Research Article (Araştırma Makalesi)

Seasonal Variability in Metabolic Profiles Among Individuals with Type 2 Diabetes: A One-Year Retrospective Analysis

Tip 2 Diyabetli Hastalarda Mevsimsel Metabolik Profil Değişkenliği: Bir Yıllık Retrospektif Analiz

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Özet

Amaç: Bu çalışma, Tip 2 diyabetli (T2D) bireylerde HbA1c düzeylerinin mevsimsel değişimini ve bu varyasyonun lipid profili ile ilişkisini tanımlamayı amaçlamaktadır.

Gereç ve Yöntemler: Bu retrospektif kesitsel çalışmaya, 2024 yılı boyunca bir şehir hastanesinin iç hastalıkları polikliniğine başvuran 823 T2D tanılı birey dahil edilmiştir. Mevsimsel farklılıklar; normal dağılım göstermeyen değişkenler için Kruskal–Wallis testi, normal dağılım gösteren değişkenler için ise tek yönlü ANOVA ile değerlendirilmiştir. Mevsimsel etkinin trigliserid ve HDL-kolesterol gibi metabolik kovaryatlardan bağımsızlığını test etmek amacıyla çok değişkenli ANCOVA modelleri kullanılmıştır.

Bulgular: HbA1c düzeyleri mevsimler arasında anlamlı şekilde farklılık göstermiştir (Kruskal-Wallis $p<0.05$). Düzeltilmiş ortalama HbA1c değerleri kış mevsiminde en yüksek (%8.75), yaz mevsiminde ise en düşük düzeyde bulunmuştur (%8.20); yaz–kış karşılaştırması anlamlıdır ($p = 0.035$). Çok değişkenli ANCOVA analizinde trigliserid düzeyleri HbA1c ile pozitif yönde ($\beta = 0.002$; %95 GA: 0.001–0.003, $p < 0.001$), HDL-kolesterol ise negatif yönde ilişkili bulunmuştur ($\beta = -0.019$, %95 GA: -0.031 ile -0.007, $p = 0.002$). Lipid parametrelerine göre düzeltme yapıldığında dahi mevsimsel etkinin bağımsız olarak anlamlılığını koruduğu görülmüştür (genel mevsim etkisi: $p = 0.021$).

Sonuç: T2D tanılı bireylerde HbA1c düzeyleri belirgin mevsimsel değişim göstermekte; yaz aylarında iyileşmekte, kış aylarında ise belirgin bir bozulma izlenmektedir. HbA1c ile trigliserid ve HDL-kolesterol arasındaki bağımsız ilişkiler, mevsimsel glisemik dalgalanmaların metabolik belirteçlerle etkileşim içinde geliştiğini düşündürmektedir. Bu bulgular, diyabet yönetiminde mevsimsel dinamiklerin sistematik olarak dikkate alınmasının klinik açıdan önemli olabileceğini göstermektedir.

Anahtar Kelimeler: Tip 2 diyabet, HbA1c, mevsimsel varyasyon, lipid metabolizması, trigliserid, HDL-kolesterol

Abstract

Objective: This study aimed to evaluate the seasonal variation in HbA1c levels among individuals with type 2 diabetes (T2D) and to examine the relationship between these fluctuations and lipid parameters.

Materials and Methods: In this retrospective cross-sectional study, 823 adults with T2D who presented to an internal medicine outpatient clinic during 2024 were included. Between-season comparisons were performed using the Kruskal–Wallis test for non-normally distributed variables and one-way ANOVA for normally distributed variables. To determine whether the seasonal effect on HbA1c was independent of metabolic parameters, multivariable ANCOVA models were constructed.

Results: HbA1c levels varied significantly across seasons (Kruskal–Wallis $p < 0.05$). The highest adjusted mean HbA1c occurred in winter (8.75%), whereas the lowest values were observed in summer (8.20%); the summer–winter contrast remained significant ($p = 0.035$). In the multivariable ANCOVA model, triglycerides were positively associated with HbA1c ($\beta = 0.002$; 95% CI: 0.001–0.003; $p < 0.001$), whereas HDL cholesterol showed an inverse association ($\beta = –0.019$; 95% CI: –0.031 to –0.007; $p = 0.002$). Notably, seasonal differences remained independently significant after adjusting for lipid parameters (overall seasonal effect $p = 0.021$).

