*. 2017; 9: 486.
189. Vennemann FBC, Ioannidou S, Valsta LM, Dumas C, Ocké MC, Mensink GBM, et al. Dietary intake and food sources of choline in European populations. *British Journal of Nutrition*. 2015; 114: 2046-2055.
190. Vinceti M, Filippini T, Jablonska E, Saito Y, Wise LA. Safety of selenium exposure and limitations of selenoprotein maximization: Molecular and epidemiologic perspectives. *Environmental Research*. 2022; 211: 113092.
191. Viridi S, Jadavji NM. The Impact of Maternal Foliates on Brain Development and Function after Birth. *Metabolites*. 2022; 12: 876.
192. Wallace TC, Blusztajn JK, Caudill MA, Klatt KC, Natker E, Zeisel SH, et al. Choline: the underconsumed and underappreciated essential nutrient. *Nutrition today*. 2018; 53: 240.
193. Wallace TC, Fulgoni VL. Usual choline intakes are associated with egg and protein food consumption in the United States. *Nutrients*. 2017; 9: 839.
194. Watanabe F, Yabuta Y, Bito T, Teng F. Vitamin B12-containing plant food sources for vegetarians. *Nutrients*. 2014; 6: 1861-1873.
195. Willekens J, Runnels LW. Impact of Zinc Transport Mechanisms on Embryonic and Brain Development. *Nutrients*. 2022; 14: 2526.
196. Williams EB, Hooper B, Spiro A, Stanner S. The contribution of yogurt to nutrient intakes across the life course. *Nutrition Bulletin*. 2015; 40: 9-32.
197. Wood AHR, Chappell HF, Zulyniak MA. Dietary and supplemental long-chain omega-3 fatty acids as moderators of cognitive impairment and Alzheimer's disease. *European Journal of Nutrition*. 2022; 61: 589-604.
198. Wu M, Han F, Gong W, Feng L, Han J. The effect of copper from water and food: changes of serum nonceruloplasmin copper and brain's amyloid-beta in mice. *Food & function*. 2016; 7: 3740-3747.
199. Xu H, Wang S, Gao F, Li C. Vitamin B6, B9, and B12 Intakes and Cognitive Performance in Elders: National Health and Nutrition Examination Survey, 2011-2014. *Neuropsychiatric Disease and Treatment*. 2022; 18: 537.
200. Yang X, Yu X, Fu H, Li L, Ren T. Different levels of prenatal zinc and selenium had different effects on neonatal neurobehavioral development. *Neurotoxicology*. 2013; 37: 35-39.
201. Youness RA, Dawoud A, ElTahawy O, Farag MA. Fat-soluble vitamins: updated review of their role and orchestration in human nutrition throughout life cycle with sex differences. *Nutrition & Metabolism*. 2022; 19: 60.
202. Zamroziewicz MK, Barbey AK. Nutritional cognitive neuroscience: innovations for healthy brain aging. *Frontiers in neuroscience*. 2016; 10: 240.
203. Zeisel SH, Klatt KC, Caudill MA. Choline. *Advances in nutrition*. 2018; 9: 58-60.
204. Zhang DM, Ye JX, Mu JS, Cui XP. Efficacy of vitamin B supplementation on cognition in elderly patients with cognitive-related diseases: a systematic review and meta-analysis. *Journal of geriatric psychiatry and neurology*. 2017; 30: 50-59.
205. Zhang B, Burke R. Copper homeostasis and the ubiquitin proteasome system. *Metallomics: integrated biometal science*. 2023; 15: m fad010.
206. Zhou G, Ji X, Cui N, Cao S, Liu C, Liu J. Association between serum copper status and working memory in schoolchildren. *Nutrients*. 2015; 7: 7185-7196.