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Physiological Factors Influencing Intelligence: The Role of Vitamin D$_3$ and Magnesium in School Students

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ABSTRACT

Intelligence is increasingly recognized as a biologically influenced trait with a central role in shaping students' cognitive and academic development. This study aimed to investigate the association between vitamin D3 and magnesium levels and intelligence among school-aged students. A total of 90 male students from three types of schools (public, distinguished, and high-achieving) participated. The Standard Progressive Matrices (SPM) test was used to assess mental age and IQ before any intervention, and both SPM and Advanced Progressive Matrices (APM) were administered before and after a 15-day nutritional intervention involving walnuts and dark chocolate. Vitamin D$_3$ and magnesium levels were also measured to assess physiological influences. Before the intervention, significant differences were observed between the three groups in both mental age and IQ. Post-intervention results showed a notable improvement in the public-school group, particularly in APM scores. The distinguished group showed improvement mainly in the SPM test, while the high-achievers group showed no significant changes. Vitamin D$_3$ levels differed significantly among the groups, with higher levels in public students than in distinguished and high-achieving school students. In contrast, magnesium levels showed a different pattern, with public students having significantly higher mean levels, followed by high-achieving students, while distinguished school students had the lowest. The findings indicate that biological factors may contribute to differences in cognitive performance among student groups. Moreover, the nutritional intervention appeared to positively affect intelligence in students with initially lower cognitive scores, especially in public schools.

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1. INTRODUCTION

Cognitive abilities are a set of higher-order processes that enable humans to receive, analyze, and utilize information in various activities, such as attention, logical reasoning, learning, memory, and problem-solving [1]. Intelligence is one of the most important cognitive components from which other mental abilities branch out. It is a key factor in academic achievement and in adapting to the demands of daily life [2]. The literature has shown that intelligence is influenced not only by genetic and environmental factors, but also by physiological factors that support brain health and function [3]. In this context, certain nutrients, such as vitamin D3 and magnesium, have emerged as essential for maintaining mental performance. Vitamin D$_3$ is more than just a regulator of calcium metabolism and bone health; it has widespread receptors in the brain, particularly in areas associated with learning and memory, such as the temporal horn and hippocampus [4].

Studies have shown that this vitamin participates in regulating neurotransmitter synthesis and neuroplasticity, thereby directly influencing executive functions and mental abilities [5]. Vitamin D$_3$ deficiency is associated with decreased cognitive performance and an increased risk of mood disorders such as depression and anxiety, reflecting the vitamin's dual role in supporting mental and psychological health [6]. Magnesium is an essential mineral involved in more than 300 enzymatic reactions within the body and is considered a key regulator of neuronal activity [7]. Its importance lies in its role in stabilizing neuronal cell membranes and regulating the activity of N-methyl-D-aspartate (NMDA) receptors, which are critical for synaptic plasticity processes underlying memory and learning [8]. Low magnesium levels are associated with cognitive impairments, difficulty concentrating, and heightened stress-related responses, underscoring the critical role of magnesium in maintaining neurological and cognitive balance [9]. Despite the significant research interest in explaining intelligence and cognitive function physiologically, studies on the effects of vitamin D_3 and magnesium remain limited, particularly in various educational settings. Recent literature suggests that nutritional interventions can enhance mental performance by improving neurochemical balance[10]. Among these interventions, walnuts and dark chocolate stand out as rich sources of nutrients that support brain health, whether through their magnesium, antioxidant, or flavonoid content, making them helpful for enhancing cognitive functions in students.

Accordingly, the current study aims to investigate the dual effects of vitamin D3 and magnesium from physiological and cognitive perspectives. This study aims to analyze their biological levels and link them to intelligence and mental age in government, distinguished, and high-achieving school students, using Raven's tests (SPM and APM) before and after the implementation of a nutritional intervention based on dark chocolate and walnuts.

