2

Review of Literature

The review of literature pertaining to the study entitled **"Digital Technology Assisted Nutrition Support for Children with Attention Deficit Hyperactivity Disorder"** is presented under the following headings:

2.1. Attention Deficit Hyperactivity Disorder (ADHD) -An Insight

2.2. Neurodevelopment in children with ADHD

2.3. Nutritional status of children with ADHD

2.4. Food and dietary habits of children with ADHD

2.5. Strategies to reduce ADHD symptoms and improve behaviour function

2.1. Attention Deficit Hyperactivity Disorder (ADHD) -An Insight

2.1.1. Introduction

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental psychiatric disorder that affects 5% of children worldwide and is characterized by excessive and impairing inattentive, hyperactive, and impulsive behaviour (American Psychiatric Association, 2013). Children affected by this disorder are at risk of learning disability, behavioural and social problems and also have serious impairment such as academic failure, substance abuse and juvenile delinquency in adolescents and adulthood. Hence, this disorder places substantial demand on mental health, educational, and judicial services. Genetic and environmental factors are involved in its etiology (Faraone and Larsson, 2018).

Pathophysiology of ADHD is unclear but research on children with ADHD has shown a general reduction in brain volume, with a proportionally greater reduction in the volume of the left-sided prefrontal cortex (Samea *et al.*, 2019). At present, ADHD has been treated with psychoeducation, parent training, child behavioural interventions, and

drugs such as stimulants (methylphenidate and amphetamines), noradrenergic treatment as atomoxetine and alpha-2A-adrenergic agonists as guanfacine and clonidine (Feldman *et al.,* 2018).

One of the risk factors for ADHD that can be targeted for intervention is food (Thapar *et al.,* 2013; Nigg and Holton, 2014). Adverse physical reactions to foods as eczema, asthma, and gastrointestinal problems affect various organ systems and also affect the brain, resulting in adverse behavioural effects (Bull-Larsen *et al.,* 2019). Colourings and preservatives negatively affect the behaviour of children with or without ADHD (Yu *et al.,* 2016).

Food affects the behaviour of children in different ways such as food allergy, food intolerance and gut–microbiota–brain axis (Petra *et al.,*2015). Food allergy causes increased levels of antigen-specific immunoglobulins and mast cell marker in the brain and these brain allergic responses are associated with behavioural impairments, including motor and learning deficits (Zhou *et al.,* 2019).

Many trials have investigated the effects of food on ADHD symptoms as colourings free diet, restricted elimination diet, gluten free diet and low sugar diet and there was a reported statistically significant and clinically relevant positive effect on ADHD (Pelsser *et al.*,2017).

2.1.2. Prevalence of ADHD

The most recent worldwide pooled prevalence as published in PubMed after assessing 175 eligible studies was 7.2 per cent (Sanders *et al.,* 2015). Earlier worldwide prevalence of ADHD is around 5.3 per cent according to Smith (2017) who did the first meta-analysis of the prevalence of ADHD in 9105 records and 303 text articles available in Medline and Psyco INFO database. It has been frequently diagnosed among children in the age group of 4-17 years (Matthews *et al.,* 2014).

In the past few years, there has been an increase in the number of reported cases of ADHD world over. Walkup *et al.,* (2014) reported an increase in the number of cases of ADHD among 4 -17 year old children in the United States. Compared to the number of reported cases of ADHD in 2003, approximately 2 million more are being treated for ADHD. This information is based on the survey conducted by CDC (Centre for Disease

Control), National Survey of Children Health conducted once in four years since 2003. The statistics compiled by the CDC revealed that the number of children diagnosed with ADHD in 2003 was 7.8 per cent of the population, 9.5 per cent in 2007 and 11 per cent in 2011. There has been an average increase of five per cent per year in the number of reported cases of ADHD.

In 2016, another study was conducted on 1147 school students of age group 8 to 15 years among three rural schools in Wardha district of Maharashtra. Initially, the teachers were sensitized about ADHD and by using Vanderbilt Attention Deficit hyperactive Diagnostic Teacher Rating Scale (VADTRS) was asked to be filled by the teachers based on the selected students. Later, these students were seen by the Psychologist, Psychiatrist and Paediatrician to confirm the diagnosis based on DSM-IV criteria for ADHD (Naik *et al.*, 2016)

According to Bhardwaj *et al.,* 2019 the prevalence in Coimbatore, a South Indian city was found to be 11.3 per cent (Venkata & Panicker, 2013).Using a purposive sampling and Connors Abbreviated Rating Scale (CARS) for diagnosis, 770 children in the age group of 6 to 11 years were studied. The results revealed that ADHD was significantly common among boys (66.7 per cent) and was more prevalent among the 9-11 year olds from lower socio-economic classes (16.3 per cent).

A study was carried out in Chennai, a metropolitan city in South India, (Venkatesh *et al.,* 2012) on children who were referred to a tertiary care clinic. Among 251 referrals, 20.3 per cent of them found to have ADHD, with the mean age of 5.7 years. The occurrence of ADHD in boys was six times higher than girls. The study also pointed out the prevalence of ADHD to be higher among the lower socio-economic class and the middle class. The study further concluded that a single study is not entirely conclusive of the extent to which the incidence of ADHD has increased in India, the fact that boys showed statistically increased incidence is noteworthy. (Anand *et al.,* 2016). Table I presents the key findings related to the prevalence of ADHD symptoms among school children, as stated in various studies.

TABLE I

Key findings related to the prevalence of children with ADHD symptoms

References	Year	Key findings related to the prevalence of children with ADHD symptoms
Sanders, Doust and Glasziou	2015	**7.2 per cent –Worldwide** (Assessment of 175 eligible studies)
Matthews, Nigg and Fair	2014	**Increased prevalence** among children in the age group of 4-17 years-**Worldwide** (Assessment of 9105 records and 303 text articles)
Walkup, Stossel and Rendleman	2014	**Increased prevalence** of ADHD among 4 -17 year old -United States
Polanczyk, Silva de Lima, Horta, Biedermanand Rohde	2007	**5.29 per cent- Worldwide prevalence**
CDC (Centre for Disease Control)	2003-2011	**2003 -7.8 per cent** **2007 -9.5 per cent** **2011-11 per cent** **Average increase of 5 per cent per year** in the prevalence inthe population,
Willcutt,	2012	**6.4 per cent- Jordan** **16.4 per cent - Asian continent** (Saudi Arabia)
Venkata and Panicker,	2013	**11.32 per cent - Coimbatore,** a South Indian city
Venkatesh, Ravikumar,Andal and Virudagirinathan	2012	**20.3 per cent in tertiary care clinic, Chennai**, South Indian city Mean age 5.7 years, six times higher prevalence among girls and lower socio-economic class

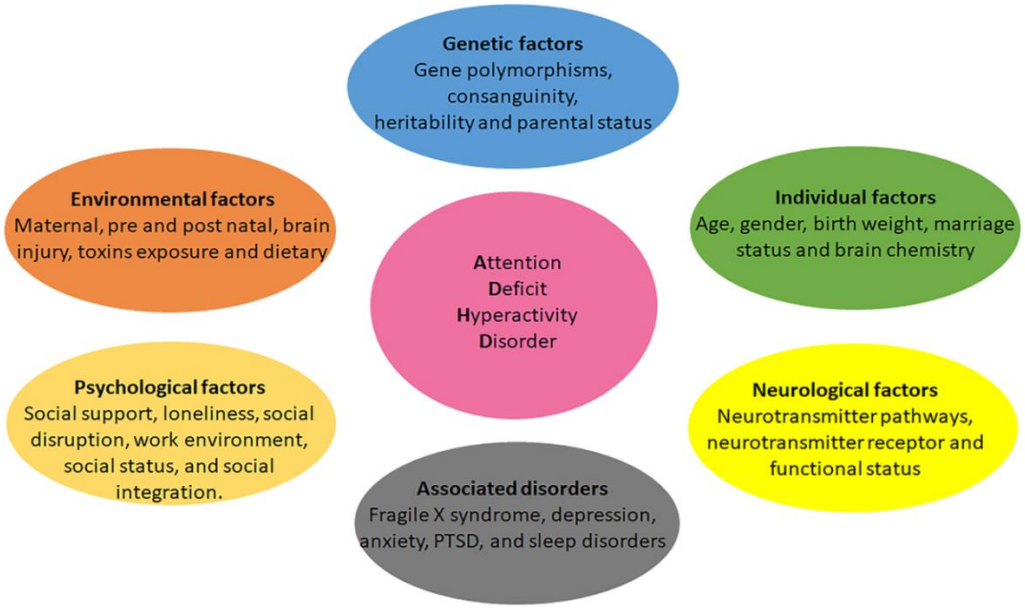
2.1.3. Causes of Attention Deficit Hyperactivity Disorder

In 2006, the first study was conducted on Indian children with ADHD in the age group of 2- 15 years by Das *et al.*,(2006) to establish the link between Monoamineoxidase A (MAOA) polymorphism and ADHD. MAOA regulates the dopaminergic signals in the presynaptic area. The results indicated that the preferential transmission of a short allele from the mother to the male child, thus indicating the role of MAOA polymorphism to be associated with ADHD in Indian population. The researchers also surmised that this preferential transfer of the defect in the gene to male offspring might also be the reason why ADHD is more common among boys. An observation of Yadav *et al.,* (2021)

confirmed the association of ADHD and MAOA polymorphism to be restricted among the males in the ADHD-HI sub group.

