International Research Journal of Multidisciplinary Scope (IRJMS), 2026;7(3):442-454

Original Article | ISSN (O): 2582-631X DOI: 10.47857/irjms.2026.v07i03.011670

Brain Food: Evaluating the Role of Dietary Macronutrients and Micronutrients in Adolescent Cognitive Abilities

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Abstract

Cognitive abilities are encapsulated as set of higher-order functions which are pivotal for interpreting, analyzing and navigating one's environment. As adolescence is recognized as a crucial period of physiological, psychological and neural development, nutritional deficiencies spanning both macro and micronutrients can significantly deteriorate the cognitive maturation. This has prompted a growing scholarly interest in analyzing how specific dietary components can influence varied dimensions of cognition. The key rational of this study is to examine the dimensions of dietary macronutrients and micronutrients that demonstrate direct relationship with the cognitive functions of adolescents. Utilizing a correlational research design, this study analyzed a sample of 305 adolescents from government schools of Delhi, India using purposive sampling procedure. Correlation and regression methods were used to analyze the data. The statistical output derived using correlation analysis demonstrates a significant positive relationship between nutritional intake—specifically macronutrients (energy, protein, fats and carbohydrates) and micronutrients (iron, calcium and phosphorus)—and multiple cognitive domains, including awareness, memory, understanding, reasoning and problem solving, as well as the composite cognitive ability score. The regression models further establish that dietary intake specifically energy, carbohydrates, iron and calcium are serves as a primary determinant for various cognitive ability domains. These evidences have concluded that nutrition-rich dietary regime is fundamental for fostering adolescent cognitive development. These results will help family, society and government authorities for developing multi-faceted approach which ensure that each and every adolescent will receive essential Macronutrients and Micronutrients for safeguarding them against cognitive impairment.

Keywords: Adolescents, Cognitive abilities, Macronutrients, Memory, Micronutrients, Problem Solving.

Introduction

Adolescence is recognized as the most crucial stage of the life span, designated by swift physical and mental growth and nurturance. This span serves as a transition between the stages of childhood and adulthood, marked by shift from being a dependent child to becoming a self-sufficient adult.

Cognition is elucidated as a set of states and systems through which children engage in thinking, judgment, analysis, evaluation, exploration and figure out things. It encompasses all mental processes, both at conscious and unconscious levels, which are responsible for the acquisition of knowledge and skills, as well as the comprehension, understanding and interpretation of situations using senses and experiences. The development of cognitive abilities during the adolescence phase upholds prime importance, as it enables individuals to nurture the sense of mastery across all aspects of their lives. Physiological factors, particularly the ingestion of dietary macronutrients and micronutrients, are essential components for nurturance of cognitive abilities during adolescence period.

Food is considered as any nourishing substance that can be consumed in its raw, processed, or prepared forms, which organisms ingest orally to sustain life, fulfill daily energy requirements and regulate various biochemical systems essential for nurturance. Researchers consistently emphasize the importance of a balanced diet that ensures the adequate intake of macronutrients and micronutrients necessary for maintaining a healthy life.

(Received 14th April 2026; Accepted 02nd June 2026; Published 08th July 2026)

Diet and nutrition, composition of nutrients and meal pattern are essential factors for transmuting children's cognitive abilities and behaviors (1).

Macronutrients (Carbohydrates, Fats and Proteins) are the components that make up a capital portion of our diet and are needed in substantial quantities by the body. Carbohydrates – one of the key macronutrients, which is mainly broken down into glucose, serving as the pivotal energy source for the brain and its related functions. Experimental study involving healthy undergraduate students at Manchester University revealed that intake of glucose is positively linked with the memory functioning on free and cued recall tasks (2). Research has also indicated that the intake of carbohydrate-rich foods with a low glycemic index during breakfast is accountable for improved cognitive performance in school-aged children (3). Diet with lower carbohydrates level is responsible for substandard performance on memory-related tasks (4). Hence, insufficient carbohydrate intake in an individual's diet can impair cognitive processes and functions.

