phrp
OSONG PUBLIC HEALTH AND RESEARCH PERSPECTIVES

pISSN 2210-9099 eISSN 2233-6052
https://doi.org/10.24171/j.phrp.2024.0337
Osong Public Health Res Perspect 2025;16(2):100-115

Review Article

The contribution of dietary total antioxidant capacity to type 2 diabetes risk and levels of glycemic biomarkers: a systematic review

Sorayya Kheirouri[1], **Hamed Alizadeh**[2]

[1]Department of Nutrition, Faculty of Nutrition and Food Sciences, Tabriz University of Medical Sciences, Tabriz, Iran
[2]Patient Safety Research Center, Clinical Research Institute, Urmia University of Medical Sciences, Urmia, Iran

ABSTRACT

Objectives: This study systematically reviewed and analyzed epidemiological evidence regarding the association between dietary total antioxidant capacity (DTAC) and both the risk of developing diabetes and glycemic biomarker levels.

Methods: We searched the PubMed, Scopus, ScienceDirect, and Google Scholar databases through July 2024 without imposing any date restrictions. Original studies that examined the relationship between DTAC and either the risk of developing diabetes or glycemic biomarker levels—specifically fasting blood glucose (FBG), hemoglobin A1C (HbA1C), insulin, and the homeostatic model assessment for insulin resistance (HOMA-IR)—were eligible for inclusion. After eliminating duplicates and irrelevant records, relevant studies were selected, and data were extracted through rigorous critical analysis.

Results: A total of 32 articles were included in the review. Of the 19 studies that evaluated diabetes risk, 15 reported a lower risk among subjects with higher DTAC values. All 4 studies examining prediabetes risk found lower risk in participants with high DTAC scores. Additionally, significant inverse relationships were observed between DTAC values and FBG (9/15 studies), HbA1C (1/6 studies), insulin (5/6 studies), and HOMA-IR (8/9 studies).

Conclusion: The majority of evidence indicates that high adherence to an antioxidant-rich diet may reduce diabetes risk and improve glycemic biomarkers, including FBG, insulin, and HOMA-IR.

Keywords: Blood glucose; Diabetes mellitus; Dietary total antioxidant capacity; Glycated hemoglobin; Insulin resistance; Insulin

Received: December 10, 2024
Revised: February 16, 2025
Accepted: February 24, 2025

Corresponding author:
Sorayya Kheirouri
Department of Nutrition, Faculty of Nutrition and Food Sciences, Tabriz University of Medical Sciences, Attar Nishabouri St., Tabriz, I. R. Postal code: 5166614711, POBOX: 14711, Iran
E-mail: Kheirouris@tbzmed.ac.ir

Introduction

Type 2 diabetes (T2D) is a chronic condition characterized by insulin resistance and elevated blood glucose levels. As of 2021, approximately 537 million adults worldwide have diabetes, with

more than 90% of these cases being T2D—a figure projected to rise to 643 million by 2030 [1]. In 2021, T2D accounted for an age-standardized mortality rate of 18.5 per 100,000 individuals [2] and, in 2019, a disability-adjusted life years rate of 801.5 per 100,000 individuals [2]. T2D leads to severe complications, including cardiovascular diseases, kidney damage, and neuropathy [3]. Major contributing factors include obesity, physical inactivity, and unhealthy dietary habits [4].

There is growing interest in the role of oxidative stress and inflammation in chronic conditions such as atherosclerosis, obesity, and T2D [5]. An imbalance between prooxidants and antioxidants, resulting in oxidative stress, is a key pathogenic mechanism that increases diabetes risk [6]. Hyperglycemia promotes glucose autoxidation, non-enzymatic glycation, and impairs monocyte function, all of which lead to increased free radical production [7]. In addition, reduced levels of antioxidants exacerbate oxidative stress [8], resulting in lipid and DNA damage as observed in patients with diabetes [9].

A healthy diet rich in antioxidants and anti-inflammatory compounds may reduce the risk of chronic diseases, including cardiovascular disease, diabetes, and certain cancers [10]. Dietary intake has been linked to modulation of oxidative stress [11,12], and energy restriction has been suggested to lower levels of oxidative stress intermediaries [13]. Consumption of antioxidants is proposed as a protective strategy to mitigate oxidative damage [14], and evidence indicates that dietary antioxidants reduce T2D risk by inhibiting peroxidation chain reactions [15]. Moreover, consuming fruits and vegetables is associated with reduced incidence and mortality from various chronic diseases [16,17]. One hypothesis suggests that the collective impact of antioxidants—such as vitamins C and E, carotenoids, flavonoids, and proanthocyanidins—protects cells against free radical-induced oxidative damage [18].

Recent research indicates that higher total plasma antioxidant capacity is correlated with the intake of antioxidant-rich fruits and vegetables [19,20]. Because individual antioxidant concentrations do not fully capture the overall antioxidant potential of whole foods, the concept of dietary total antioxidant capacity (DTAC) was introduced [21]. DTAC functions as a valuable indicator of the overall antioxidant status of a diet [22,23].

Over recent decades, researchers have developed various methods to assess the total antioxidant capacity (TAC) of complex materials like foods. These assays include ferric reducing-antioxidant power (FRAP), which measures the reduction of Fe^{3+} to Fe^{2+}; total radical-trapping antioxidant parameter (TRAP), which monitors protection during a controlled peroxidation reaction; Trolox equivalent antioxidant capacity (TEAC), which compares the ability of antioxidants to quench the $ABTS^{1+}$ radical with that of Trolox; and oxygen radical absorbance capacity (ORAC), which evaluates the complete reaction of antioxidants with biologically relevant free radicals [24,25].

HIGHLIGHTS

- Oxidative stress contributes to the pathophysiology of diabetes.
- An antioxidant-rich diet intake may reduce diabetes risk.
- An antioxidant-rich diet intake may improve glycemic biomarkers, including fasting blood glucose, insulin, and homeostatic model assessment for insulin resistance.

In recent years, substantial research has focused on the relationship between DTAC and T2D risk [26,27]. Although a recent systematic review examined the relationship between DTAC and cardiometabolic risk factors in diverse populations, no review has comprehensively summarized the evidence linking DTAC to T2D risk and related biomarkers such as fasting blood glucose (FBG), hemoglobin A1C (HbA1C), insulin levels, and homeostatic model assessment for insulin resistance (HOMA-IR).

Materials and Methods

We adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines to ensure a transparent and systematic report [28].

Search Strategy

We conducted a systematic literature search in PubMed, Scopus, ScienceDirect, and Google Scholar up to July 2024 without imposing any date restrictions. Our search strategy used specific keywords relevant to the research question: "Dietary antioxidant capacity OR Dietary antioxidant index OR Dietary antioxidant intake OR Dietary total antioxidant" in title, abstract, and keywords, combined with "Diabetes OR Glycemic indices OR Metabolic indices OR insulin resistance OR insulin OR HOMA-IR OR glucose OR sugar" in title, abstract, and keywords. Only English-language original articles were included. Details of the search strategy are provided in Table S1. Reference lists of the included studies were also reviewed to identify additional relevant articles.

The research question was: "Is there an association between DTAC and T2D risk and levels of glycemic biomarkers?" Table 1 outlines the population, exposure, comparator, outcome (PECO) approach for this review, with individuals with

Table 1. Description of the PECO strategy

Element	Description
Population	People with diabetes or at risk of diabetes
Exposure	Low dietary total antioxidant capacity
Comparator	People with high dietary total antioxidant capacity
Outcome	Diabetes risk and diabetes-related glycemic biomarkers including FBG, HbA1C, insulin, and HOMA-IR

FBG, fasting blood glucose; HbA1c, hemoglobin A1C; HOMA-IR, homeostatic model of insulin resistance.

diabetes or at risk defined as the population, low DTAC as the exposure, high DTAC as the comparator, and diabetes risk and glycemic biomarkers (FBG, HbA1C, insulin, and HOMA-IR) as the outcomes.

Eligibility Criteria

We included original articles published in English that evaluated the association between DTAC and either the risk of developing diabetes or glycemic biomarkers (including FBG, HbA1C, insulin, and HOMA-IR). Studies were excluded if they focused on a single dietary antioxidant (e.g., vitamin E or carotenoids) in relation to T2D, the effects of antioxidant supplementation on diabetes biomarkers, the impact of specific active constituents with antioxidant activity from special foods on diabetes management, interactions between DTAC and specific genotypes (e.g., the caveolin-1 gene variant, rs 3807992) on diabetes biomarkers, or the combined effect of DTAC with other factors on diabetes or glycemic biomarkers. Animal studies, theses, dissertations, conference abstracts, editorials, reviews, and posters were also excluded.