A systematic review revealed that, ADHD symptoms manifest themselves due to an interaction of genes and environmental causes. The environmental factors may initiate, minimize or maximize the manifestation of the psychopathological symptoms and knowledge of these interactions can help us in drawing a course of treatment plan by working on the external-environmental factors (Borsboom *et al.*, 2019).

Lautarescu *et al.*, (2020) studied the influence of prenatal maternal smoking on the neural circuitry of their offspring using functional Magnetic Resonance Imaging (MRI).The results were indicative of more obvious ADHD symptoms, pointing out the possible effect of prenatal exposure to nicotine. Zhu *et al.*, (2014) studied the association between ADHD and a smoking parent which was more pronounced, when the mother was smoking or using nicotine replacement during pregnancy. The results of a study by Daseking *et al.*, (2015) in Germany stated that, inhibitory deficits were found to be four times more among children of smoking mothers than the children of non-smoking mothers. Figure 1 depicts the conceptual framework for the causes of ADHD symptoms



Source:http://www.nimh.nih.gov/health/topics/attention-deficit-hyperactivity-disorder-adhd/index.shtml

Figure 1

Conceptual Framework for the causes of ADHD symptoms

The smallest amount of alcohol can cause problems during pregnancy, can predispose the child to Fetal Alcohol Syndrome (FAS) and Fetal Alcohol Spectrum Disease (FASD). Almost all studies related to alcoholism and ADHD has been based on self-reported consumption. Thus, the quantification of the alcohol consumption must be looked into through other means to assess the least amount of alcohol that can harm the child in any way (Wozniak *et al.,* 2019).

Assessment of nutritional status particularly, in the lower socio-economic status where maternal nutrition might be compromised, is very important not only in light of its potential predisposal to ADHD but a range of other disorders too. Complications during birth are one of the environmental causes of ADHD. The time during birth is associated with rapid brain development of children. It is believed that any trauma during childbirth is associated with long lasting effects on cognition and behaviour (Borge *et al.*,2021)

2.1.4. Types of Attention Deficit Hyperactivity Disorder

The heterogeneity in ADHD yields the different subtypes/presentations, namely, predominantly inattentive (ADHD-PI), predominantly hyperactive-impulsive (ADHD-HI), and combined (ADHD-C) presentations. (Luo *et al.*,2019) The terminology and diagnostic criteria for ADHD, similar to other neuropsychiatric disorders, have been improved and developed over the past 50 years, in response to the evolving understanding and conceptualization of the core deficits of the disorder . The current diagnostic approach of ADHD utilizes the Diagnostic and Statistical Manual of Mental Disorders (DSM) and its counterpart, the International Classification of Diseases (ICD), which conceptualize ADHD as a categorical diagnosis. This approach, however, has some limitations, necessitating the development and determination of alternative diagnostic structures for ADHD (Posner *et al.,* 2020).

Since its first appearance in the DSM, there have been controversies surrounding the ADHD-PI subtype of ADHD (De La Pena *et al.*,2020). For instance, the validity of this subtype has been questioned because prior to its representation in the DSM-III in 1980, it was not expected that there would be children who would present significant attention problems without hyperactivity and impulsivity (Morin *et al.*,2016). Since then, a number of studies have examined the validity of this subtype.

Moreover, works by (Fenollar Cortes *et al.,* 2017) were instrumental in the identification of two ADHD symptom clusters, namely, inattention and hyperactivity/ impulsivity, which eventually led to the determination of the three ADHD subtypes in the DSM-V. As noted earlier, these are the ADHD combined (hyperactivity or impulsivity and inattention present to a significant extent), ADHD-HI (hyperactivity or impulsivity with subthreshold inattention), and the ADHD-PI (significant inattention with subthreshold hyperactivity and impulsivity) types.

The DSM-5 criteria for ADHD also reflect a change in the ADHD subtype nosology (i.e., from ADHD "subtypes" in the DSM-IV to "presentations" in DSM-5) in view of the observed instability of ADHD symptoms over time within individuals across their lifespan (Niina, *et al.,* 2022). For instance, many children diagnosed with ADHD-C eventually have a transition to ADHD-PI, given that the inattention symptom is relatively stable across development. In contrast, the hyperactivity/impulsivity symptoms often diminish with age (Boxhoorn, *et al.,* 2018). Accordingly, the "presentation" terminology better captures the person's current symptomatology and its instability, in contrast to the more stable, trait-like characteristic denoted by the "type" terminology.

Furthermore, it has been proposed that the nature of the inattention symptom differs between ADHD-PI and ADHD-C. Accordingly, while ADHD-PI is associated with defects in sensory processing and poorly focused attention (Lau-Jensen *et al.,* 2021), ADHD-C is characterized by difficulty in sustaining attention, distractibility, lack of persistence, and disorganization . Moreover, children with ADHD-PI sometimes show elevated sluggish cognitive tempo (SCT) symptoms, for example, slow orientation and response to cognitive and social stimuli as compared with children with ADHD-C (Gaur *et al.,*2020)

2.1. Neurodevelopment in children with ADHD symptoms:

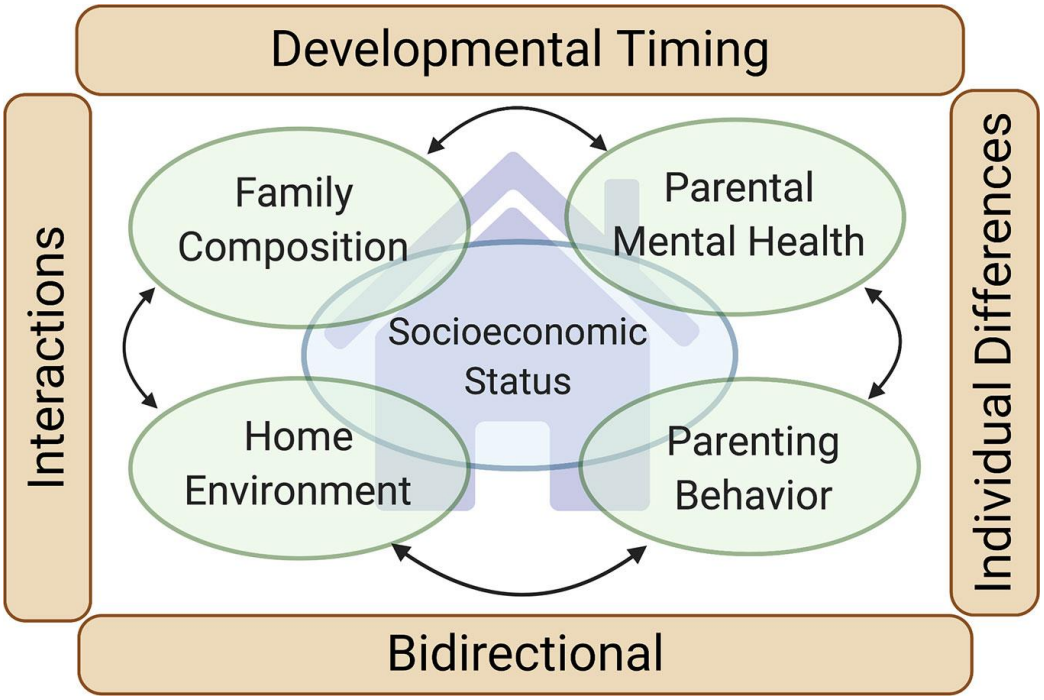
2.1.1. **Definition:**

The World Health Organization criteria defines neurodevelopmental disorders as "behavioural and cognitive disorders that arise during the developmental period that involve significant difficulties in the acquisition and execution of specific intellectual, motor, or social functions" (WHO,2020).