Conclusion: HbA1c levels showed a distinct seasonal pattern, improving during summer and worsening during winter in individuals with T2D. Independent associations of HbA1c with triglycerides and HDL cholesterol suggest that seasonal glycemic variation occurs in interplay with underlying metabolic features. These findings underscore the clinical relevance of incorporating seasonal factors into diabetes management strategies.

Keywords: Type 2 diabetes, HbA1c, seasonal variation, lipid metabolism, triglycerides, HDL-cholesterol

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INTRODUCTION

Type 2 diabetes (T2D) is a complex and multifactorial metabolic disorder with a rapidly increasing global prevalence (1). Optimizing glycemic control remains central to preventing microvascular and macrovascular complications associated with chronic hyperglycemia, and glycated hemoglobin (HbA1c) is widely regarded as the most reliable indicator of long-term glycemic status in clinical practice (2,3).

Beyond pharmacological, behavioral, and lifestyle determinants of glycemic control, increasing attention has been directed toward the role of environmental influences, particularly seasonal fluctuations, in shaping HbA1c levels. Studies conducted in temperate climates consistently demonstrate a recurrent pattern in which HbA1c peaks during winter and early spring, followed by a decline through summer and early autumn (4,5). Proposed mechanisms include reduced physical activity, seasonal shifts in dietary behavior, and physiologic responses to colder ambient temperatures (6).

However, seasonal glycemic variation is not uniform across geographical settings. Investigations from semi-arid regions have reported peak HbA1c values in spring or summer (7), whereas highly urbanized or tropical regions exhibit minimal seasonal amplitude (8). Such heterogeneity suggests that seasonal variation in HbA1c reflects a multifaceted interplay of climate, photoperiod, physical activity, dietary behavior, and cultural practices rather than a single explanatory mechanism.

Turkey's marked geographical heterogeneity provides a distinctive natural setting in which to examine these interactions. Kahramanmaraş, located at the convergence of the hot, dry Mediterranean climate and the cooler, more humid continental climate, constitutes a well-defined ecological transition zone and therefore an inherently suitable environment for investigating seasonal glycemic variation (9). Despite this, systematic assessments of HbA1c seasonality in such transitional climatic regions are scarce, and to our knowledge, no study has previously characterized HbA1c seasonality specifically within the Kahramanmaraş region.

MATERIALS AND METHODS

Study Design and Participant Selection

This retrospective cross-sectional study investigated seasonal variation in metabolic parameters among adults with type 2 diabetes mellitus (T2DM) who presented to the Internal Medicine outpatient clinic of Kahramanmaraş Necip Fazıl City Hospital between 1 January and 31 December 2024. Eligible participants were 18 years or older, carried a confirmed diagnosis of T2DM, and had a complete laboratory panel including HbA1c, LDL-cholesterol, HDL-cholesterol, triglycerides, creatinine, and alanine aminotransferase (ALT). When individuals had more than one visit during the study period, only the first record containing a complete laboratory dataset was retained to prevent duplication and misclassification. Exclusion criteria included age under 18 years, type 1 or gestational diabetes, documented pregnancy, incomplete or erroneous laboratory results, and any record showing duplication or internal inconsistency.

Data Acquisition and Laboratory Measurements

Demographic and biochemical data were retrieved retrospectively from the hospital information management system. Variables included age, sex, HbA1c, LDL-cholesterol, HDL-cholesterol, triglycerides, creatinine, and ALT. All laboratory measurements were performed in the hospital's central laboratory using standardized, accredited protocols to ensure analytical precision and methodological consistency across the study period.