Selection of Studies

Extracted studies were transferred to an EndNote file, and duplicate articles were removed. Two independent researchers screened the remaining articles based on their titles and abstracts to identify potentially eligible studies. Full texts of the selected articles were then reviewed independently to assess eligibility and extract relevant data. Any disagreements regarding study eligibility were resolved through discussion until consensus was reached.

Data Extraction

The following information was collected: first author and year of publication, study country and design, participant demographics (including age and sex), physical condition, follow-up duration, dietary assessment method, DTAC evaluation method, covariates, and outcome measures reported as correlation indicators (odds/hazard ratios, confidence intervals, *p*-values, if available). Only results from fully adjusted models were considered.

In studies that employed multiple statistical approaches to assess the association between DTAC and T2D risk, priority was given to findings from regression analyses. When analyses were conducted separately by sex and an association was observed in only 1 sex, only the relevant sex-specific findings were documented.

Ethics Approval

The ethics committee of Tabriz University of Medical Sciences, Tabriz, Iran, registered and approved the protocol of this study (IR.TBZMED.REC.1401.824).

Results

Selection of Studies

Initially, 314 studies were retrieved (Figure 1). After removing duplicates, 143 studies remained. A review of titles and abstracts identified 43 publications relevant to the study's scope. Following critical appraisal, 11 studies were excluded because 1 was irrelevant, 1 was unavailable, 1 was a duplicate of an already included study, 1 was a letter, 5 investigated the interaction of DTAC with other factors regarding T2D, and 2 focused on single dietary antioxidants. Ultimately, 32 studies were included in the review (comprising 8 cohort studies, 20 cross-sectional studies, and 4 case-control studies) (Figure 1).

Characteristics of the Included Studies

As shown in Table 2, the included investigations [26,27,29–58] were conducted across diverse global regions. The studies were published between 2010 and 2024, with the majority ($n=26$) published after 2015. In the cohort studies, follow-up durations ranged from 3 to 37 years, although 4 studies had excessively long follow-up periods. Most studies (23 of 32) used food frequency questionnaires (FFQs) to assess dietary intake. DTAC was measured using various methods, including FRAP (21 studies), ORAC (9 studies), TRAP (5 studies), TEAC (5 studies), a composite dietary antioxidant index (3 studies), and other methods (2 studies). Different cut-off points were employed to categorize DTAC values. Twenty-one studies focused on subjects with

https://doi.org/10.24171/j.phrp.2024.0337

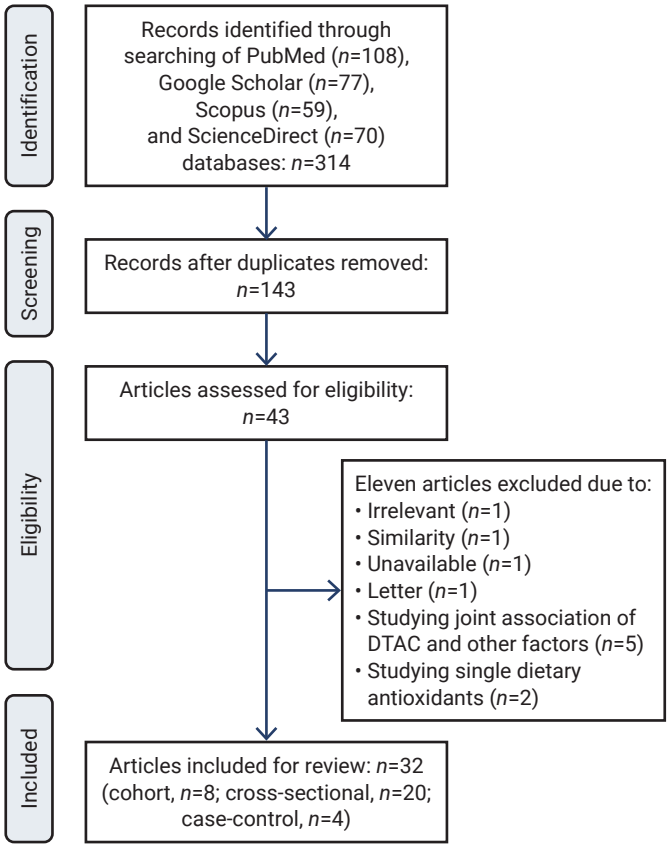

Figure 1. Flow diagram of the study. DTAC, dietary total antioxidant capacity.

diabetes or prediabetes, and most studies ($n=23$) adjusted for potential covariates in their analyses.

Relationship between DTAC and Risk of Developing Prediabetes and Diabetes

Among the 19 studies assessing the association between DTAC and diabetes risk [27,29–46], 15 reported a lower risk of diabetes in individuals with higher DTAC values [30,31,33–35,37–46]. In contrast, 4 studies found no significant association [27,29,32,36]. All 4 studies that evaluated the link between DTAC and prediabetes risk reported lower risk in individuals with higher DTAC values [27,40,47,48].

Relationship between DTAC and Glycemic Biomarkers

As shown in Table 2, out of 15 studies that evaluated the association between DTAC and FBG [26,27,29,31,43,48–57], 9 reported lower FBG levels in individuals with higher DTAC values [27,29,43,48,51–54,57]. Six studies investigated the association between DTAC and HbA1C [27,31,49,50,55,56], with only 1 study reporting lower HbA1C levels in those with higher DTAC values [27]. Furthermore, 6 studies assessed the

Table 2. Summary and characteristics of the 28 selected studies assessing the relationship of DTAC with diabetes risk and its related glycemic biomarkers

Study	Year	Country/study design	Target population	Age (y)	Method of dietary intake assessment	Method of DTAC evaluation	Follow-up (y)	Findings					Statistical analysis method/considered confounders
								FBS	HbA1C	HOMA-IR	Insulin	Risk of diabetes	
Bahadoran et al. [29]	2012	Iran/cohort	1,983 Adults (47% men)	40.4 ± 13.0	168 Food-items semiquantitative FFQ	ORAC: Q1, <842; Q2, 842–958; Q3, 959–1,080; Q4, >1,080	3	At baseline: FBG did not significantly differ across DTAC categories. DTAC was negatively associated with FBG (p-trend <0.01). After a 3 years follow-up, DTAC was not associated with FBG.	-	-	-	Hyperglycemia (FPG ≥100 mg/dL) did not differ across the DTAC quartiles and during 3-year follow-up, hyperglycemia did not significantly correlate with DTAC value.	Age, sex, BMI, physical activity, smoking status, energy and macronutrient intakes, dietary potassium intake

(Continued to the next page)

Table 2. Continued

Study	Year	Country/study design	Target population	Age (y)	Method of dietary intake assessment	Method of DTAC evaluation	Follow-up (y)	Findings					
								FBS	HbA1C	HOMA-IR	Insulin	Risk of diabetes	Statistical analysis method/considered confounders
Baharirad et al. [26]	2022	Iran/cross-sectional	189 T2D patients	35–65	FFQ	ORAC (tertile)	-	The mean values of FBS did not show statistically significant difference among the DTAC tertiles. There was no significant relationship between DTAC and FBS (tertile 3 vs. tertile 1: β, −0.90; 95% CI, −1.23 to 1.05; $p = 0.87$; adjusted model).	-	-	-	-	Logistic regression/age, sex, BMI, physical activity, and total caloric intake
Capas et al. [27]	2018	Turkey/descriptive	Adults with T2D; people with diabetes, $n = 29$ ($n = 20$ female); healthy subjects, $n = 15$ ($n = 10$ female)	40–70	3 Days of 24-hour food record	Modified version of the FRAP	-	In people with diabetes, a negative correlation was found between DTAC and FBG ($r = -0.406$, $p = 0.036$).	In people with diabetes, a negative correlation was found between DTAC and HbA1C ($r = -0.531$, $p = 0.004$).	-	-	DTAC did not differ between the 2 groups.	Group comparison and Spearman correlation/ not stated
Cetiner et al. [30]	2021	Turkey/cross-sectional	People with diabetes, $n = 60$ ($n = 33$ female); healthy subjects, $n = 25$ ($n = 14$ female)	Newly diagnosed T2DM, 50.8 ± 6.8; formerly diagnosed T2DM, 51.8 ± 7.4; controls, 45.6 ± 8.6	3 Days of 24-hour recall	FRAP, TEAC, TRAP, ORAC	-	-	-	-	-	DTAC was lower in diabetes than in controls ($p < 0.001$).	Groups comparison/ confounders have not been considered.
Chen et al. [31]	2023	China/cross-sectional	11,956 Participants	Mean > 42	24-Hour dietary recall	CDAI (6 dietary antioxidants)		FBS did not significantly differ among the CDAI quartiles. In full adjusted model, CDAI did not independently associate with fasting glucose.	Percentage of HbA1C was lower in the highest quartile of CDAI ($p = 0.03$). In full adjusted model, CDAI was not independently associated with HbA1C.	-	-	Percentage of people with diabetes were lower in the highest quartile of CDAI ($p < 0.001$) Compared with the lowest quartile of CDAI, the highest quartile was related to reduced risk of diabetes (OR, 0.84; 95% CI, 0.71–0.99; $p = 0.035$).	Multivariable logistic regressions/age, sex, race, education, physical activity, smoking status, hypertension, and coronary heart diseases