2. METHODOLOGY

2.1 Study Sample

The study sample consisted of 90 male students aged 17 to 20 years (mean=17.7, SD=9), representing all students from the available classes in three Iraqi schools in Anbar province. All students were in middle school (6th-grade science), equivalent to Grade 12 in most international educational systems. The student sample was distributed as follows: 17 from the distinguished school (admission requiring general intelligence or achievement tests, with no students having previously taken the Raven test), 28 from the high-achiever school (admission requiring achievement tests), and 45 from the public school (admission requiring no tests and representing general public school students). The equivalence of the three school groups was first verified by a demographic questionnaire providing data on several relevant demographic variables, including nutrition (vegetarian, non-vegetarian, or vegan), exercise (exerciser or non-exerciser), socioeconomic status (high, medium, or low), consumption of drinks (tea, coffee, or soft drinks), and smoking (smoker vs. non-smoker). Student responses on categorical variables were analyzed using the χ^2test to identify statistically significant differences between groups. The groups were found to be equivalent in these variables. (As shown in Table 1).

Subsequently, a subsample of 44 students was randomly selected to participate in an experimental nutritional program. This group was chosen through the use of a random number generator using Excel's RAND function to ensure that every student in the sample had an equal chance of being selected. This approach minimizes selection bias and supports the representativeness of the subsample. This subsample included 17 students from the distinguished school, 5 from the high-achiever school, and 22 from the public school.

2.2 Nutritional intervention

A 15-day dietary program was implemented. Each student was provided 100 grams of walnuts and 70 grams of dark chocolate (85% cocoa) for daily consumption during this intervention. Data collection allowed observation of changes in intelligence variables from before to after the nutritional program. The study was a preliminary exploration of the implementation of a nutrition program and was not designed to represent a randomized controlled trial in an experimental design, nor to provide comparisons between students who did and did not receive the intervention, due to inherent differences among the study groups.

2.3 Intelligence tests

Raven's Progressive Matrices, developed by John C. Raven in 1939 [11], assesses general intelligence in individuals aged 5 and above. The test involves identifying the missing element in increasingly difficult visual matrices. This study used two versions: the Standard Progressive Matrices (SPM), with five sets of 12 items each, covering a wide range of abilities, and the Advanced Progressive Matrices (APM), with 36 items, for assessing higher cognitive levels [12].

Ravens Progressive Matrices confirmed that SPM is intended for people of normal intelligence, whereas APM is intended for people of high intelligence. Materials provided to students for this data collection included the test booklet containing matrices, answer sheets, and pens.

These tests were scored by awarding one point for each correctly solved matrix within a set, providing a total number of correct answers across all sets. Raw scores were converted to mental age using standard tables from recent studies [13]-[16] and the traditional and widely accepted Ravens manual [17] as a secondary comparison source. Raw scores were matched to average ages to estimate each student's mental age. After determining mental age, students' intelligence quotients (IQ) were calculated by comparing cognitive development with actual age, using the following traditional equation:

$$\frac{Mentalage}{Chronologicalage} \times 100. \qquad (1)$$

Standard tables from an official manual were consulted to calculate the percentile reflecting each student's rank among same-age peers.

Table (1). Baseline demographic characteristics of the sample

Category	Subcategory	Distinguished	High-achievers	Public	Total	Pearson χ^2	Degrees of freedom (df)	Asymptotic p-value
Food Regime	Vegetarian	<5	<5	<5	5			
	Non-vegetarian	14	22	45	81	3.120	4	0.539
	Vegan	<5	<5	<5	<5			
Exercises	Non-exerciser	7	19	11	37	4.105	2	0.128
	Exerciser	10	9	34	53			
Socioeconomic Status	High	<5	<5	<5	7			
	Medium	13	24	39	76	2.510	4	0.643
	Low	<5	<5	<5	7			
Drinks	Tea	5	<5	<5	11			
	Coffee	<5	5	<5	13			
	Soft drinks	<5	6	<5	12	9.834	12	0.628
	Tea and Soft drinks	<5	<5	8	11			
	Coffee and Soft drinks	<5	<5	5	8			
	Tea and Coffee	<5	<5	12	16			
	All of them	<5	9	10	19			
Smoking	Nonsmoker	16	26	37	79	1.225	2	0.542
	Smoker	<5	<5	8	11			

