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Micronutrient intake and HbA1c in Saudi Arabian patients with type 2 diabetes: a cross-sectional analysis

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ORIGINAL ARTICLE

Abstract

Diabetes is a major global health concern, with a high and increasing prevalence of type 2 diabetes mellitus (T2DM) in Saudi Arabia. Glycated hemoglobin (HbA1c) is a key marker for long-term glycemic control. Despite the crucial role of diet, research on micronutrient intake within traditional Saudi diets is limited. This study investigated the association between micronutrient intake and HbA1c in Saudi T2DM patients. This cross-sectional study involved 196 adult T2DM patients in Riyadh, Saudi Arabia. Dietary intake was assessed via 24-hour recalls, and HbA1c levels were biochemically measured. Participants were categorized into controlled (HbA1c < 8.0%) and uncontrolled (HbA1c ≥ 8.0%) groups. Group comparisons were conducted using t-tests and Chi-square tests. Logistic regression analysis was used to examine adjusted associations between nutrient intakes and elevated HbA1c, controlling for age and sex. Patients with uncontrolled HbA1c had significantly higher sodium intake and lower intakes of potassium, vitamin C, pantothenic acid, and selenium (all $p \leq 0.05$). Adjusted logistic regression showed that higher vitamin C and selenium intakes were associated with lower odds of elevated HbA1c. Conversely, higher vitamin D and thiamine intakes were associated with increased odds. Pantothenic acid showed contradictory associations between mean differences and adjusted odds**.** This study identifies distinct dietary patterns linked to glycemic control. Uncontrolled HbA1c was associated with higher sodium and lower potassium, vitamin C, pantothenic acid, and selenium intakes. Adjusted analyses indicated that higher vitamin C and selenium intakes were linked to improved odds, while higher vitamin D and thiamine were linked to worse odds. The complex role of pantothenic acid warrants further investigation. These findings underscore the nuanced role of micronutrients in glycemic regulation, suggesting their potential for tailored dietary interventions in T2DM.

Keywords: diabetes type 2, HbA1c, macronutrients dietary intake, micronutrients dietary intake

Introduction

The global diabetic landscape presents an urgent public health challenge, with an estimated 537 million adults currently diagnosed with diabetes. Projections indicate that this number will rise to 643 million by 2030 and 783 million by 2045 (Sun *et al.*, 2022). The Middle East and North Africa region exemplifies this troubling trend, currently reporting 73 million individuals (16.6%) with diabetes, a figure anticipated to escalate to 95 million by

2030 (Sun *et al.*, 2022). The ramifications of inadequate glycemic control extend beyond immediate health implications, culminating in severe macrovascular and microvascular complications such as retinopathy, nephropathy, stroke, and ischemic heart disease (Borgharkar *et al.*, 2019). These complications not only diminish individual quality of life and elevate mortality rates but also impose significant economic burdens on healthcare systems and patients alike (Ali *et al.*, 2020; Bain *et al.*, 2020).

In Saudi Arabia, the prevalence of T2DM has exhibited a notable upward trajectory, with estimates ranging from 16.4% to 34.6% (Jarrar *et al.*, 2023; Al Mansour, 2019). Meta-regression analyses reveal a consistent annual increase in prevalence of 0.46% (Owolabi *et al.*, 2020). The multifactorial etiology of T2DM encompasses several pivotal risk factors, including obesity, physical inactivity, unhealthy dietary patterns, smoking, and advanced age (Yahya Mari Alneami & C. Coleman, 2015). Furthermore, sociodemographic variables, such as low income and certain marital statuses (particularly being divorced or widowed), contribute to an elevated risk of T2DM (Al Mansour, 2019).

HbA1c serves as a critical biomarker for long-term glycemic assessment, providing a comprehensive overview of average blood glucose levels over the preceding 2–3 months (Sherwani *et al.*, 2016; Kurniawan, 2024). Its clinical relevance transcends mere glucose monitoring; it functions as a reliable diagnostic tool and prognostic indicator for diabetes progression. HbA1c is produced through the glycation of hemoglobin A at the N-terminal of its valine beta-globin chain and exhibits a strong correlation with the risk of long-term diabetic complications (Kurniawan, 2024). Moreover, elevated levels of HbA1c are recognized as an independent cardiovascular risk factor applicable to both diabetic and non-diabetic populations (Sherwani *et al.*, 2016).