(Continued to the next page)

https://doi.org/10.24171/j.phrp.2024.0337

Table 2. Continued

Study	Year	Country/study design	Target population	Age (y)	Method of dietary intake assessment	Method of DTAC evaluation	Follow-up (y)	Findings					
								FBS	HbA1C	HOMA-IR	Insulin	Risk of diabetes	Statistical analysis method/considered confounders
Cyunczyk et al. [32]	2022	Poland/cross-sectional	413 Adults (40% male); normoglycemia, 171 (41.40%); prediabetes, 202 (48.91%); T2D, 40 (9.69%)	49.84±9.47	3 Days of 24-hour dietary recall	FRAP (Q1, ≤8.37; Q2, 8.38–11.27; Q3, 11.2–14.50; Q4, ≥14.51)	-	-	-	DTAC was inversely associated with HOMA-IR (β=−0.39, p=0.02).	-	The higher quartile of DTAC was significantly associated with a reduced odds ratio for the prevalence of prediabetes (Q3 vs. Q1; OR, 0.583; 95% CI, 0.309–0.945), but not with the risk of diabetes.	Linear regression/age, sex, family history of diabetes, education level, physical activity, dyslipidemia, hypertension, BMI, waist circumference, smoking status, daily alcohol intake and daily energy intake
Daneshzad et al. [33]	2020	Iran/case-control	Pregnant women with GDM; GDM, n=200; healthy, n=263	28.33±6.23	3 Days of a 24-hour dietary record	FRAP, TRAP, TEAC; tertile values were not stated.	-	-	-	-	-	FRAP was significantly lower in pregnant women with GDM than in controls. The risk of GDM was 85% lower among those in the highest tertile of FRAP (OR, 0.15; 95% CI, 0.08–0.29; p-trend < 0.0001). There was no significant association between the risk of GDM and TRAP as well as TEAC.	Group comparison and binary logistic regression/age, BMI, energy intake, physical activity, number of offspring, carbohydrate, fat, and protein intake, and supplementation
Daneshzad et al. [49]	2020	Iran/cross-sectional	265 T2D women	59.66±8.94	168-Item semiquantitative	FRAP (T1, <3.68; T2, 3.68–5.18; T3, >5.18); ORAC	-	FBS levels did not differ significantly across the tertiles of DTAC.	HbA1C levels did not differ significantly across the tertiles of DTAC.	-	-	-	Analysis of variance/age, BMI, energy intake, physical activity, blood pressure, medication, supplement consumption
Fagherazzi et al. [34]	2018	France/cohort	402 Women at very high risk of T2DM; women with T2DM, 117 (29%); women free of T2DM, 285 (71%)	55.7±6.65	Semiquantitative FFQ (57 predefined food groups)	FRAP	19	-	-	-	-	FRAP scores did not differ between 2 groups. A high DTAC was associated with less developing T2DM, in women with a moderate or high Western dietary pattern score.	Group comparison and regression/not stated
El Frakchi et al. [35]	2024	Morocco/cross-sectional	254 T2D outpatients	54.52±7.21	255 Food-item FFQ	FRAP; high, >10.6 mmol; low, <10.6 mmol	-	-	-	-	-	Percentage of people with diabesity was lower among those with higher DTAC (p=0.02).	Student t-test/-

(Continued to the next page)

Table 2. Continued

Study	Year	Country/study design	Target population	Age (y)	Method of dietary intake assessment	Method of DTAC evaluation	Follow-up (y)	Findings					
								FBS	HbA1C	HOMA-IR	Insulin	Risk of diabetes	Statistical analysis method/considered confounders
Galarregui et al. [50]	2018	Spain/cross-sectional	112 Overweight or obese adults	50.8±9	137-Item semiquantitative FFQ	FRAP (T1, <8.6; T, 8.6–11.36; T3, >11.36)	-	Glucose level did not change significantly across the tertiles of DTAC.	HgA1C level did not change significantly across the tertiles of DTAC.	Subjects with higher values of TAC had significantly lower HOMA-IR ($p=0.03$).	Subjects with higher values of TAC had significantly lower insulin concentration ($p=0.01$).	-	-
Hermsdorff et al. [51]	2011	Spain/cross-sectional	266 Healthy subjects (105 men/161 women)	22±3	Brazilian sample ($n=123$), 3 day-record; Spanish sample ($n=143$), 136 food-items semiquantitative FFQ	TEAC	-	DTAC value was inversely associated with glucose ($p<0.05$).	-	DTAC values were inversely associated with HOMA-IR ($p<0.05$).	DTAC values were inversely associated with insulin levels ($p<0.05$).	-	Multiple linear regression/ age, sex, waist circumference, energy intake, smoking habit, physical activity, and vitamin supplement use
Heshmati et al. [44]	2024	Iran/prospective cohort	1,856 pregnant women; GDM, 369	18–45	168 Food-items FFQ	FRAP	Between February 1, 2020 and August 31, 2021	-	-	-	-	The adjusted risk of GDM decreased by 34% (95% CI, 10%–52%; $p=0.023$) for each DTAC score increase. Women in the highest quartile of DTAC had a lower risk of developing GDM compared to those in the lowest quartile (adjusted RR, 0.29; 95% CI, 0.12–0.68; $p=0.005$).	Age, BMI, occupation, hypertension, diabetes, education, and working rotating shift
Jimenez-Ortega et al. [58]	2024	México/cross-sectional	830 Children and adolescents	7–18	116 Food-items FFQ	Based on the intake of 6 vitamins and minerals (vitamins A, C, E, selenium, magnesium, and zinc)		-	-	In total participants, people in the highest DAI category had low insulin resistance (OR, 0.49; 95% CI, 0.30–0.80). Female participants in the highest DAI category had significantly lower odds of developing insulin resistance than those in the lowest DAI category (OR, 0.54; 95% CI, 0.29–0.98).	-	-	Multiple logistic regression/ age, sex, BMI, smoking status, vitamin D intake, polyunsaturated intake, alcohol intake, family history of diabetes, Tanner stages, protein intake and total fat intake

