From Nutrition to Knowledge: Leveraging Biotechnology to Combat Deficiencies and Enhance the Academic Performance of EFL Students

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Abstract

Nutrition plays a crucial role in supporting brain function, cognitive performance, and learning efficiency. Despite growing interest in educational neuroscience, limited attention has been given to how micronutrient status influences academic outcomes among university students, particularly those enrolled in English as a Foreign Language (EFL) programs. The present study explored the relationship between nutritional status, cognitive function, and academic achievement among EFL students, aligning its objectives with the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 4 (Quality Education). Furthermore, the study examined how the integration of artificial intelligence (AI)-based nutritional monitoring systems could promote healthier learning environments and enhance educational outcomes through evidence-based nutritional interventions. A combination of quantitative and qualitative methods was employed, involving 222 students at the university in Saudi Arabia. A quantitative approach was employed to administer a structured questionnaire that assessed dietary habits, cognitive challenges, and learning performance. A total of 100 participants were selected through stratified random sampling, including 50 students with high CGPAs (≥ 3.0) and 50 with low CGPAs (< 3.0). Laboratory Results analyses were performed to determine serum levels of iron, vitamin B_{12}, and vitamin D. Data were analyzed using descriptive statistics and independent sample *t*-tests ($p < 0.05$). Results revealed that students with higher CGPAs had significantly greater serum levels of iron (110 ± 15 µg/dL), vitamin B_{12} (470 ± 85 pg/mL), and vitamin D (32 ± 6 ng/mL) compared to their low-performing peers (65 ± 12 µg/dL, 210 ± 60 pg/mL, and 15 ± 4 ng/mL, respectively; $p < 0.001$). Micronutrient deficiencies were associated with fatigue, poor concentration, and reduced alertness. Conceptual modeling suggests that AI-based nutritional platforms such as NutriSense and FoodAI could support real-time dietary tracking, deficiency prediction, and personalized nutritional interventions. The findings suggest that optimal levels of iron, vitamin B_{12}, and vitamin D are strongly linked with superior cognitive and academic performance among EFL students. Integrating AI-driven nutrition monitoring systems offers a promising avenue for early detection and prevention of micronutrient deficiencies, thereby supporting enhanced cognitive health and academic success. By bridging nutrition, language education, and technological innovation, this research contributes to achieving the Sustainable Development Goals (SDGs), particularly by advancing health, quality education, and sustainable innovation through evidence-based, technology-supported interventions.

Keywords: EFL, SDG, nutrition, cognition, academic performance, micronutrients, AI-based monitoring, NutriSense, FoodAI

1. Introduction

Nutrition and cognition are deeply interconnected domains that significantly influence academic performance and overall mental function (Puri et al., 2023). Adequate nutrition supports essential neurocognitive processes such as memory, attention, and learning capacities that are fundamental to students' academic success (Carrillo-López, 2023; Johal & Singh, 2022). Conversely, deficiencies in key micronutrients, such as iron, vitamin D (cholecalciferol), and vitamin B12 (cobalamin), can impair neurotransmitter synthesis, reduce synaptic plasticity, and lead to fatigue, poor concentration, and diminished learning capabilities (Abdelwahab et al., 2024; Binquryan et al., 2024). Within academic environments, particularly in higher education, the implications of such deficiencies extend beyond physical health to directly affect cognitive and linguistic development (Aithal & Aithal, 2023). English as a second language students, who often face linguistic and cultural challenges in addition to academic demands, are especially vulnerable to the consequences of nutritional inadequacy.

In Saudi Arabia, university students enrolled in EFL programs frequently encounter multifaceted challenges, including limited access to nutritional information in their native language, dietary habits influenced by socio-economic and cultural factors, and a general lack of awareness about balanced nutrition (Alshahrani, Bafaraj, and Alamri, 2024). These factors may lead to unrecognized nutritional deficiencies that compromise both cognitive performance and language acquisition. Cognitive skills, such as comprehension, vocabulary retention, and problem-solving, are vital for success in EFL learning; yet, they are among the first to deteriorate under nutrient-deficient conditions. The integration of nutritional science with language education, therefore, presents a promising interdisciplinary pathway to improve students' cognitive and academic outcomes.

Advancements in biotechnology and artificial intelligence (AI) have transformed the capacity to diagnose, monitor, and manage nutritional health. Biotechnological tools such as enzyme-linked immunosorbent assays (ELISA), chemiluminescence immunoassays (CLIA), and high-performance liquid chromatography (HPLC) provide precise biochemical profiling to identify micronutrient deficiencies (Balch et al., 2024; Zheng & Tako, 2024). Meanwhile, AI-driven nutritional assessment platforms, such as NutriSense and FoodAI, facilitate real-time dietary monitoring and predictive analytics, offering a scalable solution for evaluating and addressing nutritional gaps (Prasad et al., 2025; Zheng et al., 2024). When applied to education, these innovations create an unprecedented opportunity to link biological data with academic metrics, thereby uncovering how nutritional health influences learning capacity and performance among students. Vitamin D, vitamin B_{12}, and iron were selected for this study due to their established association with neurocognitive processes and learning performance. Vitamin D regulates neuroplasticity and neurotransmission, influencing mood, executive function, and cognitive engagement(Liu et al., 2025). Iron supports oxygen transport, dopaminergic activity, and neuronal metabolism, which are crucial for attention, working memory, and learning (Rhoten et al., 2025). Vitamin B_{12} contributes to myelin synthesis, synaptic transmission, and overall cognitive efficiency(Nawaz et al., 2020). Although nutrients such as omega-3 fatty acids have also been linked to cognitive function, this study focused on these three micronutrients owing to their measurable biochemical relevance and higher prevalence of deficiency among students. By targeting these nutrients, the study aims to investigate their specific contributions to cognitive and academic performance in the context of English as a Foreign Language (EFL) learning.

