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The relationship between ultra-processed food consumption and advanced glycation end products in university students: evidence from the skin autofluorescence method

Ayşe Gül Çeçen[1,2] and Gözde Dumlu Bilgin[3*]

Abstract

Background Ultra-processed foods (UPFs) contribute substantially to total dietary energy intake and have been linked to various non-communicable diseases (NCDs). During industrial processing, UPFs are exposed to high heat, producing advanced glycation end products (AGEs). However, it remains unclear whether the consumption of AGE-rich UPFs influences AGE accumulation in skin collagen. This study aimed to examine the potential association between the frequency of UPF consumption and skin AGE levels among university students.

Methods This cross-sectional study included university students at a foundation university in Istanbul between 2022 and 2023. Data including sociodemographic characteristics, health information, anthropometric measurements, skin AGE levels, 24-hour recall, and UPF frequency were gathered via face-to-face interviews.

Results The total sample included 535 participants (63.6% women) with a mean age of 20.9 ± 3.7 years. The percentage of UPF consumption was 35.2 ± 28.6%, with no significant difference between genders. The main contributors to the UPF intake of the students are chocolate (17%), carbonated beverages (11.8%), and packaged biscuits (9.3%), which have a high daily consumption rate. The average skin AGE levels for the overall students was 1.48 AU, significantly higher in women (1.49 AU) than men (1.45) ($p = 0.041$). However, the association between UPF consumption percentage and AGE levels were not statistically significant ($p = 0.168$).

Conclusions The consumption of UPF is a prevalent phenomenon among university students. Although this highlights the importance of elucidating the relationship between UPF consumption and skin AGE accumulation to prevent potential risks, our findings did not demonstrate a significant association between the two variables. Nonetheless, the use of non-invasive skin AGE measurement (SAF) remains a valuable tool for assessing long-term AGE-related health risks. Further comprehensive studies are required to gain a deeper understanding of this subject.

The manuscript is derived from the master's thesis of the first author. A preliminary version of the study was previously presented in abstract form as an oral presentation at the XI. International Nutrition & Dietetics Congress, Ankara, Türkiye.

*Correspondence:
Gözde Dumlu Bilgin
gozde.dumlu@yeditepe.edu.tr

Full list of author information is available at the end of the article

Keywords Advanced glycation end products, Ultra processed foods, Skin autofluorescence method, Nutrition

Introduction

The university student represents a demographic group experiencing typical alterations and exposure to risks during the period of transition from adolescent to mid-adult [1]. The lack of time for planning the daily diet of university students, combined with limited budget, inadequate cooking skills, and accessibility, generally leads to diets based mainly on ready-to-eat or quickly prepared meals made from ultra-processed foods (UPFs) [2].

UPFs have been defined as products that are ready-to-eat or ready-to-reheat as a consequence of different industrial processes. They typically consist of five or more components, including added sugars, refined vegetable oils, refined flours, additives, and preservatives [3, 4]. Such foods are calorie-dense, highly glycemic, high in fat or salt, and low in fiber, protein, several micronutrients, and other bioactive substances [5]. The consumption of large amounts of UPFs disrupts the regulation of energy, leading to an increased risk of weight gain and chronic non-communicable diseases (NCDs) like cardiovascular disease (CVD), type 2 diabetes, and cancer [6, 7]. Moreover, a number of non-enzymatic and biochemical reactions can occur during food processing, and the Maillard Reaction (MR), non-enzymatically formed between reducing sugars and the amino groups of proteins, is the most predominant reaction that occurs after heat treatment [8]. As the reaction proceeds, a large number of Maillard Reaction Products (MRPs) with different sizes and chemical structures can be formed, including unwanted carcinogenic substances namely acrylamide, heterocyclic amines and 5-hydroxymethylfurfural. Among these, the advanced glycation end products (AGEs) are a group of heterogeneous compounds originating from the "advanced" stage of MR, some of which possess different photo physical properties [9]. Besides these exogenous AGEs, also known as dietary AGEs (dAGEs), the generation of AGEs is part of normal metabolism, and when endogenously formed in high quantities, AGEs exhibit diabetic and pro-inflammatory effects that lead to negative metabolic and vascular health outcomes [8, 10]. Both endogenous and exogenous AGEs can be pathogenic when they reach excessive levels in tissues and circulation, contributing to the progression of chronic and age-related diseases, such as obesity, CVD, diabetes mellitus, renal failure, autoimmune diseases, and Alzheimer's disease [11, 12].