Seasonal Classification and Data Processing

Presentation dates were categorized into four meteorologically defined seasons: winter (December–February), spring (March–May), summer (June–August), and autumn (September–November). To ensure data integrity, all duplicate, incomplete, or internally inconsistent records were removed. After this curation process, a total of 823 unique individuals remained for the analysis. Seasonal distribution across the seasons was balanced, comprising 231 participants in winter, 197 in spring, 196 in summer, and 199 in autumn.

The study adhered to the Declaration of Helsinki and Good Clinical Practice guidelines. This study was approved by the Ethics Committee of Sütçü İmam University (Protocol No. 2025/35, Date: 08.12.2025). All data were anonymized before analysis.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 28.0 and R software (version 4.3.2; R Foundation for Statistical Computing, Vienna, Austria). The distribution of continuous variables was evaluated using the Shapiro–Wilk test and supported by graphical assessment (histograms and Q–Q plots). Normally distributed variables are presented as mean ± standard deviation (SD), whereas non-normally distributed variables are reported as median and interquartile

range (IQR). Categorical variables are summarized as counts and percentages. Between-season differences were examined using one-way ANOVA for normally distributed variables or the Kruskal–Wallis test for non-parametric data. When global significance was detected, post-hoc pairwise comparisons were performed with Bonferroni correction to control for type I error. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate.

To evaluate the independent effect of season on HbA1c, an analysis of covariance (ANCOVA) model was constructed with season as the main factor. Model assumptions—including linearity, normality of residuals, and homogeneity of variances—were assessed and met; Levene's test indicated homoscedasticity ($p = 0.529$). Residual diagnostics confirmed adequate model fit. Candidate covariates (LDL-cholesterol, HDL-cholesterol, triglycerides, creatinine, and ALT) were considered for inclusion if they met a univariate screening threshold of $p < 0.20$. The final adjusted model incorporated triglycerides, HDL-cholesterol, and age (borderline significant in univariate analyses). Multicollinearity was assessed using variance inflation factors, with no concerning levels detected (VIF < 5). Effect sizes were quantified using partial eta-squared (partial η^2). All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant.

RESULTS

Participant Characteristics

A total of 823 individuals were included in this retrospective cross-sectional study. The median age of the study population was 57 years (interquartile range [IQR]: 46–64), with a female predominance (62.8%, n = 517). Median (IQR) values for key metabolic parameters were as follows: HbA1c 8.1% (6.9–9.5), triglycerides 171 mg/dL (117–248), LDL cholesterol 127 mg/dL (104–155), HDL cholesterol 48 mg/dL (40–56), ALT 20 U/L (15–29), and creatinine 0.84 mg/dL (0.72–0.99).

Seasonal Variation in HbA1c

Table 1 presents the comparison of clinical and laboratory variables across seasons. Core demographic characteristics, including age and sex, as well as LDL cholesterol, HDL cholesterol, triglycerides, creatinine, and ALT levels, did not differ significantly between seasons (all $p > 0.05$). In contrast, HbA1c exhibited a clear seasonal variation ($p < 0.05$). As shown in **Figure 1**, HbA1c values were highest during winter, declined throughout spring, and reached their lowest levels in summer.

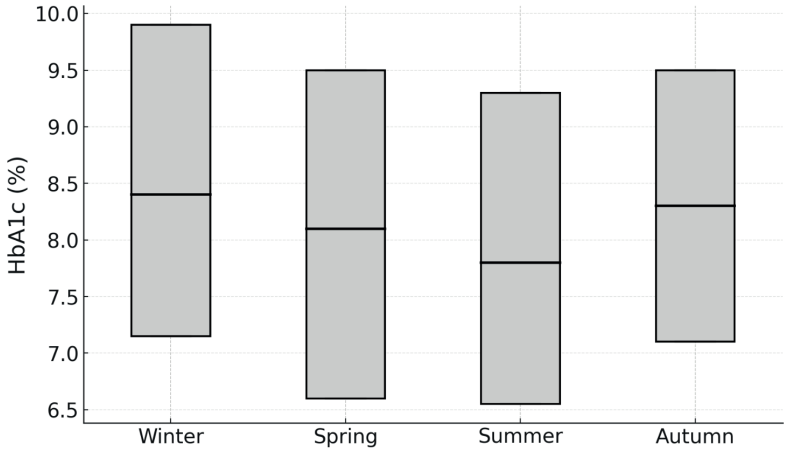
In Bonferroni-corrected pairwise analyses, HbA1c levels during summer were significantly lower than in

Table 1. Comparison of Clinical and Laboratory Characteristics Across Seasons.