2.4 Data collection procedures

The Raven Standard Progressive Matrices (SPM) and Advanced Progressive Matrices (APM) tests were first administered at baseline to provide baseline comparisons of students among the three schools. The APM and SPM tests were collected by the principal researchers in a calm, controlled environment with open timing. Participants received clear instructions to examine each matrix and select the correct missing element from the multiple-choice options, with all procedures explained in advance. On March 16, 2025, after completion of the nutritional intervention, a 5 mL blood sample was drawn from each student and transferred into gel tubes. To extract the serum, the blood was allowed to clot for 30 minutes at room temperature, then centrifuged at 3,000 rpm and transferred to white tubes for physiological examination. Vitamin D_3 and magnesium levels were measured using commercial ELISA kits (SunLong Biotech Co., LTD, China) according to the manufacturer's instructions. This kit is based on the principle of specific antigen-antibody interaction. The optical density was read at 450 nm using an ELISA microplate reader.

2.5 Statistical analysis

Statistical analysis was conducted using SPSS version 27. The equivalence of demographic variables between the three groups was verified using the χ^2 test. To analyze pre-test differences between the three schools before implementing the nutritional program (sample size = 90), a one-way analysis of variance (ANOVA) was used.

To measure the effect of the nutritional program on the subsample (n = 44), a paired-samples t-test was used for normally distributed variables, and a Mann–Whitney U test for non-normally distributed variables. A one-way analysis of variance (ANOVA) was also used to analyze changes in vitamin D_3 and magnesium levels after implementation. The results were considered statistically significant at ($p < 0.05$), highly significant at ($p < 0.01$), and very significant at ($p < 0.001$).

3. RESULTS

After analyzing all the data, the results of the one-way ANOVA showed statistically significant differences in mental age among the three schools (public, distinguished, and high-achieving) (F = 9.792, P = 0.0001). Statistically significant differences in IQ were also found between the same groups (F=16.48, P=0.0001). According to the mean ± standard error values, students in the distinguished school had the highest mean in mental age (18.62±0.30), followed by the high-achieving school (16.71±0.39), and then the public school (16.57±0.22). As for IQ, the highest mean was recorded among the distinguished school (107.7±2.150), followed by the high-achievers School (95.84±2.460), then the public school (90.85±1.320) (As shown in Table 2).

Table (2). SPM mental age and IQ testing of students from three schools at baseline (before nutritional intervention) (N=90)

Parameter	Group type	Number	Mean± Std. Error of Mean	F-test	p-value
Mental age	Public schools	45	16.57±0.2226	9.792	0.0001
	Distinguished Schools	17	18.62±0.3107		
	High-Achieving Schools	28	16.71±0.3988		
IQ	Public schools	45	90.85±1.320	16.48	<0.0001
	Distinguished Schools	17	107.7±2.150		
	High-Achieving Schools	28	95.84±2.460		

The results of the SPM test for public school students (n = 22) showed statistically significant differences between the pre and post-tests in both mental age and IQ. The mean mental age increased from 16.64 to 17.45 after the nutritional program, with a mean difference of 0.80 (±1.06), and this increase was statistically significant (t = 3.546, df = 21, p = 0.002). The mean IQ also increased from 91.23 to 95.20, with a mean difference of 3.96 (±6.22), which was also statistically significant (t = 2.989, p = 0.007).
For the APM test in the same group, there was a Significant increase in mental age from 17.02 to 18.68, with a mean difference of 1.66 (±1.03), and the difference was highly significant (t = 7.570, p < 0.001). The IQ increased from 92.88 to 101.93, with a mean difference of 9.05 (±5.69), indicating a statistically significant improvement (t = 7.470, p < 0.001).