According to the American Psychiatric Association Diagnostic and Statistical Manual of Mental Disorders criteria, neurodevelopmental disorders are characterized by

"developmental deficits that produce impairments of personal, social, academic, or occupational functioning. The range of developmental deficits varies from very specific limitations of learning or control of executive functions to global impairments of social skills or intelligence" (Patel *et al.*,2020).

The term "neurodevelopment" connotes the developmental unfolding of behaviour, cognition, and emotion underpinned by brain maturation. Neurodevelopmental health reflects integrated brain–behaviour patterns that promote flexible adaptation and regulation in response to shifting environmental demands. In contrast, neurodevelopmental disorders reflect delays or deviations in behavioural and psychological function due to a typicalities in brain development with associated impairment. Family environments with the varied opportunities, challenges, and experiences they provide, influence neurodevelopment with attendant effects on children's motor and sensory development, temperament, cognitive abilities, and behavioural and emotional responses. (Wakschlag *et al.*,2017) as presented in Figure 2



Source: Bush *et al.*, 2020

Figure 2

Family environment and neurodevelopment.

According to Merz *et al.,* (2017) Socioeconomic status (SES) in childhood indicated that children in lower SES families have poorer neurodevelopmental outcomes across multiple domains including global measures of cognitive performance like IQ and academic achievement , as well as specific cognitive domains such as language processing, working memory, and cognitive control.

Family composition is associated with differential neurodevelopment. Children reared in two-parent families generally fare better than those raised in single-parent families in terms of cognitive, educational, and behavioural outcomes, and these associations are consistent across age groups.(Lee *et al.*, 2015)

Creating and maintaining an optimal, safe, supportive, and stimulating early home environment is considered an essential factor in promoting children's well-being and long-term adaptive functioning, particularly in the presence of other environmental and contextual adversities e.g. poverty (Bush *et al.,*2020). Characteristics of a child's home environment and its quality can be classified into two broad categories: functional and structural. Functional characteristics specify the emotional climate and the quality of interactions and relationships among members of the household (e.g., parent-child interactions and parental stress) and structural characteristics, which reflect the physical, and often observable, aspects of the home environment (e.g., residential crowding, quality of construction materials used in the house, proper facilities for food storage and hygiene, and access to learning resources). Low-quality structural characteristics of the home environment is often associated with adverse neurodevelopmental outcomes. (Schmeer *et al.,*2016)

Parent's interactions with their children are among the strongest proximal predictors of children's neurodevelopment. One of the primary approaches to conceptualising parenting has been a dimensional approach focused on continuous dimensions of specific parental behaviours, such as sensitivity, warmth, or control. (Darling *et al.,*2017)

The complexity of parent–child interactions and how parental behaviours and responsiveness may be influenced by, the offspring's behaviour and neurodevelopment. On the other hand, higher levels of parental warmth have been linked with more positive neurodevelopmental outcomes like academic achievement, social competence, prosocial

behaviours, emotional and behavioural regulation, and lower levels of externalising behaviours (Morris *et al.,* 2020).

Behaviour can be described and explained without making ultimate reference to mental events or to internal psychological processes. The sources of behaviour are external (in the environment), not internal (in mind, in the head). (Mahamadi *et al.,* 2016)

Behaviours are responses or reactions we make or activities we engage in. Some psychologists study behaviour as an association between stimulus (S) and response (R). Both stimulus and response can be internal or external. (Miller *et al.,*2017)

Kurt Lewin first proposed the famous equation B = f(P,E) – which suggested that behaviour is the product of a person and her/ his environment. This equation revealed that the variations found in human behaviour are large because persons differ with respect to their various attributes because of their genetic endowments and diverse experiences, and so do the environments they are placed in. Here the environment is conceptualised as it is perceived or made sense of by the person (NCERT, 2021).

Children who exhibited behavioural symptoms of ADHD are often seen as having behavioural problems. They are restless, inattentive, and impulsive. In a class, students with ADHD may be seen as constantly fidgeting, playing with their pencils, or swinging their feet. They may act before thinking, call out answers before the questions are completed, and interrupt when others are speaking. These children also have difficulties waiting for their turn and may appear as though they are inattentive to the lessons being presented. Children with ADHD have difficulty in sustaining attention to a task in class. The prognosis for their education is poor if their behaviour is viewed as being a behaviour problem, rather than a problem with their behaviour. Parents, teachers and other students are often frustrated by the behaviours children with ADHD symptoms display. It is essential that an understanding of the disorder is created so that those who come in contact with children who have ADHD can understand the behaviours and can deal with them appropriately.

2.2.2. Measures and tools used for Behaviour function in children with ADHD symptoms

Multiple diagnostic techniques and protocols used by various clinicians, psychologists and special educators are used to diagnose ADHD. The first documented

evidence of ADHD was by George Still in 1902, who found that some children in his clinical practice showed resistance to discipline, could not sustain attention in one activity for a long time and could not learn from the consequence of past actions. He proposed that this might be due to some neurological deficits and was independent of the environment the child is brought up. It was in 1968, that the American Psychiatric Association brought out the Diagnostic and Statistical Manual of Mental disorders (DSM), which named this clinical disorder as the Hyperkinetic Reaction of Childhood in its II edition. A "text revision" of the DSM-IV, known as the DSM-IV-TR, was published in the year 2000. (Rafalovich *et al.*,2015)

DSM-V list all currently recognised mental disorders and gives the features associated with each mental disorder and indicated how the disorder could be differentiated from other similar problems (Gerans *et al.,* 2019). As the number of reported cases of ADHD increased, the DSM- V in 2013 called in paediatricians to play an active role in diagnosing the children who might present themselves with ADHD symptoms but would have been undiagnosed because they were not referred to a psychiatrist. This, of course, might lead to a misdiagnosis of some children who are just overactive or those who might be distracted due to boredom.

The Diagnostic and Statistical Manual of Mental Disorders (DSM) provides the standard language by which clinicians, researchers, and public health officials in the United States communicate about mental disorders. The current edition of the DSM, the fifth revision (DSM-5) was published in May 2013, marking the first major overhaul of diagnostic criteria and classification since the DSM-IV in 1994 (Joyce-Beaulieu *et al.*, 2016)

The DSM-5 was constructed to address limitations in the DSM-IV while integrating the latest scientific and clinical evidence on the empirical basis of psychiatric disorders. The priority was to ensure the best care of patients possible and, in the process, improve usability for clinicians and researchers. (Shorter *et al.*,2022)

DuPaul *et al.*,(2020) studied the reliability of the ADHD rating scale, which was developed to accommodate the new DSM -V Diagnostic checklist and whether the observations were similar among parents and teachers, to ascertain the validity of the rating scale. The parent and the teacher ratings did not vary based on gender, age and language.

Research carried out by Davidson *et al.,* (2016) assessed the validity of the Behaviour Rating Inventory of Executive Function (BRIEF), a scale used to assess executive function impairment among children with psychiatric disorders. The test was administered to 30 ADHD children and a control group, who visited a child and adolescent clinic in Iran. Children in the ADHD group had higher scores than those from the non-ADHD group in all the scales and BRIEF. Thus, they can be used to discriminate the ADHD children and non-ADHD children and could prompt proper confirmatory diagnostic procedures by clinicians.

When ICD 11 was proposed for revision, the 18 diagnostic items of DSM- IV, that were retained by DSM-V were studied to test, whether each of the diagnostic items was essential in the diagnosis and the weightage each one of them carried in addition to their usefulness in lending themselves in identifying children with and without conduct disorder as comorbidity. 1497 affected and 297 unaffected children from various centres were studied, and all 18 parameters indicated impairment in the child, but each symptom's contribution to the overall presentation varies. (Garcia Rosales, 2015).

The BASC-3 evaluated the behaviour and self-perceptions of children and young adults with three rating scales: teacher rating scales (TRS), parent rating scales (PRS), and the self-report of personality (SRP) (Reynolds & Kamphaus, 2015). It is one of the most widely used broadband assessments for ADHD diagnosis (Zhou *et al.,* 2018).

The ADHD Rating Scale—5 (DuPaul *et al.,* 2020) is an 18-item scale for assessing children that incorporated the symptoms of ADHD established in the DSM-5 (American Psychiatric Association, 2013). The symptom scale included two subscales, one for inattention (short: "Inatt.") and one for hyperactivity-impulsivity (short: "Hyp.-Imp."). The Inattention items are: (1) Attention to detail; (2) Sustaining attention; (3) Does not seem to listen; (4) Following instructions; (5) Difficulty organising; (6) Sustained mental effort; (7) Loses things; (8) Distracted; (9) Forgetful. The Hyperactivity-impulsivity items are: (1) Fidgets; (2) Leaves seat; (3) Runs about; (4) Playing quietly; (5) On the go; (6) Talks excessively; (7) Blurts out answers; (8) Awaiting turns; (9) Interrupts or intrudes. Each item is responded to using a four-point Likert scale, where 0="never or rarely"; 1="sometimes"; 2="often"; and 3="very often." Total scores for (sub)scales are to be formed using summations of all associated items.