Protein - a macronutrient made up of amino acids, essential for the structure of tissues, hormonal and enzyme systems and for the repair of injuries. Protein energy malnutrition during the crucial stage of adolescence leads to stunted growth and hindered cognitive development. Research indicated that protein-energy deficiency contributes to delays in intellectual and motor skills during childhood and adolescence (5). India study found that ongoing protein-energy undernourishment (stunting) in childhood negatively impacts the development of higher cognitive functions and may result in lasting cognitive deficits (6). Additionally, research on female Wistar rats revealed that malnutrition adversely affects the expression of neuronal nitric oxide synthase (nNOS) in the hippocampus, impairing learning and memory (7). Furthermore, a lack of protein during the prenatal period leads to a reduced density of hippocampal neurons in adult albino rats (8). These findings highlight that protein and energy undernourishment during infancy and childhood is linked to hindered growth and development.Fats and Oils - Fats and oils are comprised of fatty acids, serve as a concentrated energy source that aids the body in the absorption and transportation of vitamins and minerals. Fat-rich diet and obesity during adolescence period can lead to serious physiological and psychological health issues, including cardiovascular problems, diabetes and cognitive deficits. Study on rats indicated that intake of high-fat diet negatively affects hippocampal neurogenesis (9). The excessive consumption of a Western diet, characterized by high levels of saturated fats, refined carbohydrates and sugars, is responsible for decline in global cognitive functions, cognitive deterioration and dementia (10). Research has founded that diet-induced obesity in Long–Evans rats contribute to deficits in spatial learning and memory processes (11). The gathered evidences form distinct research studies have precisely demonstrated that macro nutrients play indispensable role for nurturance of cognition among adolescents.

Micronutrients are pivotal dietary components which are required by our body in small amounts in order to ensure disease protection and to support proper growth and development. Micronutrients include distinct vitamins and minerals, which are crucial for regulating the biochemical and metabolic functions of brain. Iron – a pivotal micronutrient, deficiency of which represents significant and widespread concern in both developing and developed nations. Research investigation has indicated that iron-deficiency anemia during infancy and childhood phase adversely affects psychomotor development (12). Research has pointed out that iron deficiency is the most prevalent nutrient deficiency which is accountable for impaired learning, memory and processing speed during developmental stages (13). Cognitive processes such as attention span, intelligence and sensory perception can deteriorate due to deficiency of iron (14). These finding collectively expressed that deficiency of iron rich food or lower serum iron level exert detrimental impact on cognitive functioning of adolescents. However, review study proposed that there is no connection between iron status and anemia in adolescents with attention, concentration, intelligence and memory (15). This study has recommended that more randomized trial studies need to be conducted for analyzing the true association between iron status and cognitive functioning.

Calcium as a micronutrient play indispensable role in the nerve excitability, as an intracellular messenger and in the regulation of neurotransmission. Ensuring appropriate intake of calcium during childhood and adolescence period is essential for the proper mineralization of growing bones, achieving peak bone mass and minimizing the risk of fractures in later life. Research study has highlighted the significance of minerals such as calcium, magnesium and zinc for achieving optimal cognitive performance (16). Research conducted among school age children has represented that higher level of serum calcium is accountable for an increase in IQ scores and vice versa (17). Calcium is also identified as the key predictor for nurturing the cognitive abilities among school aged children (18). Research indicated that lower serum phosphorus levels are associated with cerebral β-amyloid (Aβ) deposition, which is a critical factor in the development of Alzheimer's disease (AD) (19). The existing literature review has demonstrated that deficiency of dietary micronutrients iron, calcium, Phosphorus exerts a significant negative impact on adolescents' cognitive performance. However, there are gaps concerning the specific dimensions or aspects of cognitive abilities that are influenced by the intake of dietary macronutrients and micronutrients among adolescents.

The present study is articulated on Maslow's Theory of needs. He has posited a theory which is based on five-stage hierarchical model of human needs, according to which individual's basic needs which are critical for life are situated at the bottom level whereas higher order needs are situated at the top level (20). This 5-stage hierarchical concept has been modified to include cognitive and aesthetic needs and later transcendence needs (21, 22). According to this extended version of Maslow's need hierarchy model the first four needs (physiological, safety, love & belongingness and esteem needs) are considered as the deficiency needs and the rest four higher level needs (cognitive, aesthetic, self-actualization and transcendence needs) are considered as growth needs. For successful attainment of higher order functions individual's basic needs have to be fulfilled first.