For the distinguished school (n=17), the SPM test results showed statistically significant differences between the pre- and post-tests for both mental age and IQ. The mean mental age increased from 18.62 to 19.52, with a mean difference of 0.90 (±1.73), and this increase was statistically significant (t = 2.140, df = 16, p = 0.048). The mean IQ also increased from 107.73 to 112.92, with a mean difference of 5.18 (±10.05), which was also statistically significant (t = 2.128, p = 0.049). The APM test results in the same group showed a slight increase in mental age, from 18.83 to 19.04, with a mean difference of 0.21 (±1.34), whereas the difference was not statistically significant (t = 0.651, p = 0.524). Despite the fact that the IQ increased from 108.94 to 110.15, with a mean difference of 1.20 (±7.91) the difference was not statistically significant (t = 0.628, p = 0.539).

Regarding the high-achieving school participants (n = 5), the SPM test showed no statistically significant difference between the pre- and post-tests. Mean mental age increased from 16.50 to 17.10, with a mean difference of 0.60 (±3.89) (t = 0.344, df = 4, p = 0.748). IQ also increased from 94.78 to 97.14, with a mean difference of 2.36 (±20.60), but the difference did not reach statistical significance (t = 0.256, p = 0.810). For the APM test in this group, mental age increased from 17.20 to 17.50, with a mean difference of 0.30 (±0.45), but this difference was not statistically significant (t = 1.50, p = 0.208). IQ also increased from 98.86 to 100.54, with a mean difference of 1.68 (±2.48), but the difference was not statistically significant (t = 1.516, p = 0.204). (As shown in Table 3).

Table (3). Repeated samples t-test analysis of SPM and APM mental age and IQ results before and after nutritional intervention (N=44).

Test type	N	Group type	Variables	Mean		Mean Difference	Std. Deviation of Difference	Std. Error Mean	t-test	df	Sig. (2-tailed)
				Pre	Post						
SPM	22	Public school	Mental age	16.64	17.45	0.80455	1.06435	0.22692	3.546	21	0.002
			IQ	91.23	95.20	3.96364	6.22151	1.32643	2.988	21	0.007
SPM	17	Distinguished school	Mental age	18.6176	19.5176	0.90000	1.73421	0.42061	2.140	16	0.048
			IQ	107.7294	112.9176	5.18824	10.05061	2.43763	2.128	16	0.049
SPM	5	High-Achiever's School	Mental age	16.5000	17.1000	0.60000	3.89551	1.74213	0.344	4	0.748
			IQ	94.7800	97.1400	2.36000	20.60141	9.21323	0.256	4	0.810
APM	22	Public school	Mental age	17.02	18.68	1.66	1.03	0.22	7.570	21	p < .001
			IQ	92.88	101.93	9.05	5.69	1.21	7.470	21	p < .001
APM	17	Distinguished school	Mental age	18.8353	19.0471	0.21176	1.34065	0.32516	0.651	16	0.524
			IQ	108.9471	110.1529	1.20588	7.91948	1.92075	0.628	16	0.539
APM	5	High-Achiever's School	Mental age	17.20	17.50	0.30	0.45	1.32	1.500	4	0.208
			IQ	98.86	100.54	1.68	2.48	8.77	1.516	4	0.204

Note. SPM= Standard Progressive Matrices; APM= Advanced Progressive Matrices

For the public school (n = 22), the SPM test results showed statistically significant differences between the pre- and post-tests in mental age, with the mean increasing from 18.66 to 26.34, with a value (U = 157.50, Z = -1.992, p = 0.046), indicating statistical significance in favor of the post-test. Regarding IQ, the mean increased from 19.14 to 25.86, but the change was not statistically significant (U = 168.00, Z = -1.741, p = 0.082). In the same group, the APM showed statistically significant differences for both mental age and IQ: mental age increased from 15.70 to 29.30 (U = 92.50, Z = −3.568, p < 0.001), and IQ increased from 16.98 to 28.08 (U = 120.50, Z = −2.878, p = 0.004)