According to Chen *et al.,* (2021), various tools have been developed to evaluate ADHD in children and adolescents. These measurements generally can be categorised into two types: clinical diagnosis-based approach and empirical-quantitative approach. Clinical diagnosis-based measurements are developed directly based on the diagnostic system, such as the Diagnostic and Statistical Manual of Mental Disorders (DSM) system. These served as diagnostic assistance tools. Examples include the Connors Third Edition (Conners3), Swanson, Nolan, Pelham-IV Teacher and Parent Rating Scale (SNAP-IV), and Vanderbilt Assessment Scale. Among these tools, some of them (e.g., Conners 3, SNAP-IV, CBCL, Vanderbilt Assessment Scale) also evaluated ADHD-related behavioural, and emotional problems, such as oppositional-defiant disorder, conduct disorder, anxiety, depression and academic performance.

2.2.3 Associated comorbid conditions with ADHD

Studies in India, suggested that ODD, CD, SpLD, anxiety and depression are most common (Ghosh *et al.*,2018) revealed the presence of comorbidities that could be screened with the help of this scale were: ODD/conduct disorder, anxiety/depression, learning disability, and impairment in classroom behaviour performance. The most common comorbidity in this study was ODD/conduct disorder (76.3%), followed closely by learning disability (65.8%), impairment in classroom behaviour performance (50%), and the least prevalent was anxiety/depression (18.4%).

Jensen *et al.,* (2015) studied the Danish population to find out the comorbidities usually associated with ADHD in children and adolescents (4-17 years). The results showed that, 52 per cent of the subjects had at least one comorbid disorder and 26.2 per cent of the subjects had two or more than two comorbid conditions. The most common comorbid disorder is CD found in 16.5 per cent of the children. About 15.4 per cent had learning, language disorders and 7.9 per cent had intellectual disability.

Woo *et al.,* (2014) explored the memory characteristics of 97 ADHD boys with comorbid learning disabilities, 97 ADHD boys without learning disabilities and 97 healthy control subjects. Immediate, short-term, and long-term memory were measured in all three groups. Boys with ADHD with LD showed the most pronounced memory deficits in overall memory function and long-term memory function.

Mohammadi *et al.*,(2021) studied the prevalence of ADHD and comorbidities in a sample of 1508 school-going children between 6-14 years. Of this, eight per cent were diagnosed with ADHD symptoms, according to DSM-IV. Comorbidities were screened using the Childdie-SADS-PL. Sixty per cent of the children had one or more comorbidities, the common ones being LD (35.7 %) and ODD (22.6 %).

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common comorbid conditions observed in children with ASD, with the prevalence ranging from 14–70%. (Manohar *et al.*,2018). In general, both ADHD subtypes with childhood ADHD-C were more likely to have eating disorder than controls and more likely to have ODD, CD, and sleep disorders than childhood ADHD-I (Tsai *et al.,* 2019).

2.3. Nutritional status of children with ADHD symptoms

Nutritional status is the health status of the balance between nutritional needs and intake Children with special needs require special treatment in connection with developmental disorders and abnormalities experienced by the child. Children with special needs are grouped according to their abnormalities, one of which is physical or motor abnormalities. According to the United Nations Emergency Children's Fund (UNICEF), in 2011, data on the high incidence of growth and development disorders in children under five, especially motor development disorders like ADHD, cognitive deficits and learning disorders, was 27,5% or as many as 3 million children. (Anniza *et al.*,2022) Nutrition is one of the things that can affect a child's development, one of which is gross motor skills. Although poor nutrition can cause disability, it can also be a consequence.

2.3.1. Anthropometric Status

Height and weight of the children with ADHD should be taken regularly since the pharmacological medications used in the ADHD management tend to cause anorexia if they are administered at inappropriate times. It results in inadequate calorie intake and thus leading to a slowing of growth.

Shaari *et al.,* (2017), assessed the anthropometric measurement; 11.1% of the ADHD children had wasting, while 1.9% had severe wasting. In contrast, none of the typical development (TD) children had wasted. Approximately 5.6% of the ADHD children had stunting, as compared with 3.7% of the TD children, while none of the TD children had severe stunting compared with 3.7% of the ADHD children. More than half

of the ADHD children had mid-upper arm circumference (MUAC) below the 5th percentile, indicating undernutrition, compared with only 35.2% of TD children. More than one-third of the ADHD children had feeding problems compared with 9.3% of TD children. A significant negative relationship between the ADHD children's feeding problems and bodyweight (r = −0338, P = 0.012), body mass index (r = −0322, P = 0.017) and MUAC (r = −0384, P = 0.004) was observed.

ADHD was associated with obesity only in adolescent girls but not in children or boys; this effect was statistically accounted for by covarying of depression and conduct disorder. (Nigg *et al.*,2016)

Nutritional status is one of the factors that influence development. Malnutrition that occurs at an early age can cause tissue damage, growth retardation, decreased synapses, inhibited myelination and decreased development of brain maturity (Indrawati *et al.*,2016)

Gungor *et al.*, (2016) investigated the malnourished cases according to weight for height (WFH) and body mass index scores were more likely in ADHD cases than the control group. This situation suggested that ADHD is a risk factor for developing eating disorders.

Bowling *et al.*, (2017), indicated that patients aged 11 years treated for ADHD had lower BMI than those not receiving any treatment, and these children with ADHD had higher odds of poor diet regardless of medication. The BMI distribution in the ADHD group was similar to the comparison group. However, the ASD group showed almost three times greater prevalence of the high extreme BMI (standardised residual = 2.3) and nearly twice as great a prevalence of low extreme BMI (standardised residual = 1.1), with only about half having a normal BMI. (Kerekes *et al.*,2015)

2.3.2. Dietary intake

The dietary components which are suspected to be linked with ADHD, other than the artificial food colourings and additives, are the foods that cause allergy such as milk, chocolate, soy, wheat, eggs, beans, corn, tomatoes, grapes, oranges and sugar. Further, consuming excess snacks as a habit might lead to nutrition imbalances, lowering emotional intelligence and causing ADHD symptoms (Madzhidova *et al.*, 2019). Furthermore, the appetite-suppressing impact of ADHD medications may expose children to nutritional

deficiencies. The significance of diet in children with ADHD symptoms can be evaluated using the following criteria.

- By ensuring that the affected children adhere to a healthy diet
- Addressing micronutrient deficiencies such as iron, zinc, magnesium, and omega-3 fatty acids
- Identification of the nutritional insufficiency caused by decreased or altered food intake due to the appetite-inhibiting effects of ADHD medication.

Pelsser *et al.,* (2017) reviewed the diet factor in ADHD and suggested how diet can help to plan treatment. A wealth of literature has been quoted that explained the role of sugar, allergens in food that may be a cause of hyperactivity in children, how the "Western diet" is not a preferred diet for ADHD children, the role of Omega -3 fatty acids, iron, zinc, magnesium, copper in ADHD and how the supplementation of these micronutrients can be used as a supplement to stimulant medication.

Energin *et al.,* (2015) conducted a study among 200 children in Turkey. One half was normal children which made the control group, and the other half was ADHD children. They assessed the macronutrient and micronutrient intake in all the children by doing a 3-day dietary recall. The findings showed that the carbohydrate, protein and fat intake of ADHD children were lesser than that of normal children and the MUFA, zinc and niacin intakes were significantly lower than the control group.

Cortese *et al.,* (2017) examined a study after a diet modification program; 53% became normal weight, 32% overweight and 7% obese with a significant reduction in weight and body mass index (BMI), implicating the effectiveness of diet modification intervention in weight reduction.

Woo *et al.,* (2014) conducted a case-control study to identify dietary patterns associated with attention deficit hyperactivity disorder (ADHD). The study included 192 elementary school students aged seven to 12 years. Three non-consecutive 24-hr recall interviews were employed to assess dietary intake, and 32 predefined food groups were considered in a principal components analysis (PCA). PCA identified four major dietary patterns: the "traditional" pattern, the "seaweed-egg" pattern, the "traditional-healthy" pattern, and the "snack" pattern. The score of the snack pattern was positively associated

with the risk of ADHD, but a significant association was observed only in the second tertile. A significant association between ADHD and the dietary pattern score was not found for the other two dietary patterns. The study concluded that the traditional-healthy dietary pattern was associated with lower odds of having ADHD.