AGEs in the human body can be measured in blood serum or plasma; however, these levels don't accurately represent tissue concentrations, as most circulating proteins have a high turnover rate compared to long-lived tissue proteins like collagen. Assessing AGE levels in tissue requires biopsies, which are invasive and cannot be performed on a large scale [13]. During the recent years, it has become possible to determine AGE accumulation in tissues non-invasively via measurement of skin auto fluorescence (SAF) [12]. This advancement has facilitated broader research into the clinical significance of tissue AGEs, as recent studies suggest that SAF is associated with all-cause mortality as well as cardiovascular and cancer-related mortality in the general population [14] and early detection of irreversible complications and cardiovascular risk of patients with diabetes [15, 16].

Concurrently, dietary intake has emerged as a key modifiable factor influencing AGE accumulation. The increasing consumption of UPFs-which are known to contain high levels of dAGEs-has raised concerns about their impact on health, particularly among young adults such as university students, whose dietary habits are often characterized by high UPF intake [4]. This trend underscores the importance of investigating whether habitual consumption of UPFs contributes to tissue AGE accumulation and the subsequent risk of related chronic diseases. Therefore, with this study, we hypothesized to (1) determine students' UPF intake, (2) measure tissue AGE levels using the SAF method and (3) to explore the potential relationship between these concepts. By addressing these aims, we seek to contribute original data to the growing body of literature on dietary influences on AGE accumulation, with implications for public health and preventive nutrition strategies.

Methods

Participants and data collection

The study sample size was determined based on an a priori power analysis conducted using G*Power software (version 3.1.9.7). The analysis was based on a medium effect size (Cohen's d = 0.5), a significance level of α = 0.05, and a statistical power of 0.80. The results indicated that a minimum of 359 participants would be needed to detect a statistically significant effect under these conditions. A proportional stratified sampling design was employed: the total target sample was allocated to each faculty in proportion to its student population, and participants were recruited within each faculty among volunteers until the planned quota for that faculty was reached. The final study population comprised 535 volunteer young adults aged 18 years and over, who were enrolled in different faculties at a foundation university in Istanbul during the 2022–2023 academic years. Participants with dark skin tones, scars, and/or tattoos on the inner arm were excluded due to concerns that these factors could distort SAF-AGE measurements. In addition, students majoring in nutrition and dietetics were not included in the study. Furthermore, individuals who did not complete

the questionnaire were also excluded. A participant flow chart is provided in Fig. 1.

The data collection instrument for the study comprised four subsections, including sociodemographic information, inquiries regarding health and nutrition, 24-hour food recalls, and the determination of UPF consumption based on questions derived from existing literature (Supplementary data). Subsequent to the collection of these data, anthropometric measurements were obtained from the participants, and skin AGE levels were measured.

Dietary intake

A 24-hour food recall was obtained to analyze the energy and nutrient intakes of the individuals. Daily energy, macro- and micronutrient intakes of the consumed foods were analyzed using *Nutrition Information Systems Package Program (BeBIS 9.0)* designed for Türkiye.

A questionnaire based on existing literature was created to assess the frequency of UPF consumption, with options including daily, every other day, 1–2 times a week, once every 15 days, once a month, and never. It included 7 categories: milk and dairy products, meat and meat products, bread and derivatives, oils, sweets and confectionery, beverages, and ready or packaged foods, covering 58 types of UPF.

Anthropometric measures

The anthropometric measurements obtained included height, body weight, waist circumference (WC), and hip circumference. The researcher performed the measurements of the participants' body weights on a flat and hard surface with a *Tanita SC 330* body analyzer, which has a sensitivity of 0.1 kg. The participants fasted and wore thin clothes for the duration of the measurement. The researcher employed a stadiometer to ascertain the participants' height, with their heads positioned in the Frankfort plane (where the eye triangle and the top of the auricle are aligned parallel to the ground). The participants were instructed to stand upright with their feet side by side.