For the distinguished school (n = 17), the SPM showed a significant increase in mental age from 14.00 to 21.00 (U = 85.00, Z = −2.075, p = 0.038), whereas the increase in IQ from 14.82 to 20.18 was not statistically significant (U = 99.00, Z = −1.580, p = 0.122). The APM showed no significant differences in this group: mental age increased from 16.12 to 18.88 (U = 121.00, Z = −0.843, p = 0.400) and IQ from 16.29 to 18.71 (U = 124.00, Z = −0.720, p = 0.472). For the high-achiever school (n = 5), no statistically significant differences were observed for any variables. On the SPM, mental age increased slightly from 5.30 to 5.70 (U = 11.50, Z = −0.213, p = 0.831) and IQ remained 5.50 at both measurements (U = 12.50, Z = 0.000, p = 1.000). On the APM, mental age increased from 17.20 to 17.50 (U = 11.00, Z = −0.328, p = 0.841) and IQ from 98.86 to 100.54 (U = 10.00, Z = −0.532, p = 0.690), neither reaching significance (As shown in Table 4).

Table (4). Mann-Whitney test analysis of differences before and after nutritional program (N=44)

Test type	N	Group type	Variables	Mean		Sum of ranks		Mann-Whitney U	Wilcoxon W	Z-test	Asymp. Sig. (2-tailed)
				Pre	Post	Pre	Post				
SPM	22	Public school	Mental age	18.66	26.34	410.50	579.50	157.500	410.500	-1.992	0.046
			IQ	19.14	25.86	421.00	569.00	168.000	421.000	-1.741	0.082
SPM	17	Distinguished school	Mental age	14.00	21.00	238.00	357.00	85.000	238.000	-2.075	0.038
			IQ	14.82	20.18	252.00	343.00	99.000	252.0		
SPM	5	High-Achievers School	Mental age	5.30	5.70	26.50	28.50	11.500	26.500	-0.213	0.831
			IQ	5.50	5.50	27.50	27.50	12.500	27.500	0.000	1.000
APM	22	Public school	Mental age	15.70	29.30	345.50	644.50	92.500	345.500	-3.568	0.000
			IQ	16.98	28.08	373.50	616.50	120.500	373.500	-2.878	0.004
APM	17	Distinguished school	Mental age	16.12	18.88	274.00	321.00	121.000	274.000	-0.843	0.400
			IQ	16.29	18.71	277.00	318.00	124.000	277.000	-0.720	0.472
APM	5	High-Achievers School	Mental age	17.20	17.50	26.00	29.00	11.000	26.00	-0.328	0.841
			IQ	98.86	100.54	25.00	30.00	10.000	25.00	-0.532	0.690

3.1 Vitamin D_3

A one-way ANOVA was conducted to examine differences in vitamin D_3 levels among students from public, distinguished, and high-achieving schools. The analysis showed a highly significant difference between the groups, with an F-value of 18.32 and a p-value of <0.0001. As shown in Table 5 & Figure 1.

Table (5). Comparison of vitamin D3 Levels (pg/ml) Among public, distinguished, and high-achieving schools.

parameter	Group type	Count	Mean± Std. Error of Mean	F-test	p-value
Vit.D_3	Public school	45	3.814± 0.1711	18.32	<0.0001
	Distinguished School	17	2.496± 0.2483		
	High-Achieving School	28	2.353± 0.2053		

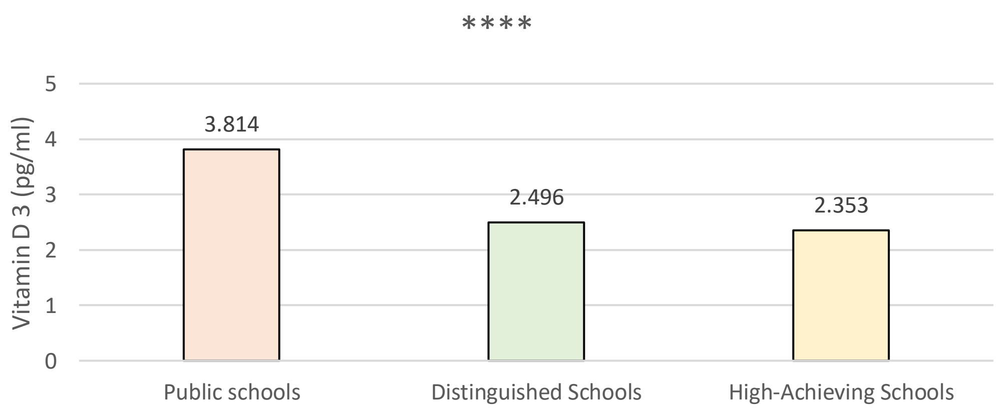

Figure (1). Vitamin D_3 Levels (pg/ml) Across public, distinguished, and high-achieving schools.