(Continued to the next page)

https://doi.org/10.24171/j.phrp.2024.0337

https://doi.org/10.24171/j.phrp.2024.0337

Table 2. Continued

Study	Year	Country/study design	Target population	Age (y)	Method of dietary intake assessment	Method of DTAC evaluation	Follow-up (y)	Findings					
								FBS	HbA1C	HOMA-IR	Insulin	Risk of diabetes	Statistical analysis method/considered confounders
Kashino et al. [36]	2019	Japan/ prospective cohort	64,660 Adults (27,809 men and 36,851 women). During the 5-y period, 1,191 participants (692 men and 499 women) were newly diagnosed with T2D.	44–76	147 Food-items FFQ	FRAP ORAC, TRAP (quartiles)	5	-	-	-	-	DTAC was not associated with the risk of T2D in multivariate-adjusted models. Similar associations were found in men and women.	Linear and logistic regression/age, sex, study area, smoking habits, physical activity, BMI, history of hypertension, family history of diabetes mellitus, use of supplements, coffee consumption, and energy intake
Li et al. [37]	2024	China/cross-sectional	12,467 Participants (female, 65.4%); people with T2D, 1,238 (9.9%)	57.04±10.13	FFQ	FRAP	-	-	-	-	-	Higher DATC was associated with a lower T2DM risk (OR, 0.96; 95% CI, 0.80–1.17; *p*-trend = 0.024).	Logistic regression/age, sex, smoking status, alcohol consumption, physical activity, BMI, WC, TG, HDL-C, hypertension, and health supplement intake
Liu et al. [38]	2024	China/cross-sectional	2,158 Participants (male, 52.12%)	58.87±0.41	24 Hour dietary recall	CDAI	-	-	-	-	-	A negative correlation between CDAI and diabetic retinopathy (OR, 0.94; 95% CI, 0.90–0.98; $p = 0.007$).	Multivariate logistic regression/age, sex, race, drinking, smoking, body mass index (BMI), hypertension, etc.
Mancini et al. [39]	2018	Germany/ prospective cohort	64,223 Women. During 15 years of follow-up, 1,751 women had validated T2Ds.	52±7	208 Food-items dietary questionnaire	FRAP (Q1, ≤8.72; Q2, 8.73–11.29; Q3,11.30–13.93; Q4,13.94–17.55; Q5, >17.55)	15	-	-	-	-	In multivariable models, higher levels of DTAC were associated with a lower risk of T2D (OR, 0.73; 95% CI, 0.60–0.89; $p < 0.0001$).	Spline regression/ smoking status, physical activity, education level, hypertension, hypercholesterolaemia, family history of diabetes, energy intake, alcohol intake, BMI
Okubo et al. [52]	2014	United Kingdom/ cohort	Men (1,441), women (1,253)	59–73	129 Food-item FFQ	ORAC, TRAP, FRAP, TEAC	37	By all 4 assays: In women, but not in men, DTAC was inversely associated with fasting glucose ($p < 0.05$).	-	By all 4 assays: In women and men, DTAC was inversely associated with HOMA-IR ($p < 0.05$).	By all 4 assays: In women and men, DTAC was inversely associated with insulin levels ($p < 0.05$).	-	Multiple linear regression/ age, sex, BMI, smoking status and physical activity level, dietary supplement use, and energy intake
Psaltopoulou et al. [53]	2011	Greece/ epidemiological study	551 Men and 467 women; normal, $n = 771$; IFG, $n = 203$; T2D, $n = 44$	Normal, 38±11; IFG, 43±10; diabetic, 52±8	Semiquantitative FFQ	TRAP, FRAP, TEAC		Using all 3 assays, an inverse association was found between DTAC and serum log-glucose ($p = 0.001$).	-	By all 3 assays, an inverse association was found between DTAC and serum log- HOMA ($p \leq 0.001$).	By all 3 assays, an inverse association was found between DTAC and serum log- insulin ($p \leq 0.002$).	-	Multiple regression analyses/age, sex, BMI, physical activity status, smoking habits, and energy intake
Puchau et al. [54]	2010	Spain/cross-sectional	153 Healthy young adults (101 women and 52 men)	20.8±2.7	136 Food-item FFQ and 3-day food record	FRAP (low, <6.9 mmol; high, >6.9 mmol)	-	Serum glucose significantly differed between subjects with high and low DTAC values ($p = 0.006$). Serum glucose was negatively associated with DTAC ($p = 0.03$).	-	HOMA-IR did not significantly differ between subjects with high and low DTAC values.	Insulin levels did not significantly differ between subjects with high and low DTAC values.	-	Groups comparison and multiple linear regression/sex and daily energy intake

(Continued to the next page)

Table 2. Continued

Study	Year	Country/study design	Target population	Age (y)	Method of dietary intake assessment	Method of DTAC evaluation	Follow-up (y)	Findings					
								FBS	HbA1C	HOMA-IR	Insulin	Risk of diabetes	Statistical analysis method/considered confounders
Rahmani et al. [47]	2021	Iran/case-control	Prediabetes, *n* = 49; healthy control, *n* = 98	47.42 ± 15.98	80 Food-item FFQ	FRAP (T1, ≤11.90; T2, 11.90–21.24; T3, >21.24)	-	-	-	-	-	Patients with prediabetes had lower DTAC scores as compared with controls. High DTAC was associated with a significantly reduced likelihood of having prediabetes (OR, 0.09; 95% CI, 0.02–0.53; *p*-trend = 0.01).	Age, sex, BMI, marital status, income, occupation, education, physical activity, dietary supplementation, family history of diabetes, and total calorie intake
Roumi et al. [45]	2024	Iran/cross-sectional	4,241 Participants; patients with T2D, *n* = 589; individuals without T2D, *n* = 3,611	35–70	FFQ	Wright's method	-	There was no significant correlation between FBG and dietary total antioxidant index.	-	-	-	Negative associations was found between T2D with total score of dietary antioxidant index (OR, 0.67; 95% CI, 0.55–0.81; *p* = 0.001).	Logistic and linear regression/age, sex, BMI, education level, marital status, occupation, physical activity, and calorie intake
Salavatizadeh et al. [55]	2022	Iran/cross-sectional	200 People with T2D	18–70	147 Food-item FFQ	FRAP		FBS was not different across DTAC tertiles (*p* = 0.44).	HbA1C did not differ across DTAC tertiles (*p* = 0.67).	People in the third tertile of DTAC had lower HOMA-IR level (*p* = 0.05).	People in the third tertile of DTAC had lower insulin level (*p* = 0.01).	-	Kruskal-Wallis test and analysis of covariance/age, sex, diabetes duration, smoking status, physical activity, BMI, waist circumference, and energy
van der Schaft et al. [40]	2019	Netherland/cohort	5,796 Men (*n* = 2,266) and women (*n* = 3,530); normoglycaemia, *n* = 4,957; prediabetes, *n* = 839	Men, 63.4; women, 64.6	170 Items semiquantitative FFQ	FRAP	15	-	-	Dietary FRAP was inversely associated with HOMA-IR (*p* < 0.001).	-	Higher FRAP score was associated with a lower risk of T2D among the total population (HR, 0.84; 95% CI, 0.75–0.95; *p* = 0.01) and among participants with prediabetes (HR, 0.85; 95% CI, 0.73–0.99; *p* = 0.03), but not with risk of prediabetes.	Cox proportional hazards regression/age, sex, BMI, hypertension, dyslipidemia, highest attained level of education, physical activity, smoking status, energy intake, daily alcohol intake and degree of adherence to guidelines for a healthy diet
Sezavar et al. [56]	2021	Iran/cross-sectional	170 Adults with morbid obesity	37.4 ± 10.17	147 Food-item FFQ	ORAC, FRAP (T1, <5.36; T2, 16.41–24.01; T3, >145.17)	-	FBS did not significantly differ across tertiles of FRAP (*p* = 0.21) and ORAC (*p* = 0.86).	HbA1C did not significantly differ across tertiles of FRAP (*p* = 0.22) and ORAC (*p* = 0.99).	-	-	-	One-way ANOVA/not stated

(Continued to the next page)