Dietary management emerges as a pivotal intervention strategy in the control of diabetes. The efficacy of various dietary approaches in glycemic regulation has been highlighted. Dietary patterns such as low-carbohydrate, Mediterranean, and Paleolithic diets have demonstrated significant potential in reducing HbA1c levels, with the Mediterranean diet showing particular effectiveness in improving both HbA1c and fasting glucose metrics (Schwingshackl *et al.*, 2018). A comprehensive approach that emphasizes the balance of macronutrient composition, strategic meal timing, and adequate micronutrient intake is crucial for optimal diabetes management (Al-Adwi *et al.*, 2022).

The existing literature presents notable research gaps regarding non-Westernized, traditional dietary patterns in Saudi Arabia. The dietary habits of the rural Saudi population, characterized by the consumption of minimally processed, nutrient-dense foods, present a unique research opportunity. These traditional diets, rich in dietary fiber, whole grains, and micronutrients, may offer distinct metabolic advantages in the management of T2DM through mechanisms such as inflammation reduction, modulation of gut microbiota, and regulation of blood glucose levels.

Local studies have explored the contributions of macronutrients to diabetes management, while the focus on micronutrients remains limited. Preliminary investigations, including those focused on vitamin D, have yielded promising results. One study identified a 52.3% prevalence of vitamin D deficiency among T2DM patients, revealing a significant inverse correlation between vitamin D levels and HbA1c, suggesting valuable therapeutic implications (Alquaiz *et al.*, 2021).

In light of these findings, this study aimed to investigate the intricate associations between micronutrient intake and HbA1c levels among T2DM patients in Saudi Arabia. By identifying specific micronutrients associated with improved glycemic control, this research seeks to bridge critical knowledge gaps and contribute to the formulation of evidence-based, population-specific dietary guidelines.

Materials and Methods

Study design and procedures

This cross-sectional study, conducted between June and December 2022, investigated patients with T2DM attending health centers in Aldawadmi, Saudi Arabia. Ethical approval was granted by the Shaqra University Ethics Research Committee (ERC_SU_20220053) on June 20, 2022. A total of 196 participants with T2DM were recruited. Prior to enrollment, all participants received comprehensive information regarding the study's objectives, design, and confidentiality protocols. Written informed consent was obtained from each participant.

Inclusion criteria stipulated that participants be 18 years of age or older with T2DM. Exclusion criteria encompassed individuals who had received antibiotic treatment within the three months preceding the study, pregnant or lactating women, and individuals diagnosed with inflammatory bowel disease and individuals on diet. Following a minimum 10-hour overnight fast, venous blood samples were collected from all participants for biochemical analysis, complete blood count (CBC), and HbA1c. Hemoglobin subfractions were assessed simultaneously with HbA1c measurement. Blood was collected in EDTA tubes, gently inverted and mixed 8–10 times, and then transported—along with plain tubes—to the chemistry

and hematology sections for analysis within one hour of collection. HbA1c levels were measured using the immunoturbidimetric method with commercial reagents on a fully automated integrated analyzer (Cobas 6000, Roche Diagnostics). Participants were subsequently stratified into two groups based on their HbA1c levels: a controlled group was defined by HbA1c levels below 8%, while an uncontrolled group consisted of participants with HbA1c levels of 8% or greater. This 8% threshold was selected to delineate distinct levels of glycemic control, acknowledging that HbA1c values at or above 8% (approximately 183 mg/dL or 10.1 mmol/L estimated average glucose) are consistently associated with a significantly increased risk of both microvascular and macrovascular complications in diabetes (Tan JK *et al.*, 2023). While the American Diabetes Association generally targets HbA1c < 7% for most non-pregnant adults, an 8% cut-off serves as a robust indicator of sustained suboptimal control within a research context (American Diabetes Association, 2024).