3.2 Magnesium

Table 6 presents the mean Mg levels (± standard error) for students from three different school group types: public schools, distinguished schools, and high-achieving schools. The analysis showed a highly significant difference between the groups, with an F-value of 24.85 and a p-value of <0.0001. As shown in Table 6 & Figure 2.

Table (6). Comparison of Mg Levels (mg/dL) Among Public, Distinguished, and High-Achieving Schools

parameter	Group type	Count	Mean± Std. Error of Mean	F-test	p-value
Magnesium	Public school	45	2.342±0.06389	24.85	p<0.0001
	Distinguished school	17	1.718±0.07408		
	High-achievers school	28	1.859±0.05406		

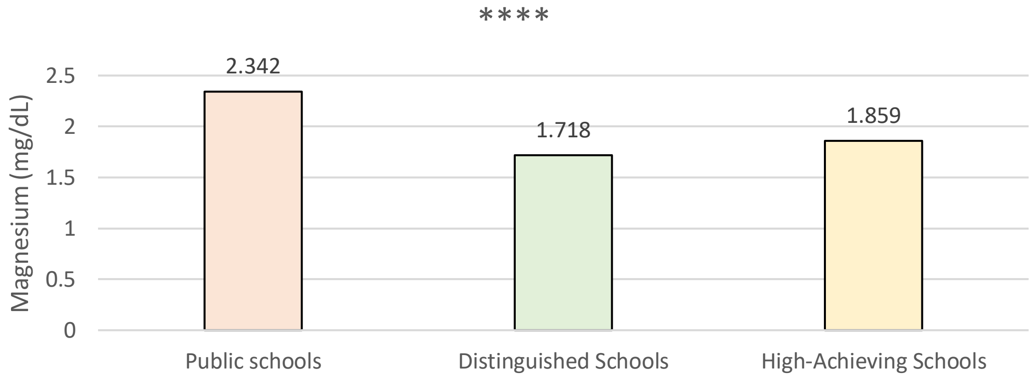

Figure (2): Mg Levels (mg/dL) Across public, distinguished, and high-achieving schools.

4. Discussion

The results of the SPM test, conducted prior to the nutritional program, showed statistically significant differences in both mental age and IQ. Students from the distinguished school showed the highest mean mental age (18.62±0.30), followed by students from the high-achievers school (16.71±0.39), whereas students from the public school showed the lowest mean mental age (16.57±0.22). The distinguished students also recorded the highest mean IQ (107.7±2.150), compared to students from high-achieving schools (95.48±2.460) and the public school (90.85±1.320). These results are consistent with the literature [18], which indicates that an educational environment enriched with intellectual challenges and psychological support contributes to improving students' mental performance. However, these results are not in line with some studies [19], which found no significant differences among schools in students' mental abilities prior to educational interventions. This may be attributed to differences in the sample's characteristics or the nature of the curricula in that study. The findings of the present study indicate that the educational environment in Distinguished Schools is characterized by advanced curricula, interactive teaching, diverse teaching methods, ongoing psychological support, and a range of school activities, which may significantly enhance students' cognitive abilities. The admissions system adopted in these schools, which includes IQ tests for admission, may also explain their higher mean mental age and IQ compared to other groups.