Salvat (2022) conducted a study on nutrient intake, and dietary habits in ADHD children. One hundred children diagnosed with ADHD were included and compared to 100 healthy normal children as the control group. As a result, ADHD children consumed more simple sugars, tea, and ready-made meals but less protein, vitamin B_1, vitamin B_2, vitamin C, zinc and calcium compared to the control group. It was concluded, that unhealthy eating behaviour was more frequent in children with ADHD, compared to normal children, which might warrant lifestyle intervention in this disorder.

Yorgidis *et al.,* (2021) reported an overrepresentation of celiac disease, identified by measuring the celiac-specific antibodies anti-gliadin and anti-endomysium in patients with ADHD. Ten out of 67 patients with ADHD were diagnosed with celiac disease. Patients and parents observed a significant improvement in ADHD symptoms under a gluten-free diet.

2.3.3. Clinical and biochemical markers

According to the Comprehensive National Nutrition Survey (2016–2018), nearly half of the children in India who appeared healthy had subclinical or biochemical markers of vitamin and mineral deficiencies. It is difficult to ensure that a child's diet contains 100 per cent of the Recommended Dietary Allowance (RDA) because children are usually picky eaters. Due to subclinical problems, a child may not reach full physical and mental growth potential. (UNICEF,2019).

The micronutrients in the child's diet provide a limited representation of the micronutrient status because the levels of vitamin B_6 and B_{12}, iron, zinc, magnesium, and omega-3 fatty acids in the body are determined by a combination of nutrient intake, digestion, absorption, and excretion. A sufficient number of micronutrients in the diet is insufficient if the digestion and absorption of a specific nutrient or the metabolism of a micronutrient is impaired. A review of literature that highlighted the current state of essential micronutrients that are typically implicated in neurodevelopmental disorders is introduced as follows:

Skalny *et al.,* (2020) have found to be both boys and girls with ADHD were characterised by 8 % ($p = 0.016$) lower serum Zn levels and 10 % ($p = 0.049$) higher Cu/Zn values when compared to neurotypical girls. (Viktorinova *et al.,* 2016) investigated Fifty-eight ADHD children and 50 healthy children (aged 6-14 years) were included in the study. The concentrations of Zinc in the plasma and Pb (lead) in the whole blood were measured by atomic absorption spectrometry. It has found to lower Zn levels ($p = 0.0005$) and higher Zn ratio ($p = 0.015$) in ADHD children when compared with the control group. The results of this study indicate that there are alterations in plasma levels of Zn as well as significant relationships to symptoms of ADHD.

Peripheral serum ferritin levels were significantly lower in ADHD children (children with ADHD = 1560, HCs = 4691, Hedges' $g = -0.246$, $p = 0.013$), but there was no significant difference in serum iron or transferrin levels. In addition, the severity of ADHD was significantly higher in the children with Intellectual Disability than those without ID (with ID = 79, without ID = 76, Hedges' $g = 0.888$, $p = 0.002$), and there was a significant association between ADHD and ID (OR = 1.636, $p = 0.031$) with lower serum ferritin levels.

Several possible pathophysiological mechanisms may explain the relationship between Intellectual Disability and ADHD. First, low peripheral iron levels, indicating insufficient iron storage, may dysregulate dopaminergic neurons, which may play a prominent role in the pathoetiology of ADHD (Khan *et al.,*2017)

In India, iron deficiency anaemia is prevalent (UNICEF, The Comprehensive National Nutrition Survey, 2019), and iron deficiency is one of the causes of ADHD in a child. Then, it is essential that the role of iron is further analysed and that the effect of iron supplements be determined through national studies.

According to Islam *et al.,* (2018), some parameters indicated iron status, such as Hb, serum iron, serum ferritin, total iron binding capacity (TIBC), mean corpuscular volume (MCV), and mean corpuscular Hb concentration (MCHC) were checked for both cases and controls. ADHD children were found to have a stronger correlation with Hb, ferritin, TIBC, MCV, MCH, and IDA those with iron deficiency were 3.82 times more likely to develop ADHD, which is slightly higher than the findings of (Berner *et al.,* 2014).

A total of 148 boys aged 4–9 years old were enrolled in this study, including 44 children with ADHD and 32 healthy neurotypical children. Mg content in hair was reduced in children with ADHD and ADHD+ASD compared to healthy controls by 11% and 15%, respectively. (Skalny *et al.*,2020). On the contrary, a study conducted by the Clinic of Noor and Ali Asghar of Isfahan University of Medical Sciences has shown deficiencies in the serum level of magnesium in 66 children with ADHD. After eight weeks of intervention, the serum levels of magnesium increased significantly in the intervention group compared with the control group. It could improve the behavioural function and mental health of children with ADHD. (Hemamy *et al.*,2021)

Chang *et al.,* (2021) indicated that children with ADHD have lower blood levels of DHA, EPA and total n-3 PUFAs compared to typically developing (TD) children. N-3 PUFAs in depression studies showed an increase in effect size in patients with inflammation (Rapaport *et al.,* 2016), suggesting that inflammation may be a potential treatment target for n-3 PUFAs treatment. Our recent clinical trial further supported this concept, showing a high EPA dosage of 1200 mg/d improved cognitive function (focused attention and vigilance) only in those children with ADHD with a low endogenous EPA level (<0.91%, more inflammed), but did not improve cognitive function in those children with moderate (between 0.91 and 1.98%) or high (1.08%) endogenous EPA level (Chang *et al.,* 2019)

A study by Altun *et al.,* (2018), on the evaluation of serum homocysteine levels, pyridoxine, folate, and vitamin B_{12} levels in children with attention deficit hyperactivity disorders (ADHD) revealed significantly lower levels in children with ADHD when compared with their controls ($p < 0.05$) and the positive significant correlation was observed between the all WISC-R scores and vitamin B_{12} level in patients ($r=0.408$, $p=0.025$). As for ADHD, (Unal *et al.*,2019) reported that Turkish children with ADHD had significantly lower vitamin B_{12} levels and that those levels negatively correlated with psychosomatic symptoms and learning problems, as reported by teachers

2.4. Food and dietary habits of children with ADHD symptoms

Nutrition is essential for human beings and is one of the most effective entry points for human development, poverty reduction and economic growth with high economic

returns (Planning Commission, 2015). Intake of nutrients affects the children's physical stamina, energy level, memory, mental ability, mood and emotional well-being. Children who cannot grow efficiently during this growth period may not compensate for the loss of growth, even on an excellent diet in later life (Kamath *et al.,* 2017).

Nutrition is the most essential basic need, being a major determinant of health, productivity, and mental development.

Nutrition is the modifiable associated environmental factor for children's cognitive development that directly affects brain function. It was identified in many longitudinal studies that there is an association between various nutrients and brain integrity or brain volume. Nutrients help to provide the building blocks for cell proliferation, synthesis of DNA, neurotransmitters, metabolism of hormones and other essential constituents of enzyme systems of the brain (Scarmeas *et al.,* 2018). Balanced nutrition is essential for school children as it is the period of vigorous growth, activity, and development of physical and cognitive functions (WHO, 2000).

Recent research suggested that a lower frequency of consuming fruit, vegetables, pasta, and rice and a higher frequency of skipping breakfast and eating at fast-food restaurants were associated with ADHD diagnosis ($P < .05$). High consumption of sugar, candy, cola beverages, and noncola soft drinks ($P < .01$) and low consumption of fatty fish ($P < .05$) were also associated with a higher prevalence of ADHD diagnosis. (Rios-Hernandez *et al.,* 2017)

According to a study by Rojo-Marticella *et al.,* (2022), dietary pattern data was collected using a food consumption frequency questionnaire. Principal component analysis was carried out to analyse dietary patterns. Western-like, sweet, and healthy patterns were identified. The ADHD group was negatively associated with the healthy pattern (p & lt; 0.001) and positively associated with the Western-like diet ($p = 0.004$). Children with inattentive presentation showed lower adherence (12.2%) to a healthy pattern than that of the control group (39.9%) (p < 0.001). There was an association between ADHD and dietary habits; children with the inattentive presentation may particularly be at risk of unhealthy eating habits.

Chou *et al.,(*2018), in a study, observed whether children with ADHD exhibited different dietary habits or nutrient profiles from healthy control subjects. The results of the

study revealed that compared to the control, children with ADHD demonstrated a higher intake proportion of refined grains (p=0.026) and a lower proportion of dairy (p=0.013), calcium (p=0.043), and vitamin B_2 (p=0.024). The composite score of dietary and nutrients could significantly distinguish patients with ADHD from healthy controls (p<0.001). The composite dietary/nutrient score significantly correlated with the severity of ADHD clinical symptoms (p<0.05).