https://doi.org/10.24171/j.phrp.2024.0337

Table 2. Continued

Study	Year	Country/study design	Target population	Age (y)	Method of dietary intake assessment	Method of DTAC evaluation	Follow-up (y)	Findings					
								FBS	HbA1C	HOMA-IR	Insulin	Risk of diabetes	Statistical analysis method/considered confounders
Sohouli et al. [57]	2020	Iran/case-control	NAFLD, *n* = 158; healthy individuals, *n* = 357	43.9 ± 5.9	168 Food-item FFQ	ORAC (tertiles)	-	Across increasing DTAC tertiles, the FBG level reduced ($p = 0.001$).	-	-	-	-	One-factor ANCOVA test/ not stated
Sotoudeh et al. [48]	2018	Iran/case-control study	300 Individuals with and without prediabetes (*n* = 150/group)	Control, 47.7 ± 7.2; prediabetic, 47.4 ± 7.5	168 Food-items semiquantitative FFQ	ORAC (Q1, < 11,878.5; Q2, 11,878.5–16,322.1; Q3, 16,322.1–24,548.8; Q4, > 24,548.8 mmol TE/100 g)	-	Across increasing DTAC quartiles, the participants had lower FBG (p-trend < 0.001).	-	-	-	The mean DTAC was lower in individuals with prediabetes than in the control group ($p < 0.001$). Participants in the fourth quartile of DTAC were less likely to experience prediabetes compared with those in the first quartile (OR, 0.18; 95% CI, 0.07–0.49; $p < 0.001$).	Logistic regression/ BMI, physical activity, education, dietary intake of fiber, fat, energy, and coffee
Tan et al. [41]	2022	South Korean/ cohort	20,594 Participants, 332 men and 360 women with T2D	40–79	106 Food-item FFQ	Self-reported dietary data linked to the TAC database	5	-	-	-	-	DTAC was inversely associated with the development of T2D in women (HR, 0.58; 95% CI, 0.40–0.83; p-trend = 0.0004). Among men, an approximately 15% reduced risk of developing T2D was observed for an SD increment in TAC (HR, 0.85; 95% CI, 0.75–0.96).	A multivariable Cox proportional hazards regression/age, BMI, education, smoking, alcohol intake, physical activity
Zhou et al. [46]	2024	China/cross-sectional	7,982 Subjects; 48.50% male and 51.50% female; diabetic, 1,607; non-diabetic, 6,375	47.32 ± 16.77	Two 24-hour dietary recalls	CDAI	-	-	-	-	-	High CDAI was associated with reduced risk of diabetes mellitus in the female population ($p = 0.046$).	Multifactorial logistic regression models/age, sex, race, and education level
Zujko et al. [42]	2014	Poland/cross-sectional	80 Patients with and without T2D and 37 controls	40–65	24-Hour food recall and dietary database	FRAP	-	-	-	-	-	DTAC was significantly higher in control than in patients with longstanding diabetes and those with newly diagnosed diabetes ($p = 0.01$).	Groups comparison/not stated

(Continued to the next page)

Table 2. Continued

Study	Year	Country/study design	Target population	Age (y)	Method of dietary intake assessment	Method of DTAC evaluation	Follow-up (y)	Findings					Statistical analysis method/considered confounders
								FBS	HbA1C	HOMA-IR	Insulin	Risk of diabetes	
Zujko et al. [43]	2018	Poland/cross-sectional	5,690 Adults (2,554 men and 3,136 women)	50.08 ± 16.44	A single 24-hour dietary recall	FRAP (tertiles)	-	In women, higher DTAC was significantly associated with reduced odds of elevated blood glucose.	-	-	-	In women, higher DTAC was associated with 27.9% lower odds of diabetes (OR, 0.721; 95% CI, 0.522–0.997).	Logistic regression/age, BMI, educational level, leisure time, physical activity, smoking, and alcohol intake

DTAC, dietary total antioxidant capacity; FBS, fasting blood sugar; HbA1c, hemoglobin A1C; HOMA-IR, homeostatic model assessment for insulin resistance; FFQ, food frequency questionnaire; ORAC, oxygen radical absorption capacity; FBG, fasting blood glucose; FPG, fasting plasma glucose; BMI, body mass index; T2D, type 2 diabetes; CI, confidence interval; T2DM, type 2 diabetes mellitus; FRAP, ferric reducing-antioxidant power; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant potential; CDAI, composite dietary antioxidant index; OR, odds ratio; GDM, gestational diabetes mellitus; TAC, total antioxidant capacity; RR, risk ratio; DAI, dietary antioxidant index; WC, waist circumference; TG, triglycerides; HDL-C, high-density lipoprotein-cholesterol; IFG, impaired fasting glucose; HR, hazard ratio; ANOVA, analysis of variance; ANCOVA, analysis of covariance; SD, standard deviation.

relationship between DTAC and insulin levels [50–55], and 5 of these found that higher DTAC values were associated with lower insulin levels [50–53,55]. Among the 9 studies evaluating DTAC and HOMA-IR [32,40,50–55,58], 8 reported lower HOMA-IR values in subjects with higher DTAC values [32,40,50–53,55,58].

Discussion

A healthy and diverse diet can enhance overall health outcomes and well-being [59,60]. Antioxidants play a critical role in maintaining health by neutralizing free radicals—highly reactive molecules that can damage cells and genetic material. These free radicals arise from metabolism, exercise, and environmental exposures such as air pollution and sunlight [61]. Evidence indicates that a diet rich in antioxidants, particularly from fruits, vegetables, and legumes, reduces the risk of chronic diseases related to oxidative stress. Epidemiological studies and meta-analyses of prospective observational studies have consistently linked higher intakes of antioxidant-rich foods with reduced risks of cardiovascular diseases, cancer, and all-cause mortality [62,63]. Thus, incorporating antioxidant-rich foods into one's diet may improve overall health and well-being [64,65].

In the present study, we reviewed both interventional and observational investigations to provide an overview of the relationship between an antioxidant-rich diet and the risk of developing diabetes or altered glycemic biomarkers. Our systematic review provides robust evidence that high DTAC is associated with decreased diabetes risk as well as improved levels of FBG, insulin, and HOMA-IR.

Oxidative stress is central to the pathophysiology of diabetes [66]. Excess production of reactive free radicals, often triggered by hyperglycemia, leads to oxidative stress, which further exacerbates diabetes and its complications [66,67]. In diabetes, oxidative stress interacts with cellular biomolecules—including proteins and lipids—resulting in harmful effects such as lipid peroxidation, which compromises cellular structure and function [68]. Genetic studies related to oxidative stress have revealed potential causal links with diabetes and microvascular complications [69]. Elevated lipid peroxidation coupled with reduced antioxidant activity has been observed in patients with diabetes [70]. Although classic antioxidants like vitamin E have not demonstrated clinical benefits in large-scale trials, a more comprehensive strategy that both prevents reactive species generation and scavenges free radicals appears promising [67]. Moreover, synergistic low-dose antioxidant blends have shown potential in reducing lipid peroxidation

https://doi.org/10.24171/j.phrp.2024.0337

and restoring redox homeostasis [71]. Understanding the interplay among dietary antioxidants, lipid peroxidation, and hyperglycemia is essential for managing diabetes and its associated complications.

Oxidative stress also contributes significantly to the development of insulin resistance. Research has shown that systemic oxidative stress is correlated with insulin resistance. For instance, data from the Framingham Offspring Study revealed that individuals with higher levels of oxidative stress (measured by urinary 8-epi-prostaglandin F2α) had an increased prevalence of insulin resistance, even after adjusting for body mass index [72]. A similar positive association between oxidative stress markers and HOMA-IR has been reported in young adults [73]. Oxidative stress may impair insulin signaling by damaging cellular components such as proteins, lipids, and DNA, leading to reduced glucose uptake [74]. Additionally, the activation of inflammatory pathways further exacerbates insulin resistance [75]. Antioxidants help counteract this process by reducing inflammation; for example, Luu et al. [76] reported an inverse association between dietary antioxidant intake and inflammatory biomarkers in a study of 3,853 women, while Beharka et al. [77] demonstrated that prolonged dietary antioxidant supplementation reduced the production of specific inflammatory mediators in mouse macrophages.

Elevated oxidative stress can also impair insulin secretion. In both type 1 and type 2 diabetes, chronic hyperglycemia contributes to complications in target organs. High glucose levels trigger the production of reactive oxygen (ROS) and reactive nitrogen species, which damage DNA, proteins, and lipids, and activate stress-sensitive pathways such as nuclear factor kappa B (NF-κB) and p38 mitogen-activated protein kinase [78]. In T2D, elevated glucose and free fatty acid levels further activate these pathways, contributing to both insulin resistance and impaired insulin secretion [78]. Studies have reported increased oxidative and endoplasmic reticulum stress in pancreatic β-cells under hyperglycemic conditions, adversely affecting insulin production [79]. Furthermore, oxidative stress compromises insulin sensitivity and contributes to insulin resistance by impairing glucose uptake into cells [66]. Accumulating evidence indicates that oxidative stress plays a central role in β-cell dysfunction and insulin secretory failure in T2D [80,81].

Dietary bioactive compounds, including antioxidants, play a crucial role in protecting pancreatic β-cells from oxidative stress, which is a key factor in the development and progression of diabetes [82,83]. Dietary antioxidants may protect β-cells by inhibiting NF-κB activity [84] and by activating nuclear factor erythroid-derived factor 2-related factor 2 (Nrf2), a transcription factor that upregulates antioxidant and cytoprotective genes [85]. NF-κB is a transcription factor that regulates the expression of genes involved in inflammation and immune responses. The activation of NF-κB increases the production of pro-inflammatory cytokines, which can damage β-cells [86]. Meanwhile, Nrf2 is a transcription factor that regulates the expression of antioxidant and cytoprotective genes. Nrf2 activation upregulates antioxidant enzymes and proteins, which help to neutralize ROS and reduce oxidative stress [87]. Studies have shown that polyphenols and other dietary antioxidants can inhibit NF-κB activation and reduce oxidative stress [88] and activate the Nrf2 pathway [89], thereby protecting β-cells from oxidative damage and improving their function.