The primary objective of this study is to investigate the role of various Macronutrients (Energy, Proteins, Fats and Carbohydrates) and Micronutrients (Iron, Calcium and Phosphorus) in different aspects of Cognitive abilities (Awareness, Memory, Understanding, Reasoning, Problem solving, and Overall Cognitive Ability) among adolescents.

Hypothesis

H1: There exist significant gender differences on Macronutrients, Micronutrients, and Cognitive Abilities among adolescents.

H2: There exists a significant positive correlation between Macronutrients, Micronutrients, and Cognitive Abilities among adolescents.

H3: Macronutrients and Micronutrients will be significant predictors of distinct dimensions of Cognitive Abilities among adolescents.

Methodology

The school students of 11th and 12th standard acted as subjects in the present study. They were drawn from Senior Secondary Government schools of New Delhi (approximate GPS coordinates 28.60595°N, 77.199351°E) using convenience sampling. This sampling method was used to access a specific demographic (ages 15–17) from government schools in-order to control the role of distinct parameter such as socio-economic status, school environment, instruction methods, teaching methodology etc. so that data could be collected under standardized conditions.

Out of 320 initial respondents, 305 have provided complete data and were included in the sample for further final analysis. The final sample consisted of 305 adolescents (Male: N=163 and Female: N=142). The sample population included adolescents aged between 15 to 17 years. Ethical integrity was maintained by obtaining prior approval from the Institutional Ethics Committee and head of various schools, while informed consent was secured from all participants before the administration of the research tests. The instruments used in this research study are as follows:

Food Frequency Questionnaire

The questionnaire was created to evaluate the dietary habits of individuals living in the northern region of India (23). It features a comprehensive scoring system to assess the nutritional values concerning Macronutrients (Energy, Proteins, Fats and Carbohydrates) and Micronutrients (Iron,

Calcium and Phosphorus) based on a 24-hour dietary recall.

Cognitive Ability Test

This is a self-administered, self-reporting, paper-and-pencil test designed to evaluate various aspects of cognitive abilities in adolescents (24). The Cognitive Ability Test comprises 40 items that evaluate five distinct cognitive dimensions: Awareness, Memory, Understanding, Reasoning Ability and Problem-solving Ability. The scale offers both dimension-specific and overall cognitive ability scores. The overall test-retest reliability for the complete test is .701 and the Cognitive Ability Test (CAT) demonstrates significant face and construct validity.

Following the collection of data across all measured variables, the acquired scores were coded for systematic analysis. Pearson's product-moment correlation and stepwise regression analysis were used to interpret the significance of the findings.

Results

The key rationale of the current research was to examine the distinct dimensions of Cognitive Abilities among adolescents in relation to Dietary Macronutrients and Micronutrients.

The objectives were derived by considering the pivotal role of nurtured Cognitive Abilities for appropriate development of an individual. Out of 305 respondents, 163 respondents (53.4%) are male and 142 respondents (46.6%) are female. The descriptive indices corresponding to each Dimension are given in Table 1 and Table 2. Perusal of these tables clearly indicated that obtained Skewness values for all the variables lies in the range -.017 to .49 and the value of Kurtosis lies in the range .227 to -1.221 for adolescent males. For adolescent females, values of Skewness for all the variables lies in the range -.037 to -.632 and the value of Kurtosis lies in the range -.141 to -1.032, which fall within the acceptable range, hence normalization of data is not required. Researchers elaborated that if the obtained values of Skewness and Kurtosis are between -2 to +2, then the gathered data may consider as having a normal distribution (25-30). Further, it has also been expressed by researchers that multivariate analyses are robust enough to tolerate mild deviations (31-33).

Table 1: Means, Std. Deviation, Skewness and Kurtosis of Adolescent Males on all the Computed Factors

Variables	Mean	Std. Deviation	Skewness	Kurtosis
Energy	3110.8799	768.25875	-.017	-.638
Protein	122.6905	38.17573	.057	-.546
Fats	47.3253	20.11570	.494	.227
Carbohydrate	550.0197	151.13561	.087	-.616
Calcium	1370.2356	622.73831	.399	-.612
Phosphorus	2540.4720	742.75967	.114	-.316
Iron	42.7877	13.18097	.220	-.517
Awareness	6.270	1.9909	-.356	-.686
Memory	4.945	1.7114	-.355	-.560
Understanding	3.939	1.5344	-.446	-.631
Reasoning	4.147	1.8400	-.081	-.756
Problem Solving	3.405	1.8480	-.088	-.680
TOTAL CAT	22.699	6.9833	-.240	-1.221