Data collection was performed during patient physical examinations by qualified healthcare providers. Demographic data, including sex, age, social status, educational level, and monthly income, were collected using a self-administered questionnaire. Anthropometric measurements, specifically height and body weight, were obtained by a trained professional adhering to standardized protocols. Measurements were taken with participants wearing minimal clothing and without shoes. Body mass index (BMI) was calculated using the standard formula: weight (kg) divided by height squared (m^2). Subsequently, BMI was categorized according to the World Health Organization (WHO) classification into normal, overweight, and obese categories (Teufel *et al.*, 2022).

Dietary and nutritional assessment

Dietary intake was assessed using two non-consecutive 24-hour dietary recalls. Data from these recalls were analyzed using Nutritics software® (Swords, Co. Dublin, Ireland) to calculate average daily intakes over the two-day period. This analysis provided comprehensive data on both macronutrient and micronutrient consumption. Specifically, the following nutrients were assessed: carbohydrates (CHO), protein, total fat, saturated fat, polyunsaturated fat, monounsaturated fat, cholesterol, sodium, potassium, dietary fiber, total sugars, calcium, iron, vitamin D, thiamine, folate, vitamin B_{12}, magnesium, zinc, selenium, copper, water, vitamin C, and total energy intake.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics software, version 24.0. Continuous variables are presented as mean ± standard deviation (SD), while categorical variables are presented as frequencies and percentages. Comparisons between the controlled HbA1c group (< 8.0%) and the uncontrolled HbA1c group (≥ 8.0%) were conducted using appropriate statistical tests. Specifically, categorical variables were compared using Chi-square (χ^2) tests, and continuous variables were compared using independent samples t-tests.

To explore the relationships between HbA1c levels and dietary intakes, both univariate and multivariate analyses were conducted. Initially, Pearson correlation analysis was employed as a univariate approach to assess the bivariate relationships between HbA1c and individual dietary components. Subsequently, multivariate linear regression analysis was performed to examine the independent associations of multiple dietary variables with HbA1c, while controlling for potential confounding factors. A two-tailed p-value of less than or equal to 0.05 ($p \leq 0.05$) was considered statistically significant for all analyses.

Results

Characteristics of the study cohort

This observational study enrolled a total of 196 participants. The overall cohort exhibited a mean HbA1c level of 9.18 (SD = 2.1), indicating suboptimal glycemic control within the study population. Participants were subsequently stratified into two groups based on their HbA1c values: a controlled group (CG, n = 66), defined by HbA1c levels below 8%, and an uncontrolled group (UCG, n = 130), characterized by HbA1c levels of 8% or greater. The rationale for employing an 8% HbA1c threshold for participant stratification is detailed within the "Methods" section.

This stratification revealed a substantial proportion (approximately 66%) of the study population with uncontrolled HbA1c.

The demographic profile of the cohort was predominantly female (n = 145, 74%), with a notable distribution of glycemic control within this subgroup. Among female participants, a larger proportion (n = 98, 68%) belonged to the UCG, while 47 (32%) were classified within the CG. A similar trend was observed among male participants (n = 51, 26%), with 32 (63%) falling into the UCG.

Analysis of age distribution indicated that the majority of participants (n = 111, 57%) were between 40 and 50 years of age, highlighting the prevalence of diabetes in this middle-aged demographic. The vast majority of participants (approximately 96%) were married.

Educational attainment within the cohort was generally low. The largest proportion of participants were either illiterate (n = 85; 43%) or had completed only elementary education (n = 66; 34%). A smaller proportion had obtained a diploma (n = 34; 17%), while only a small minority (n = 10; 5%) held a Bachelor's degree or higher.