Dietary antioxidants also help maintain serum antioxidant levels and mitigate oxidative stress, which is essential for overall health [90]. Vahid et al. [91] reported that higher dietary antioxidant intake was associated with increased serum TAC. Similarly, Jewell et al. [92] found that an antioxidant blend—including vitamin E, vitamin C, and β-carotene—increased cellular protection and improved antioxidant status in dogs and cats. Avila-Escalante et al. [11] demonstrated that a high-antioxidant diet enhances plasma antioxidant capacity and reduces oxidative stress markers in individuals with various chronic diseases. Therefore, incorporating antioxidant-rich foods into the diet is crucial for maintaining overall health and preventing chronic diseases.

In summary, as illustrated in Figure 2, consumption of antioxidant-rich foods enhances circulating antioxidant levels and mitigates oxidative stress. This effect contributes to reduced insulin resistance, improved insulin secretion and sensitivity, and ultimately lower blood glucose levels, thereby decreasing the risk of T2D and its associated complications.

Strengths of the Study

The included investigations were conducted in diverse regions worldwide, enhancing the generalizability of the findings. The recent publication dates of most studies indicate that the topic is current. The presence of several prospective cohort studies with substantial sample sizes strengthens the statistical power of the results. Additionally, most studies accounted for potential confounders in their analyses of the DTAC–diabetes risk relationship, underscoring the independent role of DTAC.

Limitations of the Study

Several studies did not adequately consider covariates in their statistical analyses, and diverse statistical methods

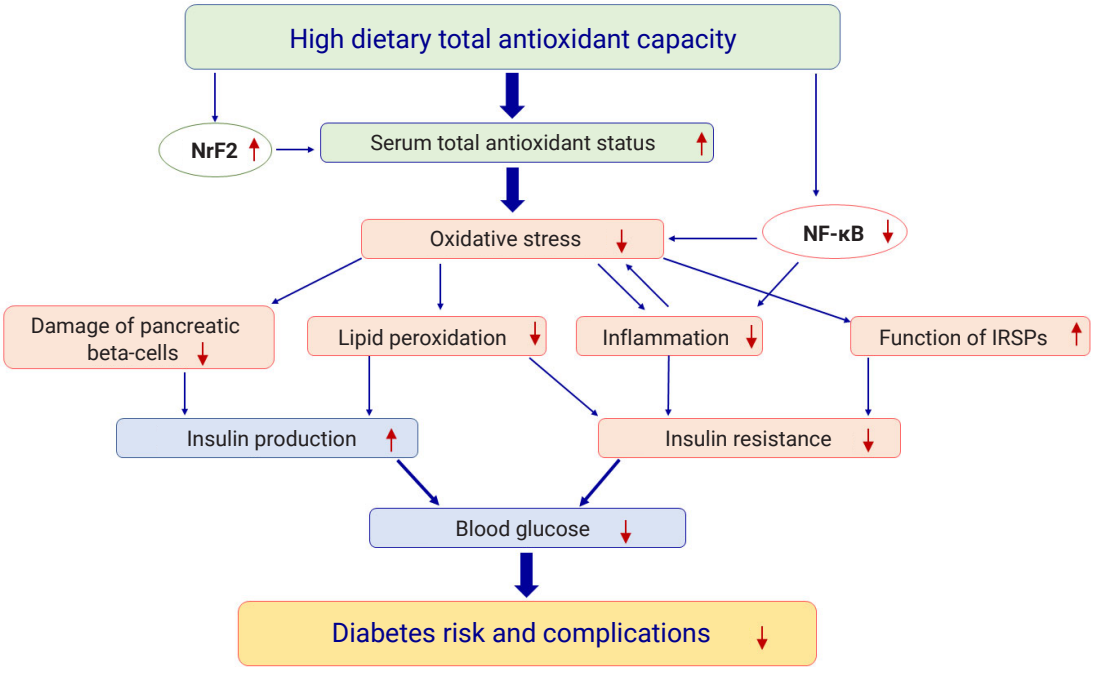

Figure 2. Potential mechanistic pathways for the association between dietary total antioxidant capacity and the diabetes risk and its related glycemic biomarkers.
NrF2, nuclear factor erythroid-derived factor 2-related factor 2; NF-κB, nuclear factor kappa B; IRSP, insulin receptor signaling pathway.

were employed across investigations. Furthermore, different techniques were used to calculate DTAC, and varying cut-off points were applied when categorizing DTAC values, which may have influenced the findings. The heterogeneity among the included studies—in terms of study populations, measured outcomes, and methodologies (including statistical analyses and DTAC evaluation methods)—precluded the performance of a meta-analysis and limited the ability to draw definitive conclusions.

Conclusion

The majority of existing evidence indicates that high adherence to an antioxidant-rich diet may reduce diabetes risk and improve glycemic biomarkers, including FBG, insulin, and HOMA-IR.

Implications of the Findings

The findings of this study have significant public health implications, particularly in managing T2D. They provide valuable insights for developing dietary recommendations aimed at preventing chronic diseases. Improved blood glucose parameters can lead to better glycemic control, reducing the risk of diabetes-related complications such as cardiovascular disease, neuropathy, and nephropathy. Enhanced glycemic control further contributes to overall metabolic health and quality of life for individuals with or at risk for T2D.

Supplementary Material

Table S1. Association between the dietary total antioxidant capacity and risk of developing diabetes or glycemic biomarkers: the database search strategy using PubMed, Scopus, Google Scholar, and ScienceDirect. Supplementary data are available at https://doi.org/10.24171/j.phrp.2024.0337.

Notes

Ethics Approval

The ethics committee of Tabriz University of Medical Sciences, Tabriz, Iran, registered and approved the protocol of this study (IR.TBZMED.REC.1401.824).

Conflicts of Interest

The authors have no conflicts of interest to declare.

Funding

This study was financially supported by Tabriz University of Medical Sciences (Project No: 70938).

Availability of Data

All study-related data are included in the publication or provided as supplementary information.