Note: Total CAT = Overall Cognitive Ability Test Score

Table 2: Means, Std. Deviation, Skewness and Kurtosis of Adolescent Females on all the Computed Factors

Variables	Mean	Std. Deviation	Skewness	Kurtosis
Energy	3163.6063	774.29438	.225	-.303
Protein	124.1018	35.89710	.258	-.141
Fats	49.9365	22.85849	.494	-.499
Carbohydrate	549.0887	133.73132	-.037	-.198
Calcium	1434.0670	563.29081	.269	-.231
Phosphorus	2513.0936	661.40258	.227	-.260
Iron	41.7698	12.02335	.118	-.579
Awareness	6.606	1.9091	-.251	-.923
Memory	5.218	1.6679	-.632	-.431
Understanding	3.894	1.5145	-.576	-.255

Reasoning	4.493	1.8325	-.399	-.662
Problem Solving	3.352	1.7267	.128	-.732
TOTAL CAT	23.549	6.8277	-.298	-1.032

Note: Total CAT = Overall Cognitive Ability Test Score

Table 3: Means and Standard Deviations of Male and Female Adolescents on all the Computed Factors along with their Statistical Significance of Difference Between Means

	Males		Females			
Variables	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**	**t-Value**	**Level of Significance**
Energy	3110.88	768.25875	3163.61	774.294	.596	.552
Protein	122.691	38.17573	124.102	35.8971	.331	.741
Fats	47.3253	20.1157	49.9365	22.8585	1.061	.289
Carbohydrate	550.02	151.13561	549.089	133.731	-.057	.955
Calcium	1370.24	622.73831	1434.07	563.291	.933	.351
Phosphorus	2540.47	742.75967	2513.09	661.403	-.338	.736
Iron	42.7877	13.18097	41.7698	12.0234	-.701	.484
Awareness	6.27	1.9909	6.606	1.9091	1.497	.135
Memory	4.945	1.7114	5.218	1.6679	1.409	.160
Understanding	3.939	1.5344	3.894	1.5145	-.253	.800
Reasoning	4.147	1.84	4.493	1.8325	1.640	.102
Problem Solving	3.405	1.848	3.352	1.7267	-.257	.798
TOTAL CAT	22.699	6.9833	23.549	6.8277	1.071	.285

Note: Total CAT = Overall Cognitive Ability Test Score

The complete sample is divided into two groups based on the gender i.e., males and females. The total count of male adolescent students is 163 and that of female adolescent students is 142. In order to analyze the gender differences across all the variables under study, univariate statistical t-test was implemented.

Perusal of Table 3 clearly indicated that there is no significant gender difference on mean scores of Nutrition i.e., Macronutrients (Energy, Proteins, Fats and Carbohydrates), Micronutrients (Calcium, Phosphorus, Iron) and different dimensions of Cognitive Abilities (Awareness, Memory, Understanding, Reasoning Ability, Problem Solving Ability and Overall Cognitive Ability Score). It means that consumption of Macronutrients, Micronutrients and Cognitive abilities is same across the gender. Hence, first Hypothesis is rejected.

Table 4: Correlations Between Macronutrients, Micronutrients and Cognitive Abilities among Male Adolescents

Variables	**Awareness**	**Memory**	**Understanding**	**Reasoning**	**Problem Solving**	**TOTAL CAT**
Energy	.780**	.780**	.631**	.679**	.693**	.917**
Protein	.726**	.702**	.511**	.597**	.625**	.817**
Fats	.472**	.474**	.323**	.455**	.483**	.572**
Carbohydrate	.751**	.736**	.633**	.629**	.630**	.867**
Calcium	.622**	.609**	.495**	.592**	.570**	.744**
Phosphorus	.741**	.703**	.585**	.649**	.623**	.850**
Iron	.701**	.702**	.556**	.655**	.599**	.827**

Note: **Correlation is significant at the .01 level (2-tailed); Total CAT = Overall Cognitive Ability Test Score

Correlations

Correlation is expounded as a statistical procedure which is used to analyze the strength of linear association among distinct parameters. The obtained values of correlations reported in the Table 4, clearly represents that there are significant positive correlations between Macro and Micronutrients and all the dimensions of Cognitive Abilities (Awareness, Memory, Understanding, Reasoning, Problem Solving and Overall Cognitive Ability) among males. The gathered value of correlations lies in the range from .323 to .917 which are highly significant. Therefore, it can be concluded that adequate consumption of Macronutrients (Energy, Proteins, Fats and Carbohydrates) and Micronutrients

(Calcium, Phosphorus and Iron) lead to nurturance of different dimensions of Cognitive Abilities such as Awareness, Memory, Understanding, Reasoning Ability, Problem Solving Ability and Overall Cognitive Ability among male adolescents.