Anthropometric measurements were also collected and analyzed. The mean height for the entire cohort was 161.57 cm (SD = 5.9). When stratified by glycemic control, the mean height was 162.06 cm (SD = 5.49) in the CG and 161.33 cm (SD = 6.16) in the UCG, indicating minimal differences between the groups. Similarly, the mean weight for the overall cohort was 80.10 kg (SD = 12.2), with values of 78.74 kg (SD = 11.19) and 80.76 kg (SD = 12.61) observed in the CG and UCG, respectively, again demonstrating minimal differences. The mean Body Mass Index (BMI) for the entire cohort was 30.60 kg/m² (SD = 4.7), classifying the cohort on average as obese. The CG had a mean BMI of 29.96 kg/m² (SD = 4.09), while the UCG had a mean BMI of 30.91 kg/m² (SD = 5.00), suggesting a slightly higher average BMI in the uncontrolled group. Importantly, statistical analysis revealed no significant differences between the controlled and uncontrolled groups in terms of demographics (sex, age, marital status, education) or anthropometrics (height, weight, BMI). Patient characteristics are summarized in detail in Table 1.

Relative daily dietary intake of nutrients in controlled and uncontrolled glycemic groups

Analysis of dietary nutrient intake was conducted to identify differences between participants with controlled (HbA1c < 8.0%, N = 66) and uncontrolled (HbA1c ≥ 8.0%, N = 130) glycated hemoglobin levels. A two-tailed Student's t-test revealed several statistically significant disparities in nutrient consumption between these groups (Table 2).

Individuals in the uncontrolled HbA1c group exhibited a tendency toward higher mean intake of sodium (1963.59 ± 2516.6 mg) compared to the controlled group (1479.05 ± 955.76 mg, $p \leq 0.05$); however, this was not significant. Conversely, the uncontrolled group demonstrated significantly lower mean intakes for several nutrients. For cholesterol, the uncontrolled group consumed 269.28 ± 210.97 mg, compared to 341.72 ± 207.96 mg

Table 1. Descriptive characteristics of the study participants stratified by HbA1c level.

Variable	Total (N = 196) *n* (%) Mean ± SD	HbA1c		p-value
		Controlled < 8.0 (N = 66) *n* (%) Mean ± SD	Uncontrolled ≥ 8.0 (N = 130) *n* (%) Mean ± SD	
Sex (*n* = 196)				0.60
Male	51 (26.0)	19 (37.25)	32 (62.74)	
Female	145 (74.0)	47 (32.41)	98 (67.58)	
Age (*n* = 196)				0.93
< 30 years	3 (1.5)	2 (66.7)	1 (33.3)	
30-40 years	20 (10.2)	8 (40.0)	12 (60.0)	
40-50 years	111 (56.6)	39 (35.1)	72 (64.9)	
> 50 years	62 (31.6)	17 (27.4)	45 (72.6)	
Marital Status (*n* = 193)				0.54
Single	8 (4.1)	3 (37.5)	5 (62.5)	
Married	185 (95.8)	61 (33.0)	122 (66.0)	
Education (*n* = 195)				0.13
Bachelor's	10 (5.1)	6 (60.0)	4 (40.0)	
Diploma	34 (17.3)	14 (41.2)	20 (58.8)	
Elementary School	66 (33.7)	23 (34.8)	43 (65.2)	
Illiterate	85 (43.4)	23 (27.1)	62 (72.8)	
Height (cm)	161.57 ± 5.9	162.06 ± 5.49	161.33 ± 6.16	0.69
Weight (kg)	80.10 ± 12.2	78.74 ± 11.19	80.76 ± 12.61	0.48
BMI (kg/m²)	30.60 ± 4.7	29.96 ± 4.09	30.91 ± 5.00	0.26

Table 2. Daily nutrient intake of participants by HbA1c control status.