A more systematic and theoretical analysis is required for six dietary patterns and six foods or macronutrient studies. Six dietary pattern studies (n: 8816) were included in this regard. The pooled analysis established that a "healthy" dietary pattern highly loaded with vegetables, fruits, legumes, and fish have significantly decreased the risk of ADHD (OR: 0·63; 95% CI: 0·41, 0·96), whereas "Western" dietary pattern including red meat, refined grains, processed meats, and hydrogenated fat (OR: 1.92; 95% CI: 1.13, 3.26; p:0.016) and "junk food" pattern containing sweetened beverages and desserts (OR: 1.51; 95% CI: 1.06, 2.16; p: 0.024) dietary patterns increased it. (Shareghfarid *et al.*,2020)

A recent study by Lee *et al., (*2022) concluded that the sweet dietary pattern was associated with a higher risk of attention deficit (AD) (relative risk [RR], 1.34; confidence interval [CI], 1.17-1.55), hyperactivity (RR, 1.40; CI, 1.19-1.64), and ADHD symptoms (RR, 1.37; CI, 1.23-1.52) and compared to the vegetable dietary pattern was associated with a lower risk of ADHD symptoms (RR, 0.81; CI, 0.72-0.90). The study's findings revealed that food item analysis of the sweet dietary pattern showed that intake scores for chocolate, chips, and fruit jams positively correlated with AD, hyperactivity, and ADHD symptoms.

A study by Swansburg *et al.,* 2021 investigated the impact of COVID-19 on lifestyle habits and mental health symptoms in paediatric attention-deficit/hyperactivity disorder (ADHD) in Canada. A total of 587 surveys were completed. The mean child age was 10.14 years (SD 3.06), including 166 females (28.3%). Children met SNAP-IV cut-off scores for inattention (73.7%), hyperactivity/impulsivity (66.8%), and oppositional defiant disorder (38.6%) behaviours. Caregivers reported changes in sleep (77.5%), eating (58.9%), exercise (83.7%), and screen use (92.9%) in their ADHD child, greatly impacting youth. Sleeping fewer hours/night, eating more processed foods, and watching TV/playing videogames >3.5 hours/day correlated with greater depression, anxiety and ADHD

symptoms, and exercising <1 hour/day further correlated with depression symptoms ($P<0.01$).

Abbasi *et al.,* (2019) was conducted to assess the relation of major dietary patterns determined by factor analysis with attention-deficit/hyperactivity disorder (ADHD) in a group of Iranian preschool- and school-aged children. Two major dietary patterns were identified: healthy and Western. The healthy dietary pattern was rich in fruits, vegetables, vegetable oils, whole grains, legumes, and dairy products. The western pattern was rich in processed meat, red meat, pizza, eggs, snacks, animal fat, hydrogenated fat, and salt. After controlling for potential confounders, children in the top quintile of the Western dietary pattern score had greater odds of having ADHD, compared with those in the lowest quintile (odds ratio [OR] = 3.45; 95% confidence interval [CI], 1.17-18.3; $p_{trend} = 0.03$). The healthy pattern was inversely associated with ADHD (OR = 0.46; 95% CI, 0.38-0.91; $p_{trend} = 0.01$).

The association of dietary phytochemical index (DPI) with the odds of ADHD symptoms in 360 children and adolescents 7–13 years old in Yazd, Iran was investigated (Darabi *et al.,* 2022). Subjects in the highest quartile of DPI have a higher intake of macronutrients, eicosatetraenoic acid, docosahexaenoic acid, calcium, zinc, iron, vitamins B_{12}, B_6, and folic acid compared to the lowest quartile. After adjusting for potential confounders, subjects in the highest quartile of DPI compared with subjects in the lowest quartile showed a lower risk of ADHD (OR: 0.44; 95% CI: 0.18–0.90). There was a significant decreasing trend in the odds of ADHD across the increasing quartile of DPI (P for trend: 0.02).

Quinoa and amaranth are broad-leaf plants (non-grasses), and their seeds have been incorporated into regular cereal-based foods. Quinoa and amaranth seeds as pseudocereal grains are gluten-free and have received much attention recently because of their exceptional nutritional value and potential health benefits. For this reason, the United Nations FAO also declared 2013 as "The International Year of Quinoa", promoting the planting, development and research on quinoa has been described, together with Amaranth, as 'one of the grains of the 21st century and related products. The high genetic variability of quinoa and amaranth allows them to be adapted in most of the world's arable regions, from tropical to temperate climates, under different environmental conditions. Quinoa and

amaranth are rich in macronutrients such as proteins, carbohydrates and fats, as well as micronutrients, including vitamins and minerals Tang *et al.,* (2017). In addition, the two grains are also gluten-free, thus offering a variety of nutritious and suitable food products for about 2% of adults and 5% of children estimated to have food allergies such as celiac disease. (Greenhawt *et al*.,2018)

Black gram (*Vigna mungo L*.) is an important legume crop cultivated worldwide in tropical and subtropical regions and is valued for the high protein in its seeds. India is the world's largest producer and consumer of black gram. It produces about 1.5 to 1.9 million tons of black gram annually from about 3.5 million hectares of area, with average productivity of 500 kg/ha (Balyan *et al.,*2016). Pulses are commonly known as food legumes with are secondary to cereals in production and consumption in India. The United Nations, declared 2016 as the "International Year of Pulses" (IYP) to heighten public awareness of the nutritional benefits of pulses as part of sustainable food production aimed at food security and nutrition. Pulses are an integrated part of many diets across the globe, and they have great potential to improve human health, conserve our soil, protect the environment and contribute to global food security. Black gram is scientifically known as *Vigna mungo* (L.) and commonly known as urd in India.

Horse gram is an unexploited food legume of the family Fabaceae and is grouped under the species; Macrotyloma uniflorum (Reddy *et al.,*2015). Okoth *et al., (*2017), more than one-third of all child deaths worldwide are affected by malnutrition, while in developing countries, 54% of child deaths were associated with child malnutrition. Malnutrition and micro-nutrient deficiency are mainly a result of consuming a highly refined cereal-based meal, which is bulky, high energy and less nutritious, especially a lack of protein and minerals (Jayathilake *et al.,*2018).

A study by Prasad *et al.,* (2015) indicated that horse gram is an excellent source of protein (17.9 - 25.3%), carbohydrates (51.9 - 60.9%), essential amino acids, low content of lipids (0.58-2.06%), source of iron, molybdenum, other minerals and vitamins. Further, horse gram could be promoted as a high-quality protein constituent of the daily diet among economically depressed communities in developing countries and potential application to reducing the high prevalence of protein and energy malnutrition.

Horse gram contained high anti-nutritional components and cause several health-beneficial effects by reacting as potential antioxidants such as phytic acids. The saponins provide neuroprotective effects on attenuation of central nervous system disorders, such as Parkinson's disease, stroke, Huntington's disease, and Alzheimer's disease, along with some *in-vivo* studies showing saponins have tumour inhibitory effects and antifungal activity.(Herath *et al.*,2020)

Date palm (*Phoenix dactylifera L.*), or khajoor in the local language, is called the tree of divine guidance and provides many people with a livelihood (Al-Alawi *et al.*,2017). They have thick skin and a dark brown colour and have many benefits, including high fibre, high antioxidants, improved brain health, good hair etc. This release inhibited neuronal necrosis, as evidenced by histopathological detection in hypo perfused brain. Date palm fruits protect against inflammation and oxidative stress in the brain. (Zhang *et al.*,2017)

The components of dates, namely hydroxycinnamates, gallic acid, ferulic acid, monohydroxybenzoic acids, flavones and α-synuclein, and anthocyanin inhibit proinflammatory cytokines, amyloid beta peptides and α-synuclein, and increase brain ATP concentrations, leading to the prevention of neurodegenerative diseases (Taleb *et al.*,2016). Dates are a source of antioxidants. It had a protective effect on the cerebro and helped maintain brain ischemia. Mebroom dates are known for developing mental functions (Alem *et al.*,2017).