Despite growing evidence highlighting the intricate relationship between nutrition and cognition, limited research has explored this connection within the context of English language education, particularly among Arab EFL learners, through the lens of the Sustainable Development Goals (SDGs). Research studies by Li & Pei (2024) and Waked et al. (2024) have primarily focused on general student populations, often neglecting the unique linguistic, cultural, and educational factors that influence the cognitive and academic profiles of EFL learners (Li & Pei, 2024; Waked et al., 2024). Addressing this gap requires interdisciplinary investigations that integrate the principles of SDG 3 (Good Health and Well-being) and SDG 4 (Quality Education) to promote holistic student development(Lakioti et al., 2025). Furthermore, incorporating biotechnological methods, AI-driven analytics, and educational assessment tools can provide deeper insights into how micronutrient deficiencies affect cognitive function, memory, attention, and language acquisition. Such an integrated approach not only enhances understanding of the nutrition–cognition–language nexus but also contributes to the global agenda for sustainable development by fostering healthier, more equitable, and technologically empowered learning environments.

Although extensive research has demonstrated the influence of diet quality and micronutrient balance on brain function, this relationship remains underexplored in English language education, particularly among Arab EFL learners. This study aims to examine how micronutrient deficiencies influence cognitive functions (memory, attention, and learning capacity) and academic performance in Arab EFL learners. The study further contributes by employing an AI-powered dietary assessment system to detect nutritional deficiencies and support personalized, data-driven nutritional interventions, offering a novel interdisciplinary framework that integrates nutrition science, biotechnology, and applied linguistics.

This investigation was guided by the following research questions:

1. What is the relationship between micronutrient status (iron, vitamin B_{12}, and vitamin D) and academic performance among EFL students?
2. How do deficiencies in key micronutrients affect cognitive abilities such as concentration, memory, and alertness?
3. What role can AI-based nutritional monitoring platforms (e.g., NutriSense, FoodAI) play in predicting and improving nutritional and cognitive outcomes in educational contexts?

2. Literature Review

2.1 Nutrition, Cognition, and Academic Performance

The relationship between nutrition and cognitive performance has been well established across decades of research; however, findings vary depending on the specific micronutrients examined and the cognitive domains assessed. (Gutierrez et al., 2021). Nutrients play a fundamental role in brain development, neurotransmitter synthesis, and energy metabolism processes that are critical for learning and memory (Fadó et al., 2022). Importantly, studies suggest that different micronutrients exert differentiated cognitive effects. For instance, iron deficiency disrupts oxygen transport to the brain and interferes with dopaminergic activity, leading to attention deficits and cognitive fatigue (Wu et al., 2023). Vitamin D insufficiency has been correlated with depressive symptoms, reduced executive function, and decreased learning motivation (Roy et al., 2020). Vitamin B12 deficiency, in contrast, has been associated with slower information processing and deficits in memory consolidation (Das et al., 2025; Tardy et al., 2020).

Among university students, nutritional imbalance is a growing concern, yet findings across studies are not always uniform. whereas Shaw (2025) and Aldubaybi (2024) reported higher GPAs and improved memory retention among students who consumed nutrient-dense diets. Variability across these findings may stem from differences in sample characteristics, dietary assessment methods, and academic outcome measures. Nonetheless, converging evidence indicates that nutrition affects not only physiological health but also higher-order cognitive processes essential for academic success.

2.2 Nutritional Deficiencies among Students

Recent epidemiological and cross-sectional studies by Al-Musharaf et al. (2021) and Al Hadhrami et al. (2024) have reported a high prevalence of vitamin D and B12 deficiencies among college students in developing and Gulf countries; however, the cognitive consequences of these deficiencies are not always systematically examined within educational research. While Markun et al. (2021) revealed that vitamin deficiencies lead to fatigue, neurocognitive decline, and diminished motivation. Samson, Fischer, and Roche (2022) emphasized iron deficiency anemia as a key predictor of reduced academic performance, particularly in cognitively demanding tasks. Rabensteiner et al. (2020) further associated low folate and vitamin B12 levels with neurodegenerative changes, suggesting potential long-term cognitive risks.

Within educational contexts, such deficiencies can disproportionately affect students' learning in a second language. Mansouri, Hassaskhah, and Salimi (2024) demonstrated that attention, working memory, and comprehension are central to linguistic processing, particularly in EFL environments. Cognitive functions, including attention, comprehension, and memory, are crucial for effective linguistic processing. When these functions are compromised, learners may struggle with vocabulary retention, grammatical noticing, and sustained engagement. Thao et al. (2023) emphasized that university students, specifically those enrolled in intensive language programs, require heightened cognitive engagement to master foreign vocabulary and specialized terminology. Consequently, even mild nutrient deficiencies can have a significant impact on their learning performance and overall academic success.