Nutrient	HbA1c		p-value*
	Controlled < 8.0 (N = 66) Mean ± SD	Uncontrolled ≥ 8.0 (N = 130) Mean ± SD	
Energy (kcal)	1720.6 ± 486.51	1635.6 ± 439.08	0.25
CHO (g)	251.51 ± 92.33	229.91 ± 74.11	0.11
Protein (g)	100.24 ± 35.138	98.13 ± 30.84	0.67
Fat (g)	37.99 ± 29.57	36.21 ± 18.57	0.66
Saturated (g)	11.29 ± 6.54	11.2 ± 9.33	0.94
Polyunsaturated (g)	5.67 ± 3.28	5.33 ± 3.28	0.5
Monounsaturated (g)	9.39 ± 5.18	8.42 ± 5.29	0.23
Cholesterol (mg)	341.72 ± 207.96	269.28 ± 210.97	**0.03**
Sodium (mg)	1479.05 ± 955.76	1963.59 ± 2516.6	**0.05**
Potassium (mg)	2157.37 ± 719.45	1932.68 ± 608.45	**0.03**
Fiber (g)	29.99 ± 31.95	40.04 ± 182.85	0.54
Sugar (g)	61.86 ± 31.56	59.79 ± 30.22	0.67
Vitamin A (IU)	8379.87 ± 10480.63	7771.7 ± 9608.56	0.7
Vitamin C (mg)	56.27 ± 82.73	35.06 ± 37.25	**0.05**
Calcium (mg)	573.74 ± 328.22	604.12 ± 395.54	0.58
Iron (mg)	11.81 ± 6.73	10.72 ± 9.15	0.35
Vitamin D (IU)	15.65 ± 33.98	18.85 ± 38.78	0.56
Vitamin E (mg)	2.3 ± 1.74	2.3 ± 1.782	0.99
Thiamin (mg)	1.48 ± 1.25	2.05 ± 6.38	0.33
Riboflavin (mg)	2.68 ± 1.94	2.45 ± 1.71	0.43
Niacin (mg)	29.76 ± 21.99	29.39 ± 20.84	0.91
B6 (mg)	2.44 ± 2.03	2.44 ± 1.891	0.1
Folate (mcg)	341.58 ± 254.11	316.05 ± 215.73	0.94
B12 (mcg)	19.7 ± 29.34	17.21 ± 29.75	0.58
Pantothenic (mg)	5.59 ± 2.99	4.71 ± 2.76	**0.05**
Phosphorus (mg)	1168.91 ± 501.4	1069.25 ± 440.98	0.18
Magnesium (mg)	329.68 ± 223.48	326.2 ± 219.51	0.91
Zinc (mg)	10.27 ± 4.628	9.16 ± 4.14	0.1
Selenium (mcg)	107.45 ± 61.29	88.06 ± 56.88	**0.03**
Copper (mg)	3.31 ± 3.85	2.99 ± 3.65	0.6
Manganese (mg)	3.14 ± 1.56	2.72 ± 1.42	0.07
Water (ml)	1147.99 ± 367.98	1086.63 ± 348.07	0.27

*Values are presented as mean ± SD.
*Statistically significant p-values (≤ 0.05) are shown in bold.

in the controlled group ($p \leq 0.05$). Potassium intake was also significantly lower in the uncontrolled group (1932.68 ± 608.45 mg) than in the controlled group (2157.37 ± 719.45 mg, $p \leq 0.05$). Similarly, vitamin C intake showed a tendency to be lower in the uncontrolled group (35.06 ± 37.25 mg) compared to the controlled group (56.27 ± 82.73 mg, $p \leq 0.05$). For pantothenic acid, the uncontrolled group consumed 4.71 ± 2.76 mg, while the controlled group consumed 5.59 ± 2.99 mg ($p \leq 0.05$). Lastly, selenium intake was significantly lower in the uncontrolled group (88.06 ± 56.88 mcg) compared to the controlled group (107.45 ± 61.29 mcg, $p \leq 0.05$). No statistically significant differences were observed for other nutrients assessed in this analysis.

Association of dietary nutrient intake with HbA1c levels

Logistic regression analysis was conducted to investigate the relationship between the intake of individual dietary nutrients and the odds of elevated HbA1c levels, with comprehensive adjustment for age and sex (Table 3).