Nuts, including ground nuts and tree nuts such as almonds, cashews, pine nuts, walnuts, pistachio nuts and macadamia nuts, are a globally consumed snack food (Rehm *et al.*,2017). They contain numerous health-promoting nutrients and a suite of bioactive non-nutritive components; they are high in protein and unsaturated fats, fibre, plant sterols, minerals (calcium, potassium, magnesium), vitamins (B group vitamins and vitamin E) and polyphenol antioxidants (Hayes *et al.*,2016). Studies quantifying nut consumption in children and adolescents are limited, and few large-scale epidemiological studies have evaluated the relationship between nut intake and dietary quality (Chang *et al.*,2016). The intake of nuts in children may be limited by policies to limit nuts being consumed at school to avoid possible food sharing and allergy risks, given that peanut allergies are especially highly prevalent (Sasaki *et al.*,2018)

Tree Nuts have produced benefits or shown positive associations regarding neurodegenerative disorders in multiple studies. (Yang *et al.*,2016) Omega-3 fatty acids have shown benefit for depression (Medawar *et al.*,2019). They affected brain structures alone and combined with exercise and stimulation (Kobe *et al.*,2016). Omega-3 fatty acids showed a possible role in preventing cognitive decline and dementia. Nuts have a high content of Quercetin, with epicatechin or curcumin, showed (Waseem *et al.*,2016) neuroprotective effects and B vitamins showed benefit on mild cognitive impairment in a (Null *et al.*,2017) small study. Zinc showed benefits for depression, and deficiency is associated with neurodegenerative disorders. (Jarosz *et al.*,2017)

Seafood, particularly fish, plays a crucial role in global food and nutrition security (FNS) as it represents an essential and nutrient-dense animal source of food, especially in many low and middle-income countries (LMICs) (FAO, 2018d). Available data also suggested a high prevalence of micronutrient deficiencies, particularly vitamin A, calcium, iron, folate, and zinc. Limited data are available for other nutrients such as vitamin D, vitamin B_{12}, selenium, and iodine (Abeywickrama *et al.*, 2018; WFP, 2018).

Fish is a good source of critical nutrients such as highly bioavailable animal protein (Bene *et al.*, 2016), marine long-chain omega-3 polyunsaturated fatty acids (n-3 LCPUFA), including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), and numerous micronutrients, including vitamin A, vitamin B_{12}, vitamin D, zinc, selenium, and iodine. Fatty fish is generally considered the best source of fatty acids (especially EPA and DHA) and fat-soluble vitamins. In contrast, lean fish generally are regarded as the best source of iodine (Torris *et al.*,2018). Furthermore, fish enhances the bioavailability of minerals such as iron and zinc from cereal and tuber-based diets, thus including even small quantities of fish in the diet may provide a range of essential nutrients otherwise lacking in diets predominantly centred on grains and tuber crops (Karaaslan Ayhan *et al.*,2022). There are many types of fish, each with its own texture, health benefits, and flavour. Trevally fish, also known as Parai fish in southern India, is a popular fish variety. Parai fish has a unique texture and flavour, making it an excellent choice for fish curries and snacks (Koralagama *et al.*,2021). Parai meen, like other fish species, is a healthy addition to one's diet because it is high in nutrients, vitamins, and minerals. Proteins, vitamin D, and zinc are all high in this food. The unique dietary habit is marked by high consumption of red meat and low consumption of marine fish, which perhaps contributes significantly to minimising the potential effects of marine fish rich in n-3 FA (Yang *et al.*,2020)

2.5. Strategies to combat ADHD symptoms and improve behaviour function

2.5.1. Diet Modification:

Diet modification program in the form of adjustment of energy and macronutrient intake, with the exclusion of food additives, gluten, milk and dairy products, eggs, and highly containing salicylate and sulphite foods and following health education tips (regular sleep, limit TV time) improved symptoms and behaviour of ADHD patients as documented by the decrease in scores of DSM-V (Abd El Baaki *et al.*,2021)

Diet modification program succeeded in reducing ADHD symptoms. Restricted carbohydrate intake in the diet effectively decreased hyperactivity and learning problems in ADHD patients. Fat intake showed a significant increase after following the diet modification program, which may be one of the reasons for decreased hyperactivity. Finally, this study concluded the great impact of diet modification on diminishing symptoms of ADHD not only by the direct effect on hyperactivity and learning problems but also by maintaining BMI, which in turn improves symptoms in ADHD patients. (Hassan *et al.*,2022)

A study by Abd El Hamid *et al.,* (2015) on Egyptian children found that childhood obesity was associated with serum levels of monocyte chemoattractant protein-1 (MCP-1) and interleukin-6 (IL-6) predisposing to systemic inflammation, including neuroinflammation causing foggy brain and development of neuropsychiatric disorders and this is also reported by a study by Teoharides *et al.*,(2015).

In comparison, Tong *et al.,* (2017) concluded that ADHD contributed to emotional eating and bulimia nervosa, but there was no significant relationship between ADHD and BMI. The present study showed a positive effect of diet modification on ADHD outcome, it was noted that there was a decrease in behavioural disturbance as assessed by CPR-RS. All subscales of CPR-RS decreased statistically significantly after diet modification.

Beela *et al.,* (2017) detected an improvement in ADHD symptoms after a reduction in carbohydrate intake in a group of Indian children aged (4–12 years) compared to the control group who were diagnosed with ADHD but did not follow carbohydrate restriction. Elimination of milk, eggs and dairy products in this study is on par with a study by Taylor *et al.,* (2018) which showed that a diet free of cow milk, egg and related by-products, and several histamine-releasers foods, produced a notable improvement of both attention and

hyperkinesia in 79% of cases. Czaja-Bulsa (2015) explained that gluten-related disorders (celiac disease, gluten allergy, non-celiac gluten sensitivity) are associated with behavioural disorders such as disturbance in attention and hyperactivity. This could be explained by those sulfotransferase inhibitors found in artificial food colours leading to an increment of catechol amines, with negative effects on the proper functioning of the prefrontal cortex where ADHD behaviour can arise, as mentioned by Nigg and Holton (2014). Bostock *et al.,* (2017) showed that calorie restriction and high fat intake diet possess broad therapeutic potential in various neurological diseases.

Cortese and Tessari (2017) showed a significant association between ADHD and obesity with a possible explanation that obesity and factors associated with it (such as sleep-disordered breathing and deficits in arousal/alertness) manifest as ADHD-like symptoms or that ADHD and obesity share common genetics and neurobiological dysfunctions, involving the dopaminergic system.

Mikirova (2015) reported that vitamin A and C intakes in the risk group of Korean children did not reach the daily recommended levels have found that subjects with ADHD were deficient in nutrients such as zinc, vitamin $B_{3,}$ magnesium, and vitamin C. Annelies *et al.,* (2018) showed that vitamin A and C have some antioxidant and neuroprotective effect. Vitamin C is a critical component of the antioxidant system. Oxidative stress caused by chronic inflammation, heavy metal or other environmental exposures, and hyper-excited neurons place heavy demands on the brain's antioxidant system, as fit (Lopresti *et al.,* 2015).

2.5.2. Nutrition Education:

Nutrition education can be defined "as any set of learning experiences designed to facilitate the voluntary adoption of eating and other nutrition-related behaviours conducive to health and well-being", nutrition education helps to address the numerous personal and environmental influences on food choices and assist individuals in practicing healthy behaviours, besides literature proposes eating patterns to be responsible for 4 out of 10 deaths (Contento, 2010). Lua and Elena, 2012 evaluated the impact of nutrition education delivered using web-based education, lectures, and supplementation and showed an improvement in food consumption, nutrition knowledge, dietary habits, physical activity, and quality of life.

Nutrition education will provide the knowledge and skills to build healthier food choices and good dietary behaviours among school children. The renewed emphasis should be on creating and implementing nutrition education initiatives incorporated into their regular school curriculum. Nutrition education can affect the learner's food choices (Perera *et al.,* 2015).

Many research studies have demonstrated the significance of a mother's education in child health and nutrition. Makoka and Masibo (2015) reported in their study that a mother's education was strongly linked to children's improved health and good nutrition

Nutrition education is an effective strategy to change health behaviour in some settings and is likely to influence the naturally occurring knowledge exchange within parent groups. Parent access to feeding support is particularly important during the COVID-19 pandemic due to the impacts on health service resources, parent isolation, and reported increases in dysregulation of the parent's own eating behaviours (Wang *et al.,*2021). Our formative work indicated that parents are willing to seek nutrition education for their own purposes and undertake two or more hours of training to become peer nutrition educators (Luesse *et al.,*2018).

Rathi *et al.,* (2017) explored teachers' and parents' opinions of food and nutrition education in Indian secondary schools. This investigation revealed shortcomings in the current food and nutrition curriculum and included a repetitive and limited curriculum; excessive emphasis on rote learning; limited opportunities for food skills training; and contradictions between the messages imparted in classroom nutrition lessons and the unhealthy nature of many of the products provided by the school food services.