Variable	Winter n= 231	Spring n= 197	Summer n= 196	Autumn n=199	P-Value
Demographic Factors					
Age (year)	57 (46-64)	57 (48-65)	57 (47-65)	56 (46-63)	0.574
Sex(Male)	85 (36.8%)	75 (38.1%)	79 (40.3%)	67 (33.7%)	0.582
Metabolic Parameters					
HbA1c (%)	8.4 (7.1-9.9)[a]	8.1 (6.6-9.5)	7.8 (6.5-9.3)[a]	8.3 (7.1-9.5)	**0.003**
LDL-cholesterol	127 (104-158)	130 (105-152)	122 (98-147)	128 (109-158)	0.136
HDL-cholesterol	47 (39-57)	49 (41-57)	47 (41-54)	49 (40-57)	0.340
Triglycerides	189 (134-261)	171 (113-251)	160 (116-216)	169 (111-256)	0.065
Creatinine	0.81 (0.70-0.97)	0.86 (0.73-1.0)	0.86 (0.72-1.03)	0.84 (0.71-0.98)	0.762
ALT	21 (15-29)	20 (15-28)	20 (15-27)	22(17-29)	0.088

Continuous variables are presented as median (interquartile range), and categorical variables as n (%). Between-season differences were tested using the Kruskal–Wallis test for continuous variables and the χ^2 test for categorical variables. Statistical significance was defined as $p < 0.05$. Post-hoc pairwise season comparisons were performed using Bonferroni correction. Seasons sharing the superscript "a" differ significantly from each other. Abbreviations: AGE, age (years); SEX, male count (%); HbA1c, glycated hemoglobin (%); LDL-cholesterol, low-density lipoprotein cholesterol; HDL-cholesterol, high-density lipoprotein cholesterol; Triglycerides; Creatinine; ALT, alanine aminotransferase.

Figure 1. Seasonal Variation in Median HbA1c Levels Across Winter, Spring, Summer, and Autmn



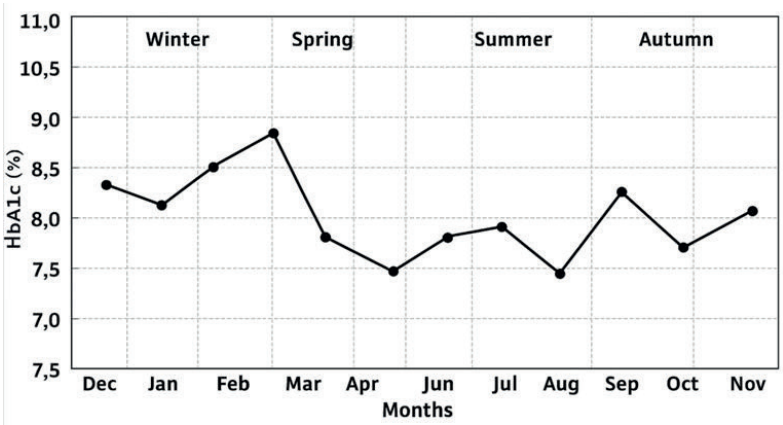
Median HbA1c values for each season are plotted. Whiskers represent the interquartile range (25th–75th percentiles).

winter (summer vs. winter: p = 0.006), with the summer–autumn contrast trending toward significance (p = 0.060). Although spring showed lower HbA1c values relative to winter and autumn, these differences were not statistically significant (spring vs. winter: p = 0.065; spring vs. autumn: p = 0.381), and no difference was observed between autumn and winter (p = 1.000). Consistent with these findings, **Figure 2** depicts the month-to-month trajectory of HbA1c across the calendar year, demonstrating a rise toward late winter and early spring, a pronounced decline across summer months, and a renewed increase during autumn. Because formal statistical testing at the monthly level would have substantially inflated the multiple-comparison burden, inferential analyses were restricted to predefined seasonal categories; **Figure 2** is therefore provided to illustrate the finer-grained temporal dynamics that complement the primary seasonal findings.