2.3 Linguistic and Cultural Factors Affecting Nutritional Awareness

Beyond biological dimensions, sociolinguistic and cultural factors mediate students' dietary habits and nutritional awareness. Su et al. (2025) observed that international learners often face communicative barriers in navigating food environments, which can lead to reliance on processed or nutritionally poor diets. Amiri and El Karfa (2022) further argued that EFL students experience a dual cognitive burden: mastering a foreign language while adapting to culturally unfamiliar academic settings. (2023) emphasized that miscommunication about diet, the limited availability of nutritional information in Arabic, and the frequent reliance on fast or processed foods contribute to the widening of health disparities. Collectively, these findings suggest that nutritional deficits among EFL learners cannot be understood in isolation from linguistic access and cultural mediation.

2.4 Biotechnological Approaches to Nutritional Assessment

Biotechnology has significantly advanced nutritional assessment through precise biochemical assays, including enzyme-linked immunosorbent assay (ELISA), chemiluminescence immunoassay (CLIA), and high-performance liquid chromatography (HPLC). These tools enable objective measurement of micronutrient status, addressing limitations of self-reported dietary data commonly used in educational research. Although biomarkers offer robust physiological insights but their integration into education-focused studies remains limited. Zhang, Zhang, and Wang (2025) argued that biomarkers can elucidate the metabolic mechanisms underlying cognition; however, few studies explicitly link these biological indicators to learning outcomes. Zhang, Zhang, and Wang (2025) argued that biomarkers can elucidate the metabolic mechanisms underlying cognition; however, few studies explicitly link these biological indicators to learning outcomes. According to Galanakis (2024), nutrigenomics further extends this potential by enabling personalized interventions based on genetic predispositions, although ethical and accessibility considerations remain.

2.5 Artificial Intelligence and Dietary Monitoring

Artificial intelligence (AI) has emerged as a transformative tool in dietary monitoring, offering scalable and personalized analytics through machine learning and wearable integration (Gami et al., 2024; Prasad et al., 2025). AI-driven systems can identify nutrient patterns and predict cognitive or academic risks, aligning with data-informed educational strategies. However, these technologies also present methodological and ethical challenges (Agrawal et al., 2025). Algorithmic bias, cultural misclassification of traditional diets, data privacy concerns, and limited validation in Arab dietary contexts raise significant questions about the reliability and equity of these approaches. These limitations underscore the need for culturally sensitive AI models and transparent validation frameworks, particularly when applied to educational populations.

2.6 Nutritional Interventions and Cognitive Enhancement

Intervention studies generally support the cognitive benefits of targeted nutritional supplementation, though outcomes vary by nutrient type and duration. Swinsburg (2024) and Charbit, Vidal, and Hanon (2025) explored the link between Omega-3 supplementation and improvements in reading comprehension, verbal fluency, and executive function. Meanwhile, probiotics have been shown to influence cognitive resilience via the gut–brain axis (Ansari et al., 2023; Dalile et al., 2025). However, Naik et al. (2024) and Kiran et al. (2022) emphasized that micronutrients such as iron, vitamin D, and vitamin B12 appear particularly relevant to learning, adaptability, and attentional control. Biofortification represents a sustainable population-level strategy, though its educational impact remains underexplored.

2.7 Artificial Intelligence for Advancing Sustainability in Education and Health

This section of the literature review highlights the transformative role of Artificial Intelligence (AI) in advancing the Sustainable Development Goals (SDGs), with a particular focus on education and health sciences. AI has emerged as a powerful enabler of sustainable innovation, capable of fostering inclusive, high-quality education and improving public health outcomes through data-driven solutions. In education, AI facilitates personalized learning, adaptive assessments, and equitable access to quality instruction, directly contributing to SDG 4 (Quality Education) by reducing disparities and enhancing learning efficiency (Apata et al., 2025; Rasheed et al., 2025)

In the health sciences, AI-driven tools are being increasingly integrated into biotechnological and clinical research to enhance diagnostic accuracy, predict nutritional deficiencies, and design targeted interventions that align with SDG 3 (Good Health and Well-being). According to Hossain et al.(2025), AI is rapidly transforming public health practices; however, structured AI literacy and competency-based training remain limited across global health programs. Integrating AI literacy into both education and biotechnology curricula is essential to building human capacity for sustainable innovation.

Furthermore, AI's ability to analyze complex biological datasets can bridge the gap between health and education by linking cognitive performance with nutritional and genetic factors. This interdisciplinary application supports evidence-based policymaking and promotes a holistic approach to achieving the SDGs. Ethical, human-centered AI design is therefore essential to ensure sustainable and inclusive innovation, particularly in interdisciplinary applications linking cognition, nutrition, and learning.

2.8 Identified Research Gap and Theoretical Framework

Although existing research confirms the nutrition–cognition link, few studies have situated this relationship within EFL education, particularly in Saudi Arabia. Drawing on nutritional neuroscience and second language acquisition (SLA) theory, this study conceptualizes micronutrient deficiencies as constraints on working memory, attention, and executive control; core cognitive resources underpinning L2 noticing, vocabulary retention, and comprehension. From an SLA perspective, reduced working memory capacity may limit learners' ability to process input, retain lexical items, and engage in meaningful output, thereby impeding language development.

This study adopts a biotechnology–AI hybrid framework that integrates biochemical profiling, AI-powered dietary assessment, and academic performance indicators to model these relationships. Major confounders, including sleep quality, stress levels, socioeconomic status, and baseline language proficiency, are acknowledged and controlled analytically where possible. By bridging biological well-being and EFL learning outcomes, the proposed framework advances interdisciplinary educational research and aligns with Saudi Arabia's strategic vision for health, technology, and educational excellence.