References

1. International Diabetes Federation (BE). Facts & figures [Internet]. International Diabetes Federation; 2025 [cited 2025 Feb 11]. Available from: https://idf.org/about-diabetes/diabetes-facts-figures.
2. Safiri S, Karamzad N, Kaufman JS, et al. Prevalence, deaths and Disability-Adjusted-Life-Years (DALYs) due to type 2 diabetes and its attributable risk factors in 204 countries and territories, 1990-2019: results from the global burden of disease study 2019. Front Endocrinol (Lausanne) 2022;13:838027.
3. Usman MS, Khan MS, Butler J. The interplay between diabetes, cardiovascular disease, and kidney disease. ADA Clin Compend 2021;2021:13–8.
4. Centers for Disease Control and Prevention (CDC) (US). Diabetes risk factors [Internet]. CDC; 2024 [cited 2025 Feb 11]. Available from: https://www.cdc.gov/diabetes/risk-factors/index.html.
5. Fulop T, Tessier D, Carpentier A. The metabolic syndrome. Pathol Biol (Paris) 2006;54:375–86.
6. Sies H. Oxidative stress: from basic research to clinical application. Am J Med 1991;91(3C):31S–38S.
7. Dierckx N, Horvath G, van Gils C, et al. Oxidative stress status in patients with diabetes mellitus: relationship to diet. Eur J Clin Nutr 2003;57:999–1008.
8. Meulmeester FL, Luo J, Martens LG, et al. Antioxidant supplementation in oxidative stress-related diseases: what have we learned from studies on alpha-tocopherol? Antioxidants (Basel) 2022;11:2322.
9. Dandona P, Thusu K, Cook S, et al. Oxidative damage to DNA in diabetes mellitus. Lancet 1996;347:444–5.
10. Kheirouri S, Alizadeh M. Dietary inflammatory potential and the risk of neurodegenerative diseases in adults. Epidemiol Rev 2019;41:109–20.
11. Avila-Escalante ML, Coop-Gamas F, Cervantes-Rodriguez M, et al. The effect of diet on oxidative stress and metabolic diseases: clinically controlled trials. J Food Biochem 2020;44:e13191.
12. Dai J, Jones DP, Goldberg J, et al. Association between adherence to the Mediterranean diet and oxidative stress. Am J Clin Nutr 2008;88:1364–70.
13. Dandona P, Mohanty P, Hamouda W, et al. Inhibitory effect of a two day fast on reactive oxygen species (ROS) generation by leucocytes and plasma ortho-tyrosine and meta-tyrosine concentrations. J Clin Endocrinol Metab 2001;86:2899–902.
14. Dandona P, Aljada A, Bandyopadhyay A. Inflammation: the link between insulin resistance, obesity and diabetes. Trends Immunol 2004;25:4–7.
15. Montonen J, Knekt P, Jarvinen R, et al. Dietary antioxidant intake and risk of type 2 diabetes. Diabetes Care 2004;27:362–6.
16. Wang X, Ouyang Y, Liu J, et al. Fruit and vegetable consumption and mortality from all causes, cardiovascular disease, and cancer: systematic review and dose-response meta-analysis of prospective cohort studies. BMJ 2014;349:g4490.
17. Fardet A, Richonnet C, Mazur A. Association between consumption of fruit or processed fruit and chronic diseases and their risk factors: a systematic review of meta-analyses. Nutr Rev 2019;77:376–87.
18. Wang Y, Yang M, Lee SG, et al. Dietary total antioxidant capacity is associated with diet and plasma antioxidant status in healthy young adults. J Acad Nutr Diet 2012;112:1626–35.
19. Ko SH, Choi SW, Ye SK, et al. Comparison of the antioxidant activities of nine different fruits in human plasma. J Med Food 2005;8:41–6.
20. Harasym J, Oledzki R. Effect of fruit and vegetable antioxidants on total antioxidant capacity of blood plasma. Nutrition 2014;30:511–7.
21. Serafini M, Del Rio D. Understanding the association between dietary antioxidants, redox status and disease: is the Total Antioxidant Capacity the right tool? Redox Rep 2004;9:145–52.
22. Puchau B, Zulet MA, de Echavarri AG, et al. Dietary total antioxidant capacity: a novel indicator of diet quality in healthy young adults. J Am Coll Nutr 2009;28:648–56.
23. Rautiainen S, Serafini M, Morgenstern R, et al. The validity and reproducibility of food-frequency questionnaire-based total antioxidant capacity estimates in Swedish women. Am J Clin Nutr 2008;87:1247–53.
24. Sadowska-Bartosz I, Bartosz G. Evaluation of the antioxidant capacity of food products: methods, applications and limitations. Processes 2022;10:2031.
25. Munteanu IG, Apetrei C. Analytical methods used in determining antioxidant activity: a review. Int J Mol Sci 2021;22:3380.
26. Baharirad N, Pasdar Y, Nachvak M, et al. The relationship of dietary total antioxidant capacity with sarcopenia and cardiometabolic biomarkers in type 2 diabetes patients. Physiol Rep 2022;10:e15190.
27. Capas M, Kaner G, Soylu M, et al. The relationship between plasma total antioxidant capacity and dietary antioxidant status in adults with type 2 diabetes. Prog Nutr 2018;20:67–75.
28. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev 2015;4:1.
29. Bahadoran Z, Golzarand M, Mirmiran P, et al. Dietary total antioxidant capacity and the occurrence of metabolic syndrome and its components after a 3-year follow-up in adults: Tehran Lipid and Glucose Study. Nutr Metab (Lond) 2012;9:70.
30. Cetiner O, Sendur S, Yalcin T, et al. Dietary total antioxidant capacity and oxidative stress in patients with type-2 diabetes. Prog Nutr 2021;23:e2021050.
31. Chen X, Lu H, Chen Y, et al. Composite dietary antioxidant index was negatively associated with the prevalence of diabetes independent of cardiovascular diseases. Diabetol Metab Syndr 2023;15:183.
32. Cyunczyk M, Zujko ME, Jamiolkowski J, et al. Dietary total antioxidant capacity is inversely associated with prediabetes and insulin resistance in Bialystok PLUS population. Antioxidants (Basel) 2022;11:283.
33. Daneshzad E, Tehrani H, Bellissimo N, et al. Dietary total antioxidant capacity and gestational diabetes mellitus: a case-control study. Oxid

Med Cell Longev 2020;2020:5471316.
34. Fagherazzi G, Gusto G, Mancini FR, et al. Determinants of 20-year non-progression to Type 2 diabetes in women at very high risk: the E3N cohort study. Diabet Med 2018;35:1716–21.
35. El Frakchi N, El Kinany K, El Baldi M, et al. Association of dietary total antioxidant capacity with general and abdominal obesity in type 2 diabetes mellitus patients. PLoS One 2024;19:e0306038.
36. Kashino I, Serafini M, Kurotani K, et al. Relationship between dietary non-enzymatic antioxidant capacity and type 2 diabetes risk in the Japan Public Health Center-based Prospective Study. Nutrition 2019;66:62–9.
37. Li X, Xue Y, Zhang Y, et al. Association between dietary antioxidant capacity and type 2 diabetes mellitus in Chinese adults: a population-based cross-sectional study. Nutr Metab (Lond) 2024;21:16.
38. Liu S, Zhu Z, Yu K, et al. The association between composite dietary antioxidant index and diabetic retinopathy in type 2 diabetic patients: evidence from the NHANES. Front Nutr 2024;11:1399763.
39. Mancini FR, Affret A, Dow C, et al. Dietary antioxidant capacity and risk of type 2 diabetes in the large prospective E3N-EPIC cohort. Diabetologia 2018;61:308–16.
40. van der Schaft N, Schoufour JD, Nano J, et al. Dietary antioxidant capacity and risk of type 2 diabetes mellitus, prediabetes and insulin resistance: the Rotterdam Study. Eur J Epidemiol 2019;34:853–61.
41. Tan LJ, Hwang SB, Jun S, et al. Dietary antioxidant consumption and the risk of type 2 diabetes in South Korean adults: a prospective cohort study based on the Health Examinees study. BMJ Open 2022;12:e065073.
42. Zujko ME, Witkowska AM, Gorska M, et al. Reduced intake of dietary antioxidants can impair antioxidant status in type 2 diabetes patients. Pol Arch Med Wewn 2014;124:599–607.
43. Zujko ME, Waskiewicz A, Witkowska AM, et al. Dietary total antioxidant capacity and dietary polyphenol intake and prevalence of metabolic syndrome in polish adults: a nationwide study. Oxid Med Cell Longev 2018;2018:7487816.
44. Heshmati S, Moludi J, Nachvak SM, et al. The association of dietary total antioxidant capacity and gestational diabetes: a prospective cohort study from the Mothers and their children's health (MATCH). Nutr Diabetes 2024;14:78.
45. Roumi Z, Kamali M, Mirshafaei MA, et al. The association between type 2 diabetes and dietary antioxidant index: a cross-sectional study in the Iranian population. Arch Endocrinol Metab 2024;68:e240170.
46. Zhou L, Xu X, Li Y, et al. Association between dietary antioxidant levels and diabetes: a cross-sectional study. Front Nutr 2024;11:1478815.
47. Rahmani J, Parastouei K, Taghdir M, et al. Healthy eating index-2015 and dietary total antioxidant capacity as predictors of prediabetes: a case-control study. Int J Endocrinol 2021;2021:2742103.
48. Sotoudeh G, Abshirini M, Bagheri F, et al. Higher dietary total antioxidant capacity is inversely related to prediabetes: a case-control study. Nutrition 2018;46:20–5.
49. Daneshzad E, Keshavarz SA, Qorbani M, et al. Dietary total antioxidant capacity and its association with sleep, stress, anxiety, and depression score: a cross-sectional study among diabetic women. Clin Nutr ESPEN 2020;37:187–94.
50. Galarregui C, Zulet MA, Cantero I, et al. Interplay of glycemic index, glycemic load, and dietary antioxidant capacity with insulin resistance in subjects with a cardiometabolic risk profile. Int J Mol Sci 2018;19:3662.
51. Hermsdorff HH, Puchau B, Volp AC, et al. Dietary total antioxidant capacity is inversely related to central adiposity as well as to metabolic and oxidative stress markers in healthy young adults. Nutr Metab (Lond) 2011;8:59.
52. Okubo H, Syddall HE, Phillips DI, et al. Dietary total antioxidant capacity is related to glucose tolerance in older people: the Hertfordshire Cohort Study. Nutr Metab Cardiovasc Dis 2014;24:301–8.
53. Psaltopoulou T, Panagiotakos DB, Pitsavos C, et al. Dietary antioxidant capacity is inversely associated with diabetes biomarkers: the ATTICA study. Nutr Metab Cardiovasc Dis 2011;21:561–7.
54. Puchau B, Zulet MA, de Echavarri AG, et al. Dietary total antioxidant capacity is negatively associated with some metabolic syndrome features in healthy young adults. Nutrition 2010;26:534–41.
55. Salavatizadeh M, Soltanieh S, Poustchi H, et al. Dietary total antioxidant capacity is inversely associated with the odds of non-alcoholic fatty liver disease in people with type-2 diabetes. Front Nutr 2022;9:1037851.
56. Sezavar H, Yousefi R, Abbasi M, et al. Anthropometric and biochemical measures in bariatric surgery candidates: what is the role of inflammatory potential of diet? Obes Surg 2021;31:3097–108.
57. Sohouli MH, Fatahi S, Sayyari A, et al. Associations between dietary total antioxidant capacity and odds of non-alcoholic fatty liver disease (NAFLD) in adults: a case-control study. J Nutr Sci 2020;9:e48.
58. Jimenez-Ortega RF, Meneses-Leon J, Hernandez S, et al. High dietary antioxidant index associated with reduced insulin resistance in female Mexican children and adolescents. Nutr Res 2024;132:53–66.
59. Tandorost A, Kheirouri S, Moludi J, et al. Association of Dietary Inflammatory Index (DII) with disease activity and inflammatory cytokines in the patients with rheumatoid arthritis. Int J Clin Pract 2021;75:e14792.
60. Keramati M, Kheirouri S, Musazadeh V, et al. Association of high dietary acid load with the risk of cancer: a systematic review and meta-analysis of observational studies. Front Nutr 2022;9:816797.
61. Harvard T.H. Chan School of Public Health (US). Antioxidants [Internet]. Harvard T.H. Chan School of Public Health; 2025 [cited 2025 Mar 3]. Available from: https://nutritionsource.hsph.harvard.edu/antioxidants/.
62. Jayedi A, Rashidy-Pour A, Parohan M, et al. Dietary antioxidants, circulating antioxidant concentrations, total antioxidant capacity, and risk of all-cause mortality: a systematic review and dose-response meta-analysis of prospective observational studies. Adv Nutr 2018;9:701–16.