The obtained values of correlations reported in the Table 5, clearly represents that there are significant positive correlations between Macro and Micronutrients and all the dimensions of Cognitive Abilities (Awareness, Memory, Understanding, Reasoning, Problem Solving and Overall Cognitive Ability) among females. The value of correlations ranges from .474 to .882 which are highly significant. Therefore, it can be concluded that adequate consumption of Macronutrients (Energy, Proteins, Fats and Carbohydrates) and Micronutrients (Calcium, Phosphorus and Iron) lead to enhancement of different dimensions of Cognitive Abilities such as Awareness, Memory, Understanding, Reasoning Ability, Problem Solving Ability and Overall Cognitive Ability among female adolescents. Thus, the obtained values of correlation have expressed that second Hypothesis is accepted.

Table 5: Correlations Between Macronutrients, Micronutrients and Cognitive Abilities among Female Adolescents

Variables	Awareness	Memory	Understanding	Reasoning	Problem Solving	TOTAL CAT
Energy	.712**	.695**	.663**	.729**	.677**	.882**
Protein	.624**	.587**	.526**	.659**	.593**	.759**
Fats	.483**	.474**	.558**	.491**	.566**	.649**
Carbohydrate	.667**	.662**	.592**	.694**	.587**	.814**
Calcium	.597**	.520**	.497**	.588**	.591**	.708**
Phosphorus	.685**	.651**	.571**	.688**	.657**	.827**
Iron	.670**	.628**	.587**	.693**	.631**	.817**

Note: **Correlation is significant at the .01 level (2-tailed); Note: Total CAT = Overall Cognitive Ability Test Score

Table 6: Stepwise Regression Analysis Indicating Predictors of Awareness in Adolescent Males and Females

Predictor Variables	R Square	Adjusted R Square	R Square change	F Value	B	Beta	t-Value	Significance level
			Adolescent Males					
Energy	.608	.606	-	250.044*	.002	.780	15.813	.001
			Adolescent Females					
Energy	.508	.504	-	144.320*	.002	.712	12.013	.001

Note: *Significant at .01

Step-wise Regression Analysis

Regression modeling is a statistical procedure used to estimate the association between Predictor variables and Criterion variables. Stepwise Regression iteratively analyzes the statistical significance of each predictor variable in a linear regression model.

Predictors of Awareness among Adolescents

Perusal of Table 6 expressed that independent variable Energy (β=.780, p<.001) with R^2 = .608 act as significant predictor of Awareness (F (1,161) = 250.886, p<.01) among male adolescents.

Results indicated that Energy is the key predictor for Awareness among male adolescents as it contributes 60.8% variance in the Awareness, using Equation [1].

$$\text{Awareness} = -.018+\text{Energy}\times.002 \quad [1]$$

Analyzing the results of Table 6 indicated that independent variable Energy (β=.712, p<.001) with R^2 = .508 act as significant predictor of Awareness (F (1,140) = 144.320, p<.01) among female adolescents.

Results indicated that Energy is the pivotal predictor for Awareness among female adolescents as it contributes 50.8% variance in the Awareness, using Equation [2].

$$\text{Awareness} = 1.048+\text{Energy}\times.002 \quad [2]$$

Table 7: Stepwise Regression Analysis Indicating Predictors of Memory in Adolescent Males and Females

Predictor Variables	R Square	Adjusted R Square	R Square change	F Value	B	Beta	t-Value	Significance level
				Adolescent Males				
Energy	.608	.605	-	249.436*	.002	.780	15.794	.001
				Adolescent Females				
Energy	.483	.479	-	130.840*	.001	.695	11.439	.001

Note: *Significant at .01.