The analysis revealed several statistically significant associations. A higher intake of vitamin C was inversely associated with the odds of elevated HbA1c. Specifically, each 1 mg increment in vitamin C intake corresponded to an odds ratio (OR) of 0.985 (95% CI: 0.97–0.99, $p \leq 0.05$), indicating a slight reduction in the odds of elevated HbA1c. Similarly, increased selenium intake demonstrated an inverse association, with every 1 mcg increase in selenium correlating to an OR of 0.973 (95% CI: 0.95–1.00, $p \leq 0.05$).

Table 3. Logistic regression analysis of dietary intakes and HbA1c levels, adjusted for age and sex.

Intakes	Odd Ratio	(95% CI)	p-value*
Energy (kcal)	1.004	0.99–1.01	0.52
CHO (g)	0.974	0.93–1.02	0.24
Protein (g)	1.039	0.96–1.12	0.34
Fat (g)	0.959	0.86–1.07	0.44
Saturated (g)	0.996	0.89–1.12	0.94
Polyunsaturated (g)	1.023	0.59–1.76	0.93
Monounsaturated (g)	1.049	0.87–1.26	0.61
Cholesterol	0.996	0.99–1.00	0.12
Sodium (mg)	1	1.00–1.00	0.34
Potassium (mg)	0.999	0.99–1.00	0.58
Fiber (g)	1	0.99–1.00	0.96
Sugar (g)	0.996	0.97–1.02	0.75
Vitamin A (IU)	1	1.00–1.00	0.73
Vitamin C (mg)	0.985	0.97–0.99	**0.02**
Calcium (mg)	1.002	0.99–1.00	0.17
Iron (mg)	0.954	0.74–1.22	0.71
Vitamin D (IU)	1.017	1.00–1.03	**0.04**
Vitamin E (mg)	0.914	0.49–1.72	0.78
Thiamine (mg)	2.417	1.21–487.88	**0.03**
Riboflavin (mg)	0.266	0.03–2.52	0.25
Niacin (mg)	0.905	0.73–1.12	0.37
B6 (mg)	1.602	0.19–13.26	0.66
Folate (mcg)	1	0.99–1.01	0.97
B12 (mcg)	1.027	0.83–1.27	0.81
Pantothenic (mg)	2.16	1.04–4.47	**0.03**
Phosphorus (mg)	0.997	0.99–1.00	0.15
Magnesium (mg)	0.989	0.98–1.00	0.07
Zinc (mg)	1.111	0.79–1.57	0.55
Selenium (mcg)	0.973	0.95–1.00	**0.05**
Copper (mcg)	1.234	0.23–6.51	0.8
Manganese (mcg)	1.511	0.67–3.41	0.32

*Statistically significant p-values (≤ 0.05) are shown in bold.

Conversely, certain nutrient intakes were positively associated with the odds of elevated HbA1c. Higher intake of vitamin D was associated with increased odds of elevated HbA1c (OR = 1.017, 95% CI: 1.00–1.03, $p \leq 0.05$). Likewise, elevated intake of pantothenic acid was significantly associated with substantially increased odds of elevated HbA1c (OR = 2.160, 95% CI: 1.04–4.47, $p \leq 0.05$). The strongest positive association was observed for thiamine, where increased intake was linked to considerably higher odds of elevated HbA1c (OR = 2.417, 95% CI: 1.21–487.88, $p \leq 0.05$). No statistically significant associations were observed for macronutrients or other micronutrients included in this analysis.

Discussion

This cross-sectional study investigated the association between dietary nutrient intake and glycemic control among patients with T2DM in Saudi Arabia. The study population displayed specific demographic and anthropometric characteristics. A notable majority of participants were married, and a substantial portion had limited educational attainment. Crucially, no significant differences were observed between the controlled and uncontrolled HbA1c groups regarding demographics (sex, age, marital status, education) or anthropometrics (height, weight, BMI). This indicates that, within this specific study population, these measured characteristics were not primary determinants differentiating HbA1c control.