Univariate ANCOVA Results

Univariate ANCOVA models adjusted for seasonal variation were applied to evaluate the season-independent associations of each demographic and metabolic variable with HbA1c. This approach allowed the direction, magnitude, and clinical relevance of each factor to be examined in isolation. Age was not significantly associated with HbA1c (β = –0.010, 95% CI: –0.020 to 0.001, p = 0.061), and sex showed no independent effect (β = –0.224, p = 0.469). Creatinine, ALT, and LDL-cholesterol were likewise unrelated to HbA1c. In contrast, HDL-cholesterol demonstrated a significant inverse association (β = –0.023, 95% CI: –0.035 to –0.012, p < 0.001), whereas triglycerides were positively and significantly associated with HbA1c (β = 0.003, 95% CI: 0.001–0.004, p < 0.001). Partial eta-squared values indicated that triglycerides (η^2 = 0.026)

Figure 2. Monthly Pattern of Glycemic Control: HbA1c Across 12 Months



Data represent the monthly mean HbA1c levels observed throughout the study period.

and HDL-cholesterol (η^2 = 0.019) contributed more to the explained variance in HbA1c than the other covariates. Results are summarized in **Table 2**.

Multivariable ANCOVA Model

Covariate selection for the multivariable ANCOVA model was based on season-adjusted univariate analyses, applying a conventional epidemiologic threshold of $p < 0.20$ to identify candidate variables. Accordingly, triglycerides, HDL-cholesterol, and age were entered into the multivariable model. The final analysis demonstrated that only a limited subset of metabolic markers exerted independent effects on HbA1c levels. Age was not significantly associated with HbA1c (β = –0.006, 95% CI: –0.017 to 0.004; p = 0.229). In contrast, triglycerides showed a positive and independent association with HbA1c (β = 0.002, 95% CI: 0.001 to 0.003; $p < 0.001$), whereas HDL-cholesterol exhibited a significant inverse association (β = –0.019, 95% CI: –0.031 to –0.007; p = 0.002). Partial eta-squared values confirmed that these two variables contributed most prominently to the explained variance (η^2 = 0.016 for triglycerides; η^2 = 0.012 for HDL-cholesterol).

Seasonal categories also retained an independent effect on HbA1c within the model (overall season effect: p = 0.021). Season-adjusted mean HbA1c levels were lowest in summer (8.20 ± 0.15) and highest in winter (8.75 ± 0.13). In Bonferroni-corrected pairwise comparisons, only the summer–winter contrast remained statistically significant (difference = 0.55, 95% CI: 0.02 to 1.07; p = 0.035), whereas no significant differences were observed among the remaining seasonal pairs. Although the model's explanatory power was modest (R^2 = 0.053; adjusted R^2 = 0.046), the findings indicate that both seasonal variation and selected metabolic covariates independently contribute to HbA1c levels **(Table 3)**.

DISCUSSION

This retrospective cross-sectional analysis demonstrates that HbA1c levels in individuals with type 2 diabetes exhibit a clear seasonal oscillation, reaching their lowest values in summer and peaking during winter, thereby indicating a systematic deterioration of glycemic control in colder months. This pattern aligns closely with the classical winter-peak/summer-nadir trajectory described in temperate-climate populations (4,5). To our knowledge, this is the first study to systematically evaluate HbA1c seasonality within the Kahramanmaraş region, a distinct Mediterranean–continental transition zone. Importantly, the seasonal effect remained statistically significant even after adjustment for triglycerides and HDL-cholesterol in multivariable models, suggesting that the observed oscillation reflects a robust and metabolically independent phenomenon rather than merely a surrogate of lipid profile fluctuations.