Body Mass Index (BMI) (kg/m^2) was subsequently calculated using the following equation: "body weight (kg)/height (m^2)." The BMI of the participants were then categorized as follows according to the World Health Organization (WHO) criteria: underweight (BMI < 18.5 kg/m^2), normal (18.5–24.99 kg/m^2), overweight (25.0–29.99 kg/m^2), and obese (BMI ≥ 30.0 kg/m^2) [17]. Waist and hip circumferences of participants were measured using an inflexible tape measure, and their ratios were calculated. Men with a WC below 94 cm are considered normal, 94–102 cm as at increased risk and above 102 cm as high risk. For women, a WC below 80 cm is normal, 80–88 cm

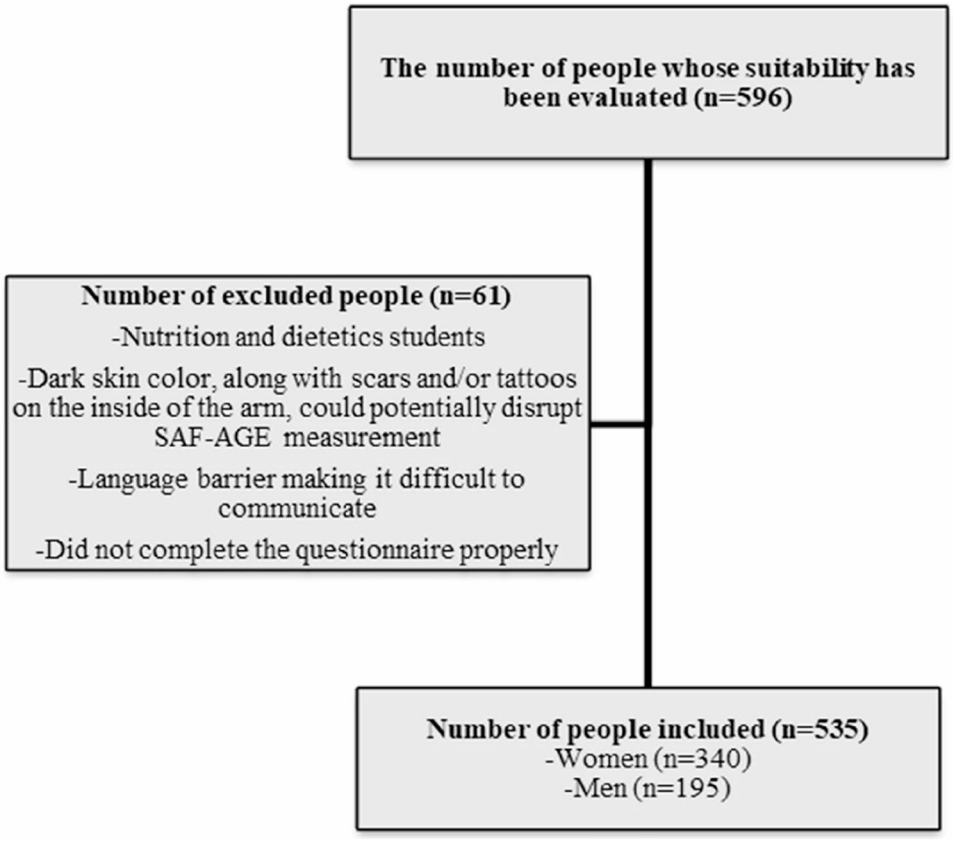

Fig. 1 Flow chart of the study

is at increased risk, and above 88 cm is high risk. In the Waist/Hip Ratio (WHR) classification, men with a WHR below 0.90 are normal, while those above 0.90 are at risk. For women, a WHR below 0.85 is normal and above 0.85 is at risk. A waist/height ratio above 0.5 is considered risky for both genders [17].

Skin auto fluorescence (SAF)

SAF was determined noninvasively through the utilization of a calibrated AGE reader *(DiagnOptics Technologies, Groningen, The Netherlands.* The investigator measured skin AGE levels on the forearm, specifically the area 10–15 cm below the elbow crease, while participants were in a seated position at room temperature. The AGE reader is equipped with a light source that generates light within the wavelength range of 300 to 420 nanometers (nm). During the measurement, the anterior surface of the arm is positioned against the AGE reader, and the light emitted and reflected within the 300 to 600-nm range is measured by a spectrometer. The SAF is then calculated by determining the ratio of emitted light (420–600 nm) to excited light (300–420 nm), and the result is presented in arbitrary units (AU) [14].