Predictors of Memory among Adolescents

Perusal of Table 7 expressed that independent variable Energy (β=.780, p<.001) with R^2 = .608 act as significant predictor of Memory (F (1,161) = 249.436, p<.01) among male adolescents. Results indicated that Energy is the key predictor for Memory among male adolescents as it contributes 60.8% variance in the Memory, using Equation [3].

$$\text{Memory} = -.458+\text{Energy}\times.002 \quad [3]$$

Perusal of Table 7 expressed that independent variable Energy (β=.695, p<.001) with R^2 = .483 act as significant predictor of Memory (F (1,140) = 130.840, p<.01) among female adolescents. Results indicated that Energy is the key predictor for Memory among female adolescents as it contributes 48.3% variance in the Memory, using Equation [4].

$$\text{Memory} = .482+\text{Energy}\times.001 \quad [4]$$

Predictors of Understanding among Adolescents

Perusal of Table 8 expressed that independent variable Carbohydrate (β=.633, p<.001) with R^2 = .401 act as significant predictor of Understanding (F(1,161) = 107.672, p<.01) among male adolescents. Results indicated that Carbohydrate is the key predictor for Understanding among male adolescents as it contributes 40.1% variance in the Understanding using Equation [5].

$$\text{Understanding} = .404+\text{Carbohydrate}\times.006 \quad [5]$$

Table 8: Stepwise Regression Analysis Indicating Predictors of Understanding in Adolescent Males and Females

Predictor Variables	R Square	Adjusted R Square	R Square change	F Value	B	Beta	t-Value	Significance level
				Adolescent Males				
Carbohydrate	.401	.397	-	107.672*	.006	.633	10.376	.001
				Adolescent Females				
Energy	.439	.435	-	109.602*	.001	.663	10.469	.001

Note: *Significant at .01

Perusal of Table 8 expressed that independent variable Energy (β=.663, p<.001) with R^2 = .439 act as significant predictor of Understanding (F (1,140) = 109.602, p<.01) among female adolescents. Results indicated that Energy is the key predictor for Understanding among female adolescents as it contributes 43.9% variance in the Understanding using Equation [6].

$$\text{Understanding} = -.206+\text{Energy}\times.001 \quad [6]$$

Predictors of Reasoning among Adolescents

Perusal of Table 9 expressed that independent variable Energy (β=.446, p<.001) with R^2 = .460 and Iron (β=.269, p<.019) with R^2 = .479 act as significant predictors of Reasoning (F(2,160) = 73.440, p<.01) among male adolescents. Results indicated that both the predictors are accountable for 47.9% variance in Reasoning of male adolescents, using Equation [7].

Reasoning = -.780+Energy×.001+Iron×.038 [7]

Perusal of Table 9 expressed that independent variables Energy (β=.513, p<.001) with R^2 = .531 and Iron (β=.249, p<.031) with R^2 = .547 act as significant predictor of Reasoning (F (2,139) = 63.597, p<.01) among female adolescents. Results indicated that both the predictors are accountable for 54.7% variance in Reasoning of female adolescents, using Equation [8].

Reasoning = -.934+Energy×.001+Iron×.038 [8]

Table 9: Stepwise Regression Analysis Indicating Predictors of Reasoning in Adolescent Males and Females

Predictor Variables	R Square	Adjusted R Square	R Square change	F Value	B	Beta	t-Value	Significance level
				Adolescent Males				
Energy	.460	.457		137.394*	.001	.446	3.910	.001
Iron	.479	.472	.018	73.440*	.038	.269	2.362	.019
				Adolescent Females				
Energy	.531	.528		158.552*	.001	.513	4.493	.001
Iron	.547	.540	.015	83.754*	.038	.249	2.175	.031

Note: *Significant at .01

Predictors of Problem Solving among Adolescents

Perusal of Table 10 expressed that independent variable Energy (β=.693, p<.001) with R^2 = .481 act as significant predictors of Problem Solving (F (1,161) = 149.135, p<.01) among male adolescents. Results indicated that Energy is the key predictor which brings 48.1% variance in Problem Solving of male adolescents, using Equation [9].