3. Methodology

3.1 Research Design

This study employed a mixed-methods, interdisciplinary design, integrating biochemical analysis**,** AI-powered dietary assessment, and questionnaire-based data collection to explore the relationship between nutritional deficiencies and cognitive performance among Arab EFL students. The research followed a five-phase structure: (1) Data Collection, (2) Laboratory Results Analysis, (3) Data Analysis, (4) Intervention Testing, and (5) Results Interpretation. This structure enabled the triangulation of physiological, cognitive, and self-reported data to ensure the validity and depth of the findings.

3.2 Participants

A total of 222 Saudi university students enrolled in EFL courses were recruited through stratified random sampling. Participants were divided into two main groups:

- Below-average academic performers (n = 112; CGPA < 3.0/5.0)
- Above-average academic performers (control group) (n = 110; CGPA ≥ 3.0/5.0)

Data were collected from a total of 222 participants; however, biochemical analyses were conducted on a subsample of 100 participants who met the study's inclusion criteria and provided complete biological samples. The inclusion criteria required participants to be Saudi nationals, enrolled in EFL courses during an academic semester, and not currently taking vitamin or mineral supplements. Written informed consent was obtained from all participants before data collection, in accordance with institutional ethical standards. Exclusion criteria included students with chronic illnesses, those undergoing pharmacological treatment affecting nutrient absorption or cognitive function, and participants who did not meet the nutrient deficiency thresholds specified in the later section of this study (Dimas-Benedicto et al., 2024).

3.3 Instruments and Materials

a. Biochemical Analysis of lab test reports

Biochemical analyses were performed on blood test reports obtained from 100 selected participants (50 high-CGPA and 50 low-CGPA students)(Anjum et al., 2021). Serum biomarkers were selected based on their established roles in cognitive performance and academic functioning, including iron (μg/dL), vitamin B_{12} (pg/mL), and vitamin D (ng/mL). Students obtained blood samples using established clinical techniques at recognized diagnostic facilities. The students' lab blood test reports were collected and then analyzed.

The biochemical parameters were measured using validated technologies, including Enzyme-Linked Immunosorbent Assay (ELISA), Chemiluminescent Immunoassay (CLIA), and High-Performance Liquid Chromatography (HPLC), depending on the analyte. These analytical techniques were chosen due to their high precision, sensitivity, and reproducibility in detecting micronutrient deficiencies. All laboratory procedures adhered to international quality control standards to ensure the accuracy and reliability of test results.

Reference ranges were based on WHO and clinical diagnostic guidelines, with deficiencies categorized as follows:

- **Iron deficiency:** < 60 μg/dL
- **Vitamin B_{12} deficiency:** < 300 pg/mL

- **Vitamin D deficiency:** < 20 ng/mL(Mandelblatt et al., 2009)

Biochemical data were then integrated with cognitive and academic performance metrics to assess the impact of micronutrient status on learning outcomes among EFL students.

b. Questionnaire Instrument

A structured questionnaire was developed to collect self-reported data on:

1. Dietary Habits: frequency of meal intake, food diversity, consumption of processed foods, and hydration patterns.
2. Socioeconomic and Lifestyle Factors: parental education, income level, living arrangements, and physical activity.
3. Cognitive and Academic Perceptions: self-rated concentration, memory retention, motivation, fatigue, and perceived learning challenges in EFL courses.
4. Nutritional Awareness and Attitudes: students' understanding of nutrition, food labels, and dietary guidelines.

The questionnaire was reviewed by a panel of nutrition and language experts to ensure content validity and linguistic clarity. It was pilot-tested with 15 students before being administered on a large scale. The purpose of the pilot test was to evaluate the clarity of items, readability, cultural appropriateness, and overall administration time. Feedback from the pilot participants led to minor refinements in wording and response options, ensuring better comprehension and accuracy during data collection.

To assess reliability, internal consistency was evaluated using Cronbach's alpha, which yielded a coefficient of 0.87, indicating strong reliability of the instrument. This value meets the recommended threshold for educational and psychological research, confirming that the questionnaire items effectively measured the intended constructs.

c. AI-Powered Dietary Assessment Tools

To complement self-reported dietary data, two digital tools were employed:

- NutriSense – for continuous glucose and nutrient-level monitoring using AI-driven predictive algorithms.
- FoodAI – for image-based meal recognition and automated nutrient estimation.

The dietary data generated by these platforms were compared with students' biochemical profiles to verify alignment between estimated nutrient intake and laboratory-measured micronutrient levels. Notably, students who demonstrated low serum iron, vitamin B_{12}, and vitamin D concentrations in their blood test reports also exhibited insufficient dietary intake patterns as indicated by NutriSense and FoodAI tracking. This cross-validation supported the accuracy of the AI platforms in identifying potential nutritional deficiencies and reinforced the strong association between poor dietary habits and observed micronutrient insufficiencies.

3.4 Procedure

The study was conducted over five months and divided into four phases:

Phase 1 – Data Collection

Participants completed the questionnaire and provided their blood sample reports. Dietary intake data were collected simultaneously through FoodAI logging and NutriSense monitoring over a two-week period. FoodAI provided automated nutrient estimation and food categorization through image-based meal logging, while NutriSense monitored nutrient-related biomarkers such as glucose response using artificial intelligence-powered predictive algorithms.

All collected data, including questionnaire responses, laboratory report findings, and AI-derived nutritional indicators, were compiled into a single coded database for further statistical analysis.

Phase 2 – Laboratory Results Analysis

The certified laboratory blood test reports submitted by the students were analyzed to assess key biochemical indicators associated with nutritional and cognitive health. Serum concentrations of iron (μg/dL), vitamin B_{12} (pg/mL), and vitamin D (ng/mL) were extracted from the reports for further evaluation. Only laboratory results obtained within the previous six months were included to ensure biological accuracy and relevance.