The differentiation of controlled and uncontrolled groups based on an 8% HbA1c threshold was a deliberate choice, grounded in both clinical guidelines and the established understanding of diabetes progression. While the American Diabetes Association (ADA) generally advocates for an HbA1c target below 7% for most non-pregnant adults to minimize microvascular complications (American Diabetes Association, 2024), an HbA1c of 8% or greater consistently indicates suboptimal glycemic control. This sustained elevation in blood glucose, corresponding to an approximate average blood glucose of 183 mg/dL (10.1 mmol/L), is strongly associated with an accelerated risk of both microvascular and macrovascular complications, including retinopathy, nephropathy, neuropathy, and cardiovascular disease (Stolar *et al.*, 2010; Tan *et al.*, 2023). Although some guidelines, such as those from the American College of Physicians (ACP), suggest that a less stringent target of 7–8% may be appropriate for certain patient populations (e.g., older adults or those with multiple comorbidities) to prevent hypoglycemia, the 8% cut-off in this study served as a clear and robust

discriminator. It effectively separated individuals with a reasonable level of glycemic management from those exhibiting clinically concerning and persistently elevated glucose levels, thereby allowing for a distinct comparison of outcomes related to sustained poor glycemic control (Tan *et al*, 2023; Qaseem *et al.*, 2018; O'Keeffe & Maraka, 2018).

Building upon this demographic context, the findings revealed statistically significant differences in the intake of specific nutrients between patients with controlled and uncontrolled HbA1c. Patients with uncontrolled HbA1c exhibited a significantly higher intake of Sodium compared to the controlled group. Conversely, the uncontrolled group demonstrated significantly lower intakes of several other nutrients, including Potassium, Vitamin C, and Selenium. While various other nutrient intake trends were observed, these differences did not reach statistical significance in this analysis. These identified disparities in nutrient intake between the groups suggest a potential role for these specific dietary components in glycemic regulation.

Previous research conducted in Saudi Arabia and Qatar has suggested an association between lower magnesium intake and uncontrolled diabetes (Soliman *et al.*, 2023; Farid, 2013). This is further supported by a meta-analysis demonstrating an inverse relationship between magnesium intake and diabetes risk (Dong *et al.*, 2011). While our study did not find a statistically significant difference in magnesium intake between the two groups, the established role of magnesium in glucose metabolism—through its influence on insulin action and glucose transport—is well documented (Kostov, 2019). Although magnesium's specific contribution in this population was not statistically highlighted, its importance in overall diabetes management remains established (Valk *et al*, 1999; López-Ridaura, Ruy *et al*, 2004).

While macronutrient intake did not significantly differ between the groups, notable differences were observed in the consumption of specific minerals. These findings are consistent with existing literature that highlights the importance of these nutrients in diabetes management and glycemic control (McClure *et al.*, 2020; Kim *et al.*, 2021).

The association between high sodium intake and poor glycemic control aligns with findings from other studies (Kheriji *et al.*, 2022; Ming *et al.*, 2023). Kheriji *et al.* (2022) also emphasized the role of processed foods in contributing to high sodium intake, which was linked to increased diabetes risk and poorer HbA1c control. A large-scale cross-sectional study in the United States demonstrated a significant positive correlation between high sodium intake and increased diabetes prevalence among non-hypertensive adults (Ming *et al.*, 2023), reporting a 1.20-fold increase in diabetes risk for every 1 g increase in sodium intake. These findings corroborate our observation of higher sodium intake in individuals with poorly controlled diabetes. However, it is important to note that some studies have reported contrasting results; for example, Suckling *et al.* (2016) found no significant effect of sodium reduction on fasting blood glucose, HbA1c, or insulin sensitivity in patients with diabetes or impaired glucose tolerance.

The observed higher potassium intake in the controlled group suggests potential benefits of potassium-rich foods, such as fruits and vegetables, in managing blood glucose. Potassium plays a crucial role in regulating blood pressure and glucose metabolism, and its deficiency may impair glycemic control. Although some studies have not found a direct link between potassium intake and cardiovascular disease (CVD) risk across all subgroups of T2DM patients (Horikawa *et al.*, 2023), higher potassium intake was associated with a significantly lower risk of CVD specifically among participants with high sodium intake. This highlights the interplay between these two minerals in managing cardiovascular risk in diabetic individuals (Horikawa *et al.*, 2023).