Problem Solving = -1.784+Energy×.002 [9]

Perusal of Table 10 expressed that independent variables Energy (β=.527, p<.001) with R^2 = .458 and Calcium (β=.206, p<.024) with R^2 = .478 act as significant predictor of Problem Solving (F(2,139) = 83.754, p<.01) among female adolescents. Results indicated that both the predictors are accountable for 47.8% variance in Problem Solving of female adolescents, using Equation [10].

Problem Solving = -1.266+Energy×.001+Calcium×.001 [10]

Predictors of Overall Cognitive Ability among Adolescents

It is evident from the values reported in Table 11, which expressed that independent variables Energy (β=.835, p<.001) with R^2 = .840 and Calcium (β=.108, p<.027) with R^2 = .845 act as significant predictors of Overall Cognitive Ability (F(2,160) = 436.351, p<.01) and both the predictors are accountable for 84.5% variance in Overall Cognitive Ability of male adolescents, using Equation [11].

Overall Cognitive Ability = -2.555+Energy×.008+Calcium×.001 [11]

Table 10: Stepwise Regression Analysis Indicating Predictors of Problem Solving in Adolescent Males and Females

Predictor Variables	R Square	Adjusted R Square	R Square change	F Value	B	Beta	t-Value	Significance level
				Adolescent Males				
Energy	.481	.478	-	149.135*	.002	.693	12.212	.001
				Adolescent Females				
Energy	.458	.454		118.376*	.001	.527	5.860	.001
Calcium	.478	.470	.020	63.597*	.001	.206	2.288	.024

Note: *Significant at .01

Table 11: Stepwise Regression Analysis Indicating Predictors of Overall Cognitive Ability in Adolescent Males and Females

Predictor Variables	R Square	Adjusted R Square	R Square change	F Value	B	Beta	t-Value	Significance level
				Adolescent Males				
Energy	.840	.839		846.651*	.008	.835	17.360	.001
Calcium	.845	.843	.005	436.351*	.001	.108	2.237	.027
				Adolescent Females				
Energy	.778	.777		491.387*	.005	.601	6.943	.001
Iron	.789	.786	.011	260.637*	.120	.210	2.749	.007
Calcium	.798	.794	.008	181.635*	.002	.135	2.401	.018

Note: *Significant at .01

It is evident from the values reported in Table 11 expressed that independent variables Energy (β=.601, p<.001) with R^2 = .778, Iron (β=.210, p<.007) with R^2 = .789 and Calcium (β=.135, p<.018) with R^2 = .798 act as significant predictors of Overall Cognitive Ability (F(3,138) = 181.635, p<.01) among female adolescents. Results indicated that all the predictors are accountable for 79.8% variance in Overall Cognitive Ability of female adolescents, using Equation [12]. Thus, the obtained regression analysis for distinct dimensions of cognitive functioning has expressed that third Hypothesis is partially accepted.

$$\text{Overall Cognitive Ability} = -.562+\text{Energy}\times.005+\text{Iron}\times.120+\text{Calcium}\times.002 \quad [12]$$

Discussion

The key goal of this study is to evaluate the association of Macronutrients and Micronutrients with distinct Cognitive abilities of adolescents. The obtained t-ratio comprehensively expressed that there exists no gender difference among Nutrition and Cognitive abilities of adolescents.

The obtained correlations between varied dimensions of Cognitive Abilities i.e., Awareness, Memory, Understanding, Reasoning Ability, Problem Solving Ability and Overall Cognitive Ability and Macronutrients (Energy, Protein, Fat and Carbohydrate), Micronutrients (Calcium, Phosphorus and Iron) among male and female adolescent students clearly represented that Nutrition play significant positive role for the nurturance of Cognitive domains of adolescents. Study elaborated that intake of Macronutrients such as Carbohydrates, Proteins and Energy is linked with cognitive functioning and inadequate nutrition is accountable for compromised brain health (34). Nutrient-rich diets act as the biological foundation for optimal brain development, reasoning and problem-solving skills (35). Macronutrient adequacy, especially sufficient protein intake, nurtures the optimal neurodevelopmental trajectories, whereas deficiencies can impair attention, memory and reasoning skills (36-38).

The obtained results are supported by the research findings that non- anemic adolescents have advanced cognitive performance as compared to the adolescents with Iron deficiency anemia (39). Researchers have also elaborated that adequate calcium intake, through diet or supplementation supports neurodevelopment and cognitive maintenance, whereas calcium deregulation impairs executive functioning and reasoning abilities (40, 41). This shows that diet rich in energy providing macronutrients and minerals is crucial for flourishing the cognitive functionality during teenage years. Hence, we can conclude that proper nutrition, specifically the right mix of macros and minerals, is the driving force behind flourishing cognitive health among adolescents.