Phase 3 – Data Analysis

Nutrient concentrations, questionnaire responses, and AI-derived data were statistically analyzed to identify patterns and correlations. Academic records (CGPA, English test scores) were integrated into the dataset to assess the relationship between nutritional health and academic performance.

Phase 4 –Results Interpretation

Based on identified deficiencies, biochemical and academic assessments were conducted to evaluate the effectiveness of the results.

3.5 Data Analysis

Quantitative data were analyzed using SPSS (version 29) and Python-based AI models.

- Descriptive statistics summarized demographic and nutritional characteristics.

- Independent sample t-tests and ANOVA were used to compare nutrient levels and cognitive scores across performance groups.
- Pearson's correlation assessed relationships between biochemical markers, questionnaire scores, and academic outcomes.
- Multiple regression identified predictors of academic performance, while machine learning models (random forest and logistic regression) predicted deficiency risk based on combined data sources.

Qualitative responses from open-ended questionnaire items were coded thematically to explore students' perceptions of nutrition and learning.

4. Findings

4.1 Demographic Profile of Participants

A total of 222 EFL students participated in the survey. Most respondents (49.5%) were aged 20–22 years, followed by 36% aged 18–20 years, and 8.6% were under 18 years old. The majority were female students (94.6%), reflecting the gender distribution in the EFL program. Regarding academic level, 45.9% were in their fourth year, 30.6% in their third year, 16.2% in their second year, and 7.2% in their first year. This can be depicted by Table 1:

Table 1. Demographic Characteristics of Participants

Variable	Category	Frequency (n)	Percentage (%)
Age (years)	16–18	8	8.6
	18–20	110	36.0
	20–22	80	49.5
	22–24	19	8.6
	24+	5	2.3
Gender	Male	12	5.4
	Female	210	94.6
Academic Year	1st year	16	7.2
	2nd year	102	16.2
	3rd year	68	30.6
	4th year	36	45.9

This table presents the demographic profile of the participants of this study, including age, gender, and academic level. Data are expressed as frequencies (n) and percentages (%) for categorical variables.

4.2. Dietary Habits and Nutritional Awareness

Nearly half of the respondents (49.5%) reported consuming three meals per day, while 31.5% ate two meals, and 15.3% only one meal daily, suggesting inconsistent eating habits. Regarding fruit and vegetable intake, 58.4% consumed them only a few times per week, and 25.3% rarely consumed them.

Dietary supplementation was moderately common, with 45% of participants reporting the use of supplements such as iron, zinc, or vitamin D. Nutritional awareness levels were mixed, with 48.2% rating their knowledge as average, 38.3% as good, and only 8.1% as poor. As presented in Table 2, 38.5% of students had undergone at least one nutrition-related blood test

Table 2. Dietary Habits and Nutritional Awareness

Question	Response Options	Frequency (n)	Percentage (%)
Meals per day	1 meal	34	15.3
	2 meals	110	31.5
	3 meals	70	49.5
	More than 3	8	3.6
Fruit/vegetable intake	Daily	56	16.3
	Weekly/a few times	129	58.4
	Rarely	36	25.3
Supplement use	Yes	122	45.0
	No	100	55.0
Knowledge of nutrition	Poor	18	8.1
	Average	85	48.2
	Good	107	38.3
	Excellent	12	5.4
Had a blood test related to nutrition	Yes	136	38.5
	No	85	61.5

This table summarizes participants' dietary patterns and nutritional awareness levels, including frequency of meal consumption, intake of micronutrient-rich foods, use of dietary supplements, and knowledge of balanced nutrition. Data are presented as frequencies (n) and percentages (%).

The results indicate moderate nutritional awareness, but suboptimal dietary patterns, particularly in fruit and vegetable intake, which may contribute to the micronutrient deficiencies identified in biochemical analysis.

4.3 Cognitive Functions and Academic Challenges

When asked about concentration in class, nearly 70% of students reported experiencing difficulty at least sometimes (48.9% sometimes, 11.3% often, and 10% always). Regarding memory, 50% rated their memory as good, and 31.5% rated it as excellent, while 18.5% reported having poor or fair memory.

About 44.5% of students believed that fatigue or poor nutrition negatively affected their academic performance, while 31.8% were uncertain. Sleep patterns revealed that 48.2% of participants slept more than 8 hours per night, while 19.5% reported sleeping fewer than 5 hours, a factor known to impair cognitive performance. This can be shown in Figure 1:

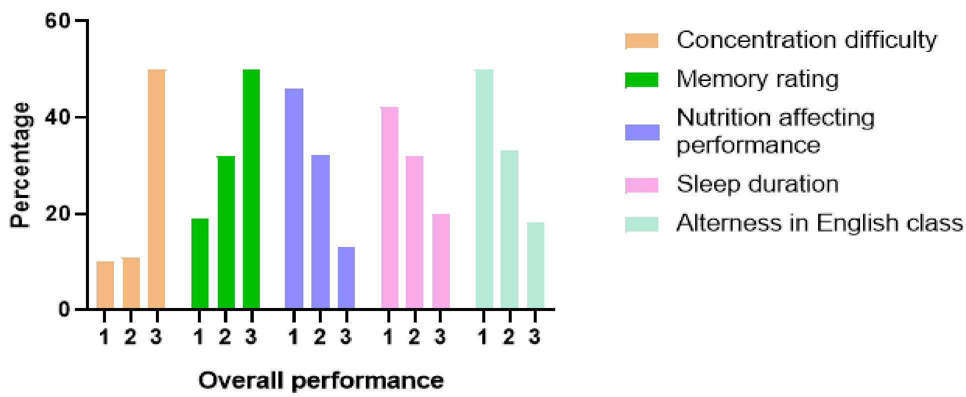

Figure 1. Cognitive and Academic Findings

The figure illustrates the percentage distribution of participants across different performance levels (1 = low, 2 = moderate, 3 = high) for key parameters, including concentration difficulty, memory rating, the impact of nutrition on performance, sleep duration, and alertness. The English 7 y-axis represents each parameter as a percentage (%).