The seasonal fluctuation in glycemic control observed in our study aligns closely with the consistent patterns reported in the international literature. A large-scale, decade-long analysis from Japan demonstrated a clear sinusoidal rhythm, with HbA1c peaking in late winter to early spring (March) and reaching its nadir in late summer (August) (4). Similarly, extensive cohort data from South Korea confirmed this trajectory,

Table 2. Season-Adjusted Univariate Associations of Demographic and Metabolic Covariates With HbA1c Levels (ANCOVA Framework)

Variable	β (95% CI)	p-value	Partial η^2
Demographic Factors			
Age (per year)	–0.010 (–0.020 to 0.001)	0.061	0.004
Sex (Female vs Male)	–0.224 (–0.832 to 0.383)	0.469	0.001
Metabolic Parameters			
ALT (U/L)	0.001 (–0.008 to 0.010)	0.773	0.000
Creatinine (mg/dL)	–0.052 (–0.175 to 0.070)	0.403	0.001
LDL-cholesterol (mg/dL)	0.001 (–0.003 to 0.005)	0.630	0.000
HDL-cholesterol (mg/dL)	–0.023 (–0.035 to –0.012)	<0.001	0.019
Triglycerides (mg/dL)	0.003 (0.001 to 0.004)	<0.001	0.026

β coefficients represent the change in HbA1c (in %) per one-unit increase in each covariate, based on season-adjusted univariate ANCOVA models. Each model includes the covariate of interest and season as fixed factors. Partial η^2 denotes the proportion of variance in HbA1c explained by each factor. Bold values indicate statistical significance ($p < 0.05$).

Table 3. Multivariable ANCOVA Model Evaluating Independent Predictors of HbA1c Levels Across Seasons

Parameter	β (95% CI) or Adjusted Mean HbA1c (SE)	p-value	Partial η^2
Demographic Factors			
Age (per year)	-0.006 (-0.017 to 0.004)	0.229	0.002
Metabolic Parameters			
Triglycerides (mg/dL)	**0.002 (0.001 to 0.003)**	**<0.001**	0.016
HDL-cholesterol (mg/dL)	-0.019 (-0.031 to -0.007)	**0.002**	0.012
Seasonal Variation			
Season (Overall)	—	**0.021**	0.012
Winter	8.75 (0.13)	0.552	0.001
Spring	8.33 (0.15)	0.148	0.003
Summer	**8.20 (0.15)**	**0.037**	0.005
Autumn (Reference)	8.63 (0.14)	—	—
Post-hoc Comparisons (Bonferroni)			
Winter vs Summer	**0.55 (0.02 to 1.07)**	**0.035**	0.005*
Model Fit	R^2 = 0.053, Adjusted R^2 = 0.046	<0.001	0.053

Data are from a multivariable ANCOVA model. β coefficients with 95% confidence intervals are presented for continuous variables. Adjusted means with standard errors (SE) are shown for seasonal categories. Partial η^2 indicates effect size. Post-hoc pairwise comparisons were Bonferroni-adjusted. Bold values represent statistical significance ($p < 0.05$).

showing the highest HbA1c values in February–March and the lowest in September–October (5). Recent data from South Africa further underscore the robustness of this phenomenon, revealing that the same directional seasonality persists across distinct climate types; HbA1c increased markedly during colder months in both the cooler inland region (Pretoria) and the milder coastal climate (Durban) (10). This convergence across geographically and climatically diverse populations suggests that seasonal HbA1c variation is unlikely to be driven solely by local lifestyle factors and may instead reflect broader biobehavioral mechanisms shaped by climate-linked and behavioral rhythms. Moreover, a recent high–temporal density study leveraging continuous glucose monitoring (CGM) demonstrated that this seasonal oscillation is reproduced not only in long-term glycemic averages but also in within-day glucose dynamics (11). Collectively, these findings indicate that seasonal glycemic variation represents not a passive reflection of mean glycemia, but a recurrent and physiologically grounded metabolic rhythm.