Any combination of educational strategies, supported by environmental support, is designed to promote the voluntary adoption of food choices and other behaviours related to food and nutrition conducive to health and well-being. Nutrition education is offered through numerous events and involves different activities at the individual, community, and policy levels (Contento, 2020). Strategies such as nutritional counselling and food supplements can dramatically reduce undernutrition

Education increased an individual's sense of personal control and self-esteem. These factors have also influenced better health behaviour (Becker *et al.,* 2014). More education has been linked to better jobs, higher income, higher socio-economic status,

better health care access and housing, better lifestyle, nutrition, and physical activity, which are all well-known health determinants (Berezowitz *et al.*,2015)

Although parents play an essential role in preventing short stature, providing continuous education to parents is critical to the government, universities, and communities. The most effective educational tool is educational counselling and two-way discussion with the parents with practical advice during the educational counselling (WHO, 2014).

A recent study studied the impact of micronutrient interventions on cognitive performance in children aged 5 to 15 years in developing countries. They found that the supplementation using food fortified with multiple micronutrients for three months to one year positively affected cognitive function (Mitra-Ganguli *et al.,* 2017). Parent-feeding practices strongly predicted the quality and quantity of foods consumed and underpin lifelong eating patterns (Collins *et al.*,2014). While parents strongly desire good health for their children, their early intentions about healthy feeding and eating can be thwarted during the preschool years by anxiety around the demands of 'food parenting' (Davidson *et al.*,2017) in an increasingly obesogenic environment (Wright *et al.*,2015). Parents who lack child feeding skills tend to resort to feeding strategies that temporarily appeased a child but ultimately resulted in poor self-regulation of intake, preference for energy-dense, nutrient-poor foods, food anxiety, and avoidance (Gevers *et al.*,2015).

Interventions to improve infants' and toddlers' eating patterns should guide parents in converting their healthy child-feeding intentions into practice. New parents may have limited exposure to evidence-based information to guide the development of feeding practices (Ball, *et al.*,2017). They are unlikely to be driven to change their feeding behaviour or seek feeding assistance by knowledge of future chronic disease risks (Henstrom *et al.*,2022). Groups of new parents with similarly aged infants frequently form long-lasting social connections. Along with family, existing friends, and the internet, these peer groups are influential in parents' child-feeding practices and dietary patterns (Ball *et al.*,2021).

Additionally, parents use their peers as a reference point for feeding practices and their children's dietary intake, rather than health service guidance. Parent's

groups provide the ideal setting for cost-effective, population-level interventions as a group's social support and norms are resistant to change (Paes *et al.*,2015).

Mangrio *et al.,* (2018) evident that interventions targeting nutrition and feeding practices typically use traditional dichotomies of 'health professional' and 'patient', yet behaviours are more likely to change if educators share similar demographics and nutritional concerns.

2.5.3. Digital Health Intervention

The term 'digital health' describes a diverse array of digital devices and software used for managing and promoting health and well-being, generating and archiving health and medical details, supporting medical education and training or offering medical services. Across many countries, and particularly in the Global North, digital technologies are widely used for health and medical purposes (Lupton,2017; WHO,2019)

Digital interventions appear to be a promising avenue for improving children's nutrition and are an intervention approach aligned with societal shifts and trends for accessing health information (Zarnowiecki 2020; Friedman, 2018). Parental use of web-based programs and smartphone apps are high, and parents feel confident using the internet and apps on smartphones, reflecting societal trends in digital technology use (James, 2018).

Nutrition promotion websites and apps can achieve small to moderate changes in fruits, vegetables and nutrient-poor foods and drinks (Grimes,2018; Knowlden,2015), albeit with more studies needed to substantiate their effectiveness further.(Nystrom *et al.*,2017)

The strategy to reach intended users will also influence engagement with digital nutrition promotion interventions. Social media approaches (predominately Facebook, Instagram and targeted website advertisements) have a wide reach and are low cost but are less effective at reaching target users (Laws,2016). Digital interventions delivered to parents in other contexts support the use of apps and websites as an effective intervention mode for improving health behaviours (Taki,2019; Litterbach,2017)

Overall, websites and apps currently used as health promotion tools targeting parents reviewed here did not meet the desired features and content identified in user

testing. Websites provided considerable information content and few interactive features, with one notable exception, which scored well for both engagement and information quality (Aydin *et al.*,2022)

Digital health is a fast-moving field of research. The current COVID-19 pandemic, in particular, has contributed to a rapid increase in the utilisation of digital health technologies for accessing health information and care providers (Hollander & Carr,2020).

Recently, the convergence of science and digital technologies, such as the Internet and mobile phones, are potential and scalable means of educating and stimulating practices for promoting healthy behaviour, known as "digital health interventions" (Potenza *et al.*, 2020).

From time immemorial, technology has been used to improve the reach and effectiveness of interventions. The digital intervention was the brainchild of an experimental electronic duo formed by British electroacoustic composer and sound engineer artist Paul Kendall and French-born British composer, Olivia Louvel (https://en.wikipedia.org/wiki/Digital_health#cite_note-ehj-4), which had improved tremendously in the ' and 90's denoted as the golden time for digital health when many professional associations around the world encouraged healthcare delivery through digital communication. In the 21st century, a hardware and software revolution in this field commenced; in the case of hardware internet usage, increase in mobile phones or smartphone usage, and the software front enormous amount of health information, open access clinical studies and guidelines were becoming widely available. This led to the coining of new terms such as mHealth (mobile health), eHealth (electronic health), and Personalized Health. From 2010 till date, with the launch of a digital health unit by the FDA in 2019, digital health has gained more significance, developed and distributed globally (Meskó *et al.*, 2017 and Meister *et al.*, 2016). The onset of the Covid -19 pandemic has widened the space for digitalisation in many fields leading to the enormous growth of digital technology among middle and low-income groups (Williamson *et al.*, 2020).

Digital health intervention has also been introduced in the field of health education to create awareness via mobile technology, social media and online learning, for improvement in terms of effectiveness, accessibility, efficiency, flexibility and safety at the convenience of the home (Ansari and Khan, 2020). Some of the technology used for such

interventions are smartphones and tablets applications, websites, social media tools such as YouTube Videos, Whatsapp, Facebook, Twitter etc., games, messages and memes, which when used individually or in combination appropriately, can help in creating awareness and promoting healthy behaviour such as improving physical activity, inculcating healthy eating habits, improve outcomes in individuals with long term health issues etc. (Murray *et al.,* 2016).

Awareness and self-care have been preferred by people recently, and this had led to an increased extent digital health interventions have been designed for self-management and support, through being connected to healthcare providers at the convenience of their homes (Georgsson *et al.,* 2016). Research indicated that social isolation and loneliness harm the health and well-being of an individual, various types of technologies and their effectiveness in dealing with social isolation identified were general ICT, video games, robotics, personal reminder information and social management system, asynchronous peer support chat room, social network sites, Telecare and 3D virtual environment as effective technologies to promote social communication (Khosravi *et al.,* 2016) also implementation and feasibility of digital technology in enhancing social connectivity studied for three months among old adults including semi-structured interviews, psychometric scales, field observations, and usability tests found the technology to be a feasible requiring an adoption period for implementation, sense of well-being and confidence were also enhanced with technology (Barbosa *et al.,* 2019).

A website on health behaviour change models, adult education, and website construction was developed to guide old adults in an experiment control evaluation, there were significantly higher ratings of usability and learning for the new site in the experimental group. They also reported that participation was likely to improve future searches. (Fink and Beck, 2015). Research evidence while determining the efficacy of a Web-based salt reduction program on knowledge, attitudes, behaviours, self-efficacy, and salt intake observed a significant improvement among individuals who took up a weekly online interactive website-based programme for five weeks (Grimes *et al.,*2018).

A study analysing different classes of websites using approval criteria for web information, namely the JAMA score, has determined that commercial websites scored lower in comparison with health-based websites, reporting better trustworthiness of health-based websites (Mubashar and Pietro, 2015).

Gamification of intervention for increasing health awareness and physical fitness to live independently for longer reduced the costs in the health care system among the elderly. Investigating the gamer types, personality factors and technical expertise on the performance and changes in the attitude towards individual health after the game. Surprisingly, gamer type had a better effect on performance besides a positive effect on the perseverance of pain was detected after the Exergame intervention (Brauner *et al.*, 2013) Gamification was used progressively in campaigns aiming at creating awareness and bringing about behavioural change, especially among the Gen Z (Generation between 1995 to 2010) the emerging gamification approach was found beneficial for a health awareness campaign to defeat the COVID-19 pandemic (Zain *et al.,* 2021).