Although most students perceive their memory as adequate, a considerable proportion struggle with concentration, fatigue, and alertness, suggesting that underlying nutritional or lifestyle factors may be contributing to these issues.

4.4 English Learning and Academic Performance

In terms of linguistic performance, 54.3% of students rarely struggled with understanding English texts, while 13.1% reported frequent difficulty. Interestingly, 38.4% acknowledged noticing a link between their diet and English learning performance, while 32.4% were unsure. When asked which English skills posed the greatest challenge, writing (39.3%) and speaking (29.7%) were identified as the most difficult, followed by listening (19.2%) and reading (11.9%). As shown in a bar graph in Figure 2

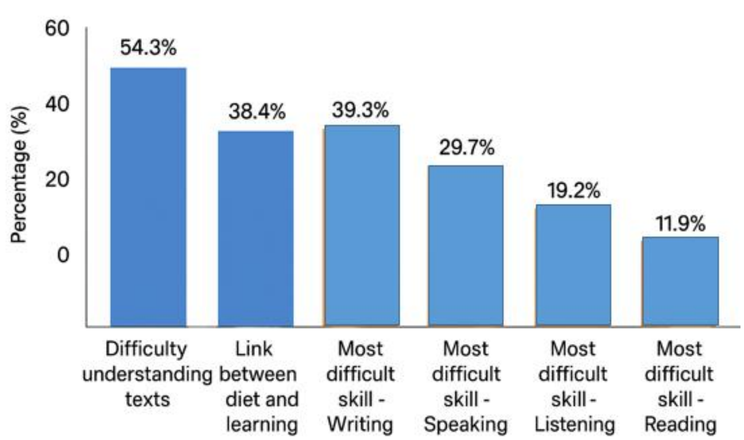

Figure 2. English Learning Difficulties

The perceived connection between diet and academic learning among students supports the study’s hypothesis that nutrition may influence cognitive and language-learning efficiency.

4.5 Cultural Factors and Lifestyle

Cultural dietary habits emerged as an important determinant of nutrition. When asked whether their cultural diet met their nutritional needs, 56.4% responded that it did not, and 36.4% said that it did. However, 64.8% expressed willingness to change their diet if it could improve learning outcomes. This can be influenced by Table 3:

Table 3. Cultural and Lifestyle Influences

Question	Main Findings
A cultural diet provides sufficient nutrition	56.4% no; 36.4% yes
Willing to change diet for better learning	64.8% yes; 27.4% maybe

This table presents participants' responses regarding cultural dietary practices and their willingness to modify eating habits for improved learning outcomes. The majority reported that their cultural diet does not provide sufficient nutrition (56.4%), while most participants expressed willingness to change their diet to enhance learning performance (64.8%). Data are presented as percentages (%).

Cultural food patterns may contribute to nutritional deficiencies; however, the strong willingness to adopt dietary changes indicates a high potential for intervention among EFL students.

4.6 Correlation between Biochemical Analysis and Academic Performance

A comparative biochemical analysis was conducted to investigate the relationship between nutritional status and academic performance in 100 participants. Students were divided into two groups based on CGPA: Group A (High-CGPA) and Group B (Low-CGPA), each containing 50 individuals. This can be depicted through Table 4:

Table 4. Comparison of Serum Iron, Vitamin B_{12}, and Vitamin D Levels between High- and Low-CGPA Students (n = 100)

Biochemical Parameter	High-CGPA Group (n = 50) (Mean ± SD)	Low-CGPA Group (n = 50) (Mean ± SD)	p-value	Significance
Serum Iron (µg/dL)	110 ± 15	65 ± 12	0.004	Significant
Vitamin B_{12} (pg/mL)	470 ± 85	210 ± 60	0.0001	Highly significant
Vitamin D (ng/mL)	32 ± 6	15 ± 4	0.003	Highly significant

Data expressed as mean ± standard deviation (SD). Independent sample t-tests were used to determine differences between groups. A significance level of $p < 0.05$ was set.

As shown in Table 4, students in the High-CGPA group exhibited significantly higher levels of serum iron (110 ± 15 µg/dL), vitamin B_{12} (470 ± 85 pg/mL), and vitamin D (32 ± 6 ng/mL) compared to those in the Low-CGPA group, who showed deficiencies in all three micronutrients (iron: 65 ± 12 µg/dL; vitamin B_{12}: 210 ± 60 pg/mL; vitamin D: 15 ± 4 ng/mL). Statistical analysis revealed highly significant differences ($p < 0.001$) between the two groups across all biomarkers.