However, the literature also reveals marked geographical heterogeneity in the direction and magnitude of seasonal HbA1c variation. A large analysis from Türkiye reported a reversal of the classical winter-peak pattern, noting higher HbA1c levels during summer; this atypical trajectory was attributed to the overlapping of the Ramadan fasting period with the summer months in the study years, leading to substantial shifts in dietary intake and activity rhythms (12). Similarly, the multicountry analysis by Higgins and colleagues demonstrated that in highly urbanized settings such as Singapore, Canada, and the United Kingdom—where indoor climate control is widespread—the seasonal amplitude of HbA1c was minimal (8). Additional discordant patterns have been described in semi-arid regions of Israel, where HbA1c peaks occurred in spring or summer, and in northern India, where peak values emerged during the monsoon season, both deviating from our observed winter-peak profile (7,13). Even in settings where seasonality was statistically detectable, such as a pediatric cohort from the United Kingdom, the amplitude was extremely small (0.3% or 3.3 mmol/mol), suggesting that the effect may be nearly attenuated in certain populations (14). In this context, although a 0.55% seasonal difference in HbA1c reached statistical significance, its clinical impact may be modest and should be interpreted cautiously. Collectively, these disparate findings underscore that seasonal variation in HbA1c cannot be attributed to a single biological driver; instead, it likely reflects a multifactorial process shaped by the interaction of photoperiod, physical activity, dietary patterns, and culturally embedded behavioral practices.

nother notable finding of our study is the independent association of HbA1c with triglyceride and HDL-cholesterol levels, irrespective of seasonal effects.

This observation suggests that glycemic variation is shaped not only by behavioral or environmental fluctuations but also by core metabolic components. The existing literature supports this interpretation: in individuals with T2D, improved summer glycemic control has been reported to coincide with lower triglyceride levels, higher HDL-cholesterol, and a more favorable triglyceride-to-HDL ratio (6). A large cohort analysis further demonstrated that the seasonal decline in HbA1c was significantly associated with increases in HDL-cholesterol and improvements in TG/HDL ratio (15). These patterns are consistent with findings from both diabetic and prediabetic populations, in which seasonal enhancements in lipid profile accompany improvements in glycemic regulation (6,16,17). However, this relationship is not universal. For instance, the Tromsø Study conducted in Scandinavia reported higher HDL-cholesterol levels during winter rather than summer (18). Such geographical variability indicates that seasonal lipid dynamics may be modulated by regional climatic conditions, genetic background, and lifestyle practices.

This study has several limitations. First, its retrospective and cross-sectional design precludes causal inference, allowing only associative interpretations. The absence of a longitudinal framework—wherein the same individuals would be followed across seasons—limits our ability to confirm within-person seasonal trajectories. Second, key determinants of glycemic control, including physical activity, dietary patterns, medication adherence, and socioeconomic status, were not available in the dataset, raising the possibility of residual confounding. Third, the analysis was conducted in a single tertiary city hospital, which may restrict the generalizability of the findings to broader or more diverse populations. Finally, the use of data confined to a single calendar year does not allow assessment of interannual variability in seasonal patterns, an aspect that longer-term investigations could better address.

In conclusion, this retrospective cross-sectional study demonstrates a clear and statistically significant seasonal variation in HbA1c among individuals with type 2 diabetes. Lower HbA1c levels observed during summer indicate a seasonal improvement in glycemic control, and this pattern persisted independently of key metabolic covariates such as triglycerides and HDL-cholesterol. These findings support the systematic incorporation of seasonal considerations into diabetes management, suggesting that therapeutic strategies and patient education may warrant seasonal tailoring, particularly for individuals who experience winter-associated deteriorations in glycemic control. Prospective longitudinal studies incorporating detailed assessments of physical activity, dietary behavior, and other lifestyle determinants will be essential to elucidate the causal mechanisms underpinning this seasonal rhythm.

Conflict of Interest: The author declares no conflicts of interest.

Ethics Approval: This study was approved by the Local Ethics Committee of Sutcu Imam University (Protocol No. 2025/35, date: 08.12.2025). The International Principles of Helsinki were followed in the study.

Author contribution: The author declares that he contributed to all aspects of the study.

Financial Disclosure: None

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