The lower selenium intake observed in the uncontrolled group aligns with previous studies suggesting a protective role of selenium against atherosclerosis and other diabetes-related complications (Liu, 2017). Selenium, an essential trace element with antioxidant properties, may improve insulin sensitivity and reduce oxidative stress (Karalis, 2019). However, conflicting evidence exists—for example, Wei *et al.* (2015) reported a positive association between dietary selenium intake and diabetes prevalence in middle-aged and elderly Chinese adults. These mixed findings underscore the need for further research to elucidate the complex relationship between selenium and diabetes across diverse populations.

Although not statistically significant, a trend toward lower manganese levels was observed in the uncontrolled group. Previous research has indicated an inverse relationship between manganese intake and the risk of T2DM, particularly among women, potentially mediated by improved insulin sensitivity and metabolic regulation (Eshak, 2021). Furthermore, Huang *et al.* (2024) identified an inverse association between dietary manganese intake and the risk of new-onset chronic kidney disease (CKD) in individuals with poor glycemic control, with obesity and waist circumference mediating approximately 35% of this effect. While our findings did not reach statistical significance for glycemic control specifically, they are consistent with these studies and suggest a possible role for manganese in metabolic health and diabetes-related complications.

The intake of Pantothenic Acid revealed particularly complex findings. While initial group comparisons showed that patients with uncontrolled HbA1c had a lower mean intake of this nutrient, adjusted logistic regression analysis paradoxically indicated that higher pantothenic acid intake was associated with increased odds of elevated HbA1c. Supporting these regression results, a case-control study reported significantly higher serum pantothenic acid levels in T2DM patients with elevated BMI, a condition potentially linked to insulin resistance (Gogna *et al.*, 2015). This discrepancy between the mean group differences and the adjusted associations from logistic regression underscores the intricate and multifaceted nature of nutrient-disease relationships, highlighting the need for further research—preferably longitudinal or interventional studies—to elucidate the precise role of pantothenic acid in glycemic control.

The higher vitamin C intake observed in the controlled group reinforces the important role of antioxidants in diabetes management. Vitamin C's antioxidant properties may help reduce oxidative stress, enhance glucose metabolism, and consequently lower HbA1c levels (Luo *et al.*, 2022). Supporting this, a meta-analysis by Nosratabadi *et al.* (2023) demonstrated that vitamin C supplementation significantly reduced HbA1c, fasting insulin, and fasting blood glucose levels in T2DM patients, with the most pronounced effects observed in long-term supplementation (≥12 weeks) and at higher doses (≥1000 mg/day).

In conclusion, this study identifies distinct nutrient intake patterns among Saudi T2DM patients with differing glycemic control, notably in sodium, potassium, vitamin C, and selenium consumption. These findings add to the growing evidence supporting the role of specific dietary components in diabetes management. Future research should focus on larger, longitudinal studies and interventional trials to clarify causal relationships and develop population-specific dietary guidelines aimed at optimizing glycemic outcomes.

Limitation to this study

This cross-sectional study limits the ability to infer causality between HbA1c levels and nutrient intake in patients with T2DM. Although Pearson correlation analysis showed weak associations between sodium and vitamin C intake and the primary outcomes, the observed heterogeneity in these nutrients between groups, despite low correlations, may introduce residual confounding.

In conclusion, this study highlights the crucial role of micronutrients in managing HbA1c levels and emphasizes the need for further research to uncover the specific biological mechanisms involved. A deeper understanding of the most effective micronutrients can provide valuable insights to help healthcare professionals guide patients toward better dietary choices. Encouraging the inclusion of these nutrients from natural food sources may contribute to improved blood glucose regulation and overall well-being.

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Authors Contribution

Dr. Alarifi was responsible for designing and writing the study protocol. Additionally, she conducted the study, contributed to and reviewed the draft of the manuscript. Dr. Alussain was responsible for interpreting the results, designing tables and figures, and drafting the manuscript. Dr. Abd EL-Rahman was responsible for extracted and analysed the data, contributed to the draft of the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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