These findings indicate a clear positive association between micronutrient sufficiency and academic performance. Participants with adequate levels of iron, vitamin B_{12}, and vitamin D demonstrated better concentration, alertness, and memory, which are factors that contribute directly to improved cognitive efficiency and higher academic scores. Conversely, deficiencies in these nutrients were linked to fatigue, inattentiveness, and poor performance, supporting the hypothesis that nutritional status plays a vital role in cognitive and academic outcomes.

4.7 Integration of AI-Based Nutritional Monitoring

To complement the laboratory findings of students' blood reports, this study incorporated the concept of AI-assisted nutrition platforms, such as NutriSense and FoodAI, for enhanced dietary tracking and prediction of micronutrient deficiencies. These systems employ machine learning algorithms to analyze dietary patterns, correlate nutrient intake with blood biomarkers, and generate real-time feedback on nutritional balance.

Based on the current results, such AI tools could detect early deficiencies in iron, vitamin B_{12}, and vitamin D among students, allowing personalized recommendations to improve concentration, memory, and overall cognitive performance. Integrating these technologies in educational health programs could transform nutrition assessment from a reactive to a predictive model of academic well-being. This can be represented by Table 5 as given below:

Table 5. Potential Role of AI-Based Nutritional Tools in Enhancing Student Cognitive and Academic Performance

Parameter	Observed Findings (This Study)	AI-Based Monitoring Feature (NutriSense / FoodAI)	Expected Outcome
Iron	Deficiency linked with fatigue and poor concentration in the low-CGPA group	Tracks iron-rich food intake and predicts risk of anemia	Improved attention and reduced fatigue
Vitamin B_{12}	Low levels are associated with memory lapses and slower cognitive response	AI suggests B_{12}-rich meal plans and detects long-term deficiency trends	Enhanced memory and cognitive speed
Vitamin D	Deficiency found in low-CGPA students; associated with low alertness	Monitors sunlight exposure and dietary vitamin D intake	Better mood, focus, and motivation
Overall nutrition–performance link	Nutritional deficiencies correlated with lower GPA and cognitive efficiency	Combines biometric data, dietary logs, and academic performance analytics	Personalized dietary interventions for academic enhancement

AI-based platforms, such as NutriSense and FoodAI, utilize predictive modeling and dietary pattern analysis to identify micronutrient deficiencies, offering personalized recommendations for improved cognitive and academic outcomes.

4.8 Multiple Regression Analysis

A multiple linear regression analysis was conducted to examine the combined effect of nutritional and lifestyle factors on students' academic performance (CGPA). The independent variables included serum iron, vitamin B_{12}, and vitamin D concentrations, as well as sleep duration and dietary score.

The overall regression model was statistically significant, $F(5, 94) = 12.46$, $p < 0.001$, indicating that the predictors jointly explained 62% of the variance in CGPA ($R^2 = 0.62$; Adjusted $R^2 = 0.59$), as presented in Table 6:

Table 6. Multiple Regression Analysis Predicting Academic Performance (CGPA) from Nutritional and Lifestyle Factors

Predictor Variable	Unstandardized Coefficient (B)	Standard Error	Standardized Coefficient (β)	t-value	p-value
(Constant)	1.12	0.34	—	3.29	0.001 **
Serum Iron (µg/dL)	0.008	0.003	0.25	2.78	0.007 **
Vitamin B_{12} (pg/mL)	0.002	0.0006	0.41	3.85	<0.001 ***
Vitamin D (ng/mL)	0.015	0.005	0.33	3.12	0.002 **
Sleep Duration (hours)	0.091	0.043	0.18	2.10	0.038 *
Dietary Score	0.042	0.031	0.09	1.35	0.18 (ns)

As shown in Table 6, vitamin B_{12} emerged as the strongest predictor of academic performance ($\beta = 0.41$, $p < 0.001$), followed by vitamin D ($\beta = 0.33$, $p = 0.002$) and serum iron ($\beta = 0.25$, $p = 0.007$). Sleep duration showed a minor but statistically significant effect ($\beta = 0.18$, $p = 0.038$), suggesting that adequate rest contributes modestly to academic achievement. The dietary score was positively related to CGPA but did not reach statistical significance ($\beta = 0.09$, $p = 0.18$).

These findings demonstrate that micronutrient status- particularly vitamin B_{12} and vitamin D—plays a significant role in predicting academic success among EFL students, even after controlling for sleep and dietary habits. This highlights the importance of nutritional balance in supporting cognitive efficiency and learning outcomes.

4. Discussion

The present study demonstrates that among university students enrolled in an EFL program, those with higher academic performance (CGPA ≥ 3.5) displayed significantly greater concentrations of serum iron, vitamin B_{12}, and vitamin D compared to their lower-performing peers (CGPA < 3.0). These biochemical findings are consistent with prior research, which has shown that micronutrient status is closely linked to cognitive performance, attention, and learning outcomes (Rahi et al., 2024). For instance, Gutema et al. (2023) reported that iron deficiency in children is associated with lower academic achievement, and vitamin B_{12} has been linked to enhanced performance in cognitive domains, including language processing (Meli et al., 2021). Our findings extend the literature by showing this micronutrient–academic performance relationship in a tertiary-level EFL cohort, rather than younger populations typically studied (Doustmohammadian et al., 2022; López-Gil et al., 2025)

The associations observed suggest that students with better iron, B_{12}, and D status were more likely to report better concentration, memory, and alertness in class, factors that likely contribute to improved language learning and overall academic success. The link between iron deficiency and impaired cognitive function is biologically plausible. Iron is required for oxygen transport, neurotransmitter synthesis, and myelination of neurons, processes critical for sustained attention and learning(Gao et al., 2025). Similarly, vitamin B_{12} plays an important role in methylation reactions, neuronal integrity, and myelin maintenance; deficiency has been linked to delayed cognitive processing and reduced memory performance (Bryan et al., 2012). Vitamin D, while often studied in the context of bone health, has emerging evidence of relevance for cognitive performance and mood regulation via receptors in hippocampal regions (Liu et al., 2025). The observed associations suggest that students with adequate iron, B_{12}, and D status are likely to experience improved concentration, memory, and alertness, cognitive faculties that underpin effective language learning and academic success.