The SPM test for public school students showed statistically significant differences between pre- and post-tests in both mental age and IQ, indicating a markedly positive impact of the nutritional program. The mean mental age in the SPM increased (16.64 ±17.45) by a statistically significant difference of (0.80). The mean IQ also increased (91.23±95.20) by a statistically significant difference of (3.96). In the APM test, conducted at the same school after the nutritional program, the results significant improvement. The students mean mental age increased from 17.02 to18.68 (by a difference of 1.66) and IQ increased from 92.88 to 101.93 (by a statistically significant difference of 9.05). This improvement could be attributed to the role of proper nutrition, particularly walnuts and dark chocolate, in improving cognitive performance and neurological functions related to attention and memory, especially among school students. These findings are consistent with those of others studies [20], who reported that walnuts and dark chocolate can make a noticeable difference in attention and concentration, improving brain health and mental abilities in general.

In contrast, the distinguished School demonstrated significant differences on the SPM test, with students from this school recording limited improvement. The mean mental age on the SPM increased (18.62±19.52) by a difference of (0.90). An increase in the mean IQ (107.73±112.92) was also observed, with a difference of (5.18). Both were statistically significant but less pronounced than in the public school. However, the APM test differences were not statistically significant, despite increases in mean mental age (18.83±19.04) and IQ (108.94±110.15). These results are in line with the literature. A study found that students with high cognitive performance may not show increases in mental age or IQ from nutritional interventions, because their cognitive levels are already high [21]. However, specially designed nutritional programs can be effective even for individuals with high intelligence [22]. This may be explained by the fact that students in this group already had high cognitive levels before the program, limiting improvement, as it is difficult to record significant increases in performance within the upper range of the test. In the high-achievers School, although there was a slight improvement in mental age and IQ, the differences were not statistically significant across all measures. Mental age on the SPM increased (16.50 ± 17.10) ($p = 0.748$), and IQ (94.78 ± 97.14) ($p = 0.810$). These results are consistent with a study that found that small sample sizes reduce statistical power, leading to a high probability that differences will not be detected even if they exist [23]. In all of these studies, small sample sizes reduce test power, but if the sample size is sufficiently large, a statistically significant difference can be observed even with low precision [24]. The main reason is likely the small sample size ($n = 5$), which reduces statistical power and makes it difficult to detect differences even when they exist.

In the non-parametric analysis using the Mann-Whitney U test, the results were consistent with the t-test findings, enhancing confidence in the statistical differences and confirming the impact and clarity of the nutritional program, regardless of the data distribution.

The study results showed statistically significant differences in vitamin D_3 levels among students at the three schools ($F = 18.32$, $p < 0.0001$). Public school students had the highest mean (3.814 ± 0.1711 pg/mL), compared with students at a distinguished school (2.353 ± 0.2053 pg/mL) and a high-achieving school (2.496 ± 0.2483 pg/mL). This difference indicates the influence of environmental and routine factors on vitamin D levels, especially since vitamin D is primarily produced through direct exposure to sunlight. The high levels of vitamin D_3 among public school students are likely due to greater outdoor exposure and less sun protection, or to a lack of awareness about sun protection. This is consistent with studies showing that the environment and daily patterns directly influence cutaneous vitamin D_3 synthesis [25].

Vitamin D_3 is an important factor in regulating neurological and cognitive processes. Adequate levels of vitamin D_3 support neuronal growth, regulate synapses, and influence the gene expression of important neuronal proteins, in addition to its role in regulating mood and attention. A recent review demonstrated that vitamin D_3 deficiency is a risk factor for cognitive decline in children and adolescents, while optimal levels enhance attention, concentration, and mental performance [26].

Despite the physiological differences recorded, the study found no similar differences in average IQ scores between these groups, suggesting that the effect of vitamin D_3 on mental performance may be indirect or conditional on intermediate factors such as lifestyle, general nutrition, and level of cognitive stimulation, which is consistent with modern explanatory models that link physiological balance to psychological and cognitive outcomes in an interactive rather than linear manner.