The reported findings by using Stepwise Regression Analysis distinctly indicated that Macronutrients (Energy and Carbohydrate) and Micronutrients (Iron and Calcium) serve as significant predictors of various cognitive domains in adolescents. The results are in line with the research findings which expressed that inadequate supply of Energy in meals results in deprived cognitive abilities among adolescents (42, 43). Intake of Carbohydrate rich food is linked with superior cognitive functioning (44). This effectively elaborated that ingestion of

energy rich diet play critical role for cognitive functioning of adolescents.

Researchers have summarized that iron deficiency is accountable for impoverished growth of cognitive abilities during developmental period whereas higher body iron stores were positively associated with superior performance on executive tasks (45). Study conducted among adolescent girls revealed that poor serum calcium concentration is linked with higher psychological scores, which represent psychological deficit (46). Adequate calcium levels obtained through diet or supplementation - supports neurodevelopment and mental processes, whereas any disruption in calcium regulation can hinder neurological functioning and mental health (47, 48).

Conclusion

This study calls attention to the significant factors of dietary nutrition which influences the distinct domains of cognitive abilities among adolescents. The research outcomes highlighted that consistent high-quality nutrition from fetal development to adolescence phase of life is crucial for systematic growth and nurturance. Conversely, nutrition deficits during these formative years showed adverse impact on work capacity, physical maturation and cognitive growth. Hence, it can be concluded that integration of targeted macro-nutrients and micronutrients into daily dietary regime is a fundamental prerequisite for adolescents to achieve higher-order cognitive functioning. Furthermore, this research fulfills an important gap in the existing literature by evaluating the nutritional profiles - focusing on dietary intake of macronutrients and micronutrients of adolescents in northern region of India and their subsequent impact on cognitive functioning. Family, society and government authorities should have to make collaborative efforts to develop appropriate policies which ensure that each adolescent will receive adequate number of macronutrients and micronutrients in accordance with the recom-mended dietary allowance (RDA). Further studies can be performed on urban/sub-urban/rural adolescents in order to identify the different patterns of development among adolescents.

While the gathered findings of this research provide valuable insights about the role of nutrition in adolescent cognitive development, several methodological limitations must be acknowledged. The study utilized convenience sampling method, which may limit the generalizability of the results to the broader adolescent population. Furthermore, socio-economic status (SES) was not formally considered into the analysis due to which contextual influence might overlook. However, adolescents from government schools were considered in order to control the impact of Socio-economic status. Finally, the application of parametric statistics over the data collected using non-probability convenience sampling method may be viewed as a limitation, however skewness and kurtosis have been considered before using multivariate analysis.

Abbreviations

Total CAT: Overall Cognitive Ability Test Score.

Acknowledgement

The authors gratefully acknowledge the invaluable support provided by Principals of Government schools for successfully conducting the study.

Author Contributions

Yashpal Singh: Conceptualization, Execution of the Study, Material Preparation, Data Collection, Data Analysis, Davinder Singh Johal: Conceptualization, Execution of the Study, Supervision, Insights for Analyzing the Obtained Results.

Conflict of Interest

The authors of the present study have declared that no potential conflict of interest with regard to the research.

Data Availability

The datasets used in the study are available from the corresponding author upon reasonable request. Data is not publicly available for maintaining the confidentiality of the respondents.

Declaration of Artificial Intelligence (AI) Assistance

The research design, data collection methods, statistical analysis, interpretation and conclusions are entirely the authors' original work. The authors take full responsibility for the content and integrity of the manuscript.

Ethics Approval

This study was approved by Institutional Ethics committee of Guru Nanak Dev University, Amritsar (Reg. No. 62/HG; dated 25.01.2022).

Funding

The authors received no financial support for the research.

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How to Cite: Singh Y, Johal DS. Brain Food: Evaluating the Role of Dietary Macronutrients and Micronutrients in Adolescent Cognitive Abilities. Int Res J Multidiscip Scope. 2026;7(3):442-454.
DOI: 10.47857/irjms.2026.v07i03.011670