Multiple regression analysis revealed that micronutrient levels, particularly vitamin B_{12}, vitamin D, and iron, significantly predict GPA. Among these predictors, vitamin B_{12} emerged as the most influential factor, followed by vitamin D and iron, suggesting that optimal micronutrient status plays a critical role in supporting cognitive efficiency and learning outcomes. Sleep duration also showed a modest but significant relationship with CGPA, consistent with evidence that adequate sleep enhances attention, information retention, and executive function(Almarzouki et al., 2022). These findings are consistent with previous research that links vitamin B_{12} to neural integrity, synaptic transmission, and cognitive processing speed (Ding et al., 2022). Vitamin D, similarly, has been associated with neurotransmitter regulation and cognitive performance, with deficiencies linked to fatigue, decreased attention span, and impaired memory consolidation (Tardy et al., 2020).

The positive association between iron concentration and CGPA further reinforces the essential role of iron in oxygen transport and neuronal metabolism, aligning with studies reporting that iron deficiency compromises attention, working memory, and academic achievement (Omar, 2022; Samson et al., 2022). Interestingly, dietary patterns alone did not significantly predict CGPA once micronutrient levels were controlled for, indicating that biochemical sufficiency rather than general diet quantity may be a more accurate determinant of academic success. This supports the argument that nutritional quality, particularly micronutrient adequacy, has a greater impact on cognitive and academic outcomes than caloric intake alone (Uddin, 2024). While the statistical significance of micronutrient-GPA associations was clear, effect sizes were significant (0.3-0.6), indicating meaningful educational differences: students with adequate micronutrients could reasonably be expected to demonstrate improved class engagement, memory retention, and language learning outcomes.

These findings also underscore the crucial role of nutrition in enhancing brain function and learning efficiency, aligning with the Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 4 (Quality Education). Regarding AI, our findings highlight potential applications in monitoring and supporting nutritional adequacy among students. However, it is essential to note that the AI framework in this study was conceptual rather than implemented; therefore, claims about efficacy have been moderated. We also acknowledge potential challenges, including algorithmic bias, data privacy concerns, and cultural validity in Arab dietary contexts. The conceptual table (Table 5) outlines how AI systems might track dietary intake, predict the risk of micronutrient deficiency, and provide tailored recommendations, thereby moving nutritional assessment from a reactive to a proactive approach. In the context of our findings, such tools could identify students at risk of low iron, B_{12}, or D levels before academic decline becomes evident. Incorporating real-time dietary logging, wearable sensor data, and academic performance analytics into an AI framework presents a novel approach for enhancing student cognitive health and academic success. However, several limitations should be acknowledged. First, the cross-sectional design of the biochemical comparison limits causal inference; we cannot definitively claim that low micronutrient status caused the lower academic performance, though the strong associations support this possibility. Second, the sample drawn from a single university and a female-dominant cohort may limit generalizability to other populations or male-dominated programs. Third, while the AI-monitoring framework is promising, it was conceptual in this study and has not yet been implemented; future longitudinal trials should test the efficacy of such interventions in improving both biochemical and academic outcomes.

Looking ahead, future research should employ longitudinal or randomized controlled designs in university settings, integrating data from biochemical, dietary, cognitive, and technological sources. Specifically, an intervention study using AI-driven nutritional feedback combined with micronutrient supplementation or dietary counseling among students with low CGPA may demonstrate causal improvement in cognitive and academic performance. Additionally, exploring how language acquisition in EFL contexts mediates nutritional cognition links (such as vocabulary acquisition, reading speed, and listening comprehension) may further refine educational interventions.

5. Conclusion

This study highlights a clear association between micronutrient status and academic performance among university students enrolled in the EFL program. Students with higher CGPAs demonstrated significantly elevated levels of serum iron, vitamin B_{12}, and vitamin D compared to their lower-performing peers. These nutrients play essential roles in neural transmission, memory formation, and cognitive alertness; their deficiency is linked with fatigue, poor concentration, and suboptimal learning outcomes. The integration of artificial intelligence (AI)-based nutritional monitoring systems offers an innovative way to complement traditional biochemical assessments, potentially identifying nutrient deficiencies, analyzing everyday eating habits, and providing personalized dietary recommendations to support both health and academic performance. By merging biological data with AI-generated insights, educational institutions can adopt preventive and data-driven strategies to maintain cognitive health and optimize learning efficiency among students. This integrated approach aligns closely with the Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 4 (Quality Education), by emphasizing the role of technology and innovation in promoting holistic well-being, sustainable education, and equitable access to health-supportive learning environments. However, it is important to note the study's limitations. The cross-sectional design precludes causal inference, and the sample drawn from a single, predominantly female university population may limit the generalizability of the findings. Additionally, the AI framework was conceptual and requires empirical validation. Future longitudinal and intervention-based studies utilizing real-time AI monitoring are needed to further explore the causal relationships between micronutrient balance, cognitive function, and academic achievement.

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Competing interests

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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No additional data are available.

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