The study results showed statistically significant differences in magnesium levels among students in public, distinguished, and high-achieving schools, as determined by an ANOVA ($F = 24.85$, $p < 0.0001$). Based on the mean, students in public schools recorded the highest magnesium levels (2.342 ± 0.06389), followed by students in high-achieving schools (1.859 ± 0.05406), and then students in distinguished schools (1.718 ± 0.07408). To understand this pattern, it is necessary to consider the physiological and psychological factors involved in magnesium regulation within the body. Magnesium is an essential element in regulating neuronal balance and inhibiting neuronal hyperexcitability through its interaction with NMDA and GABA receptors. It supports cognitive processes such as attention, working memory, and executive functions [27], [28]. Its deficiency is also associated with increased cortisol secretion and amplified stress responses via the HPA axis [29]. Recent studies indicate that continuous exposure to intense psychological and educational stress, such as in distinguished and high-achieving schools, leads to endogenous magnesium depletion through activation of the sympathetic nervous system and chronic secretion of adrenaline and cortisol, which lower serum magnesium concentrations [30]. In contrast, students in public schools, with their educational style, may be less exposed to such acute stressors, thus maintaining their magnesium levels within the normal or relatively high range. This relationship was supported by a study, which found that stress associated with high academic performance was negatively associated with magnesium levels, even in healthy adolescents [31].

A study found that academic stress during exam periods significantly reduces magnesium levels due to increased neural consumption [29]. Thus, the higher magnesium levels in public school students may be explained by their lower exposure to high academic stress, allowing the nervous system to maintain internal mineral balance. In comparison, students from high-achieving and distinguished schools, despite their high cognitive abilities, may lead demanding, competitive academic lives that can contribute to lower magnesium levels due to excessive physiological demands.

5. Limitations and Future Work

The nutritional program was implemented for only 44 of the 90 students due to differences in administrative cooperation among schools, particularly at the high-achieving school. Participant numbers were unequal across the three schools, with limited actual enrollment in the distinguished and high-achieving institutions. In addition, the lack of parental consent for some students and difficulties some participants faced in adhering to the nutritional program further restricted participation. The intervention's short duration (15 days), constrained by school timelines and academic schedules, limited the ability to evaluate long-term effects. Finally, the age-specific focus narrows the generalizability of the findings to other age groups. Future research should expand the sample to include more students from different regions, with a balanced distribution across educational stages, and extend the duration of the nutritional program to evaluate long-term effects on mental age and intelligence metrics. It would also be valuable to examine the relationships among mental age, IQ, and additional vitamins and minerals (e.g., B12 and Zn), and to implement various nutritional interventions (e.g., omega-3-rich meals or antioxidant-rich diets) to assess their cognitive and physiological effects.

6. CONCLUSION

It can be concluded that students' scores before the nutritional interventions showed statistically significant differences on the SPM test, with the distinguished recording significantly higher scores than those of high achievers and public schools. The nutritional program (100 grams of walnuts and 70 grams of 85% dark chocolate daily for 15 consecutive days) also resulted in a significant improvement in some cognitive indicators among school students, particularly in the public school, compared to the distinguished and high-achieving students. Statistical analyses showed that The improvement in the APM and SPM tests was statistically significant among public school students in the variables of mental age and IQ after the nutritional interventions. However, students in the distinguished and high-achieving schools recorded less pronounced differences, due to their higher baseline cognitive levels before starting the program. On the physiological level, vitamin D_3 levels showed statistically significant differences between the three schools, with the public school recording the highest level, followed by the distinguished schools, and then the high-achieving schools. Magnesium levels were also statistically significant, with the highest levels occurring in public schools, followed by high-achieving schools, and the lowest in distinguished schools. Our results reinforce the need to conduct pre-tests without interventions, as well as pre- and post-intervention tests to monitor the impact of any potential intervention.

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Author Contributions

First Author: Conceptualization, experimental design, data collection, biochemical analysis, writing – original draft.

Second Author: Statistical analysis, data interpretation, review, and editing of the manuscript.

Third Author: Psychological assessments, participant coordination, and interpretation of cognitive testing results.

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Conflicts of Interest

The authors declare no conflict of interest.

Ethical Approval and Consent

The study was approved by the Scientific Research Ethics Committee at Anbar University (Approval No. 18, dated 18/01/2025).

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