https://doi.org/10.24171/j.phrp.2024.0337

63. Wang W, Wang X, Cao S, et al. Dietary antioxidant indices in relation to all-cause and cause-specific mortality among adults with diabetes: a prospective cohort study. Front Nutr 2022;9:849727.
64. Giorgio M, Rigobello MP. The role of antioxidant foods and nutraceuticals in ageing. Antioxidants (Basel) 2024;13:839.
65. Deledda A, Annunziata G, Tenore GC, et al. Diet-derived antioxidants and their role in inflammation, obesity and gut microbiota modulation. Antioxidants (Basel) 2021;10:708.
66. Caturano A, D'Angelo M, Mormone A, et al. Oxidative stress in type 2 diabetes: impacts from pathogenesis to lifestyle modifications. Curr Issues Mol Biol 2023;45:6651–66.
67. Johansen JS, Harris AK, Rychly DJ, et al. Oxidative stress and the use of antioxidants in diabetes: linking basic science to clinical practice. Cardiovasc Diabetol 2005;4:5.
68. Abu Khadra KM, Bataineh MI, Khalil A, et al. Oxidative stress and type 2 diabetes: the development and the pathogenesis, Jordanian cross-sectional study. Eur J Med Res 2024;29:370.
69. Liu K, Chen Z, Liu L, et al. Causal effects of oxidative stress on diabetes mellitus and microvascular complications: insights integrating genome-wide mendelian randomization, DNA methylation, and proteome. Antioxidants (Basel) 2024;13:903.
70. Shabalala SC, Johnson R, Basson AK, et al. Detrimental effects of lipid peroxidation in type 2 diabetes: exploring the neutralizing influence of antioxidants. Antioxidants (Basel) 2022;11:2071.
71. Hannan PA, Khan JA, Ullah I, et al. Synergistic combinatorial antihyperlipidemic study of selected natural antioxidants; modulatory effects on lipid profile and endogenous antioxidants. Lipids Health Dis 2016;15:151.
72. Meigs JB, Larson MG, Fox CS, et al. Association of oxidative stress, insulin resistance, and diabetes risk phenotypes: the Framingham Offspring Study. Diabetes Care 2007;30:2529–35.
73. Park K, Gross M, Lee DH, et al. Oxidative stress and insulin resistance: the coronary artery risk development in young adults study. Diabetes Care 2009;32:1302–7.
74. Wang M, Liu Y, Liang Y, et al. Systematic understanding of pathophysiological mechanisms of oxidative stress-related conditions: diabetes mellitus, cardiovascular diseases, and ischemia-reperfusion injury. Front Cardiovasc Med 2021;8:649785.
75. Rehman K, Akash MS. Mechanisms of inflammatory responses and development of insulin resistance: how are they interlinked? J Biomed Sci 2016;23:87.
76. Luu HN, Wen W, Li H, et al. Are dietary antioxidant intake indices correlated to oxidative stress and inflammatory marker levels? Antioxid Redox Signal 2015;22:951–9.
77. Beharka AA, Han SN, Adolfsson O, et al. Long-term dietary antioxidant supplementation reduces production of selected inflammatory mediators by murine macrophages. Nutr Res 2000;20:281–96.
78. Evans JL, Goldfine ID, Maddux BA, et al. Are oxidative stress-activated signaling pathways mediators of insulin resistance and beta-cell dysfunction? Diabetes 2003;52:1–8.
79. Christensen AA, Gannon M. The beta cell in type 2 diabetes. Curr Diab Rep 2019;19:81.
80. Gerber PA, Rutter GA. The role of oxidative stress and hypoxia in pancreatic beta-cell dysfunction in diabetes mellitus. Antioxid Redox Signal 2017;26:501–18.
81. Leenders F, Groen N, de Graaf N, et al. Oxidative stress leads to β-cell dysfunction through loss of β-cell identity. Front Immunol 2021;12:690379.
82. Sheethal G, Tokala RK, Pondugala P, et al. Dietary green tea extract and antioxidants improve insulin secretory functions of pancreatic β-cells in mild and severe experimental rodent model of chronic pancreatitis. Open J Endocr Metab Dis 2024;14:53–72.
83. Moens C, Muller CJF, Bouwens L. In vitro comparison of various antioxidants and flavonoids from Rooibos as beta cell protectants against lipotoxicity and oxidative stress-induced cell death. PLoS One 2022;17:e0268551.
84. Fariña E, Daghero H, Bollati-Fogolín M, et al. Antioxidant capacity and NF-kB-mediated anti-inflammatory activity of six red Uruguayan grape pomaces. Molecules 2023;28:3909.
85. Hegazy AM, El-Sayed EM, Ibrahim KS, et al. Dietary antioxidant for disease prevention corroborated by the Nrf2 pathway. J Complement Integr Med 2019;16:20180161.
86. Lingappan K. NF-κB in oxidative stress. Curr Opin Toxicol 2018;7:81–6.
87. Ngo V, Duennwald ML. Nrf2 and oxidative stress: a general overview of mechanisms and implications in human disease. Antioxidants (Basel) 2022;11:2345.
88. Krawczyk M, Burzynska-Pedziwiatr I, Wozniak LA, et al. Impact of polyphenols on inflammatory and oxidative stress factors in diabetes mellitus: nutritional antioxidants and their application in improving antidiabetic therapy. Biomolecules 2023;13:1402.
89. Tkaczenko H, Kurhaluk N. Antioxidant-rich functional foods and exercise: unlocking metabolic health through Nrf2 and related pathways. Int J Mol Sci 2025;26:1098.
90. Kheirouri S, Alizadeh M. Vitamin D and advanced glycation end products and their receptors. Pharmacol Res 2020;158:104879.
91. Vahid F, Rahmani D, Davoodi SH. Validation of Dietary Antioxidant Index (DAI) and investigating the relationship between DAI and the odds of gastric cancer. Nutr Metab (Lond) 2020;17:102.
92. Jewell DE, Motsinger LA, Paetau-Robinson I. Effect of dietary antioxidants on free radical damage in dogs and cats. J Anim Sci 2024;102:skae153.