Statistics

Sample characteristics were expressed as mean ± standard deviation (SD) for continuous variables and as percentages (%) and numbers (n) for qualitative variables. The data collected for this study were analyzed utilizing the Statistical Package for the Social Sciences (SPSS) version 26.0 for Windows. Number, percentage, mean, and standard deviation were used as descriptive statistical methods to evaluate the data. The normality of the numerical data was determined according to the Kolmogorow-Smirnow test. The Mann-Whitney U test is employed to compare quantitative continuous data between two independent groups. Spearman correlation analysis was applied between the continuous variables of the study. Correlation coefficients were evaluated as 0.00–0.25.00.25, very weak; 0.26–0.49, weak; 0.50–0.69, moderate; 0.70–0.89, high; 0.90–1.00.90.00, very high. Statistical significance was accepted in all analyses if the p-value was less than 0.05.

Results

The general characteristics of the participants, including their nutritional status and anthropometric measurements, are provided exclusively in Table 1.

A total of 535 university students (mean age: 20.0 ± 3.7 years) were enrolled in the study, with women comprising the majority of the sample (63.6%). The majority of participants was nonsmokers (75.1%), did not drink alcohol (88.0%), lived at home (83.7%), and did not exercise at all (36.1%). When the participants' meal patterns were examined, it was recorded that the participants usually consumed 2 main meals (58.5%) and 1 snack (44.3). The majority of those who skipped main meals stated that they did not have time (28.4%), while the main reason for skipping snacks was that they were not hungry (33.8%). 37.9% of the students stated that they ate out 1–2 times a week, while 80.2% stated that they ate fast food.

Significant gender-based differences were observed in several anthropometric and dietary variables. Men had a significantly higher mean BMI (24.2 kg/m²) compared to women (22.5 kg/m²) ($p < 0.001$). In addition, men showed significantly greater WC, WHR, waist-to-height ratio, and body weight, whereas women had a significantly higher body fat percentage ($p < 0.001$). No significant differences were found in total energy and fat intake between genders; however, protein and cholesterol intakes were significantly higher among men ($p < 0.001$). Although the percentage of UPF consumption was higher among women (36.7%) than men (32.5%), this difference was not statistically significant ($p = 0.081$). Conversely, SAF levels were significantly higher in women (1.49 AU) than in men (1.45 AU) ($p = 0.041$).

The frequency of UPF consumption, as reported by participants, is presented in Table 2. The most frequently consumed UPFs on a daily basis were chocolate (17%), carbonated beverages (11.8%), mass-produced packaged bread (11%). When ranked by consumption percentage, the most commonly consumed UPFs at a frequency of at least 1–2 times per week were potato chips (43.7%), chocolate (35.9%), Ready-made sauces (ketchup, mayonnaise, hot sauce, etc.) (35.5%), and packaged biscuits (35.5%). These findings reveal a high and regular prevalence of UPF consumption among university students.

As presented in Table 3, the analysis of the relationship between anthropometric parameters and skin AGE levels revealed no statistically significant correlations between AGE levels and BMI, body weight, body fat percentage, waist and hip circumference, WHR, or waist-to-height ratio ($p > 0.05$). Additionally, Spearman correlation analysis revealed no significant association between the percentage of UPF consumption and skin AGE levels ($r = 0.06$, $p = 0.168$; $p > 0.05$). As shown in Fig. 2, the scatter plot visually supports this finding by illustrating that data points are widely dispersed across the entire range of UPF intake, with no apparent linear trend or clustering pattern. Taken together, these results indicate that in this sample of university students, UPF consumption and anthropometric indices exhibit no statistically significant associations with skin AGE accumulation.

Discussion

This study represents one of the few original contributions that assess both the frequency of UPF consumption and skin AGE levels using the SAF method in a university student population.

Table 1 General characteristics of students by gender

	(Mean ± SD)			
Variables	**Women (*n* = 340)**	**Men (*n* = 195)**	**Overall (*n* = 535)**	***p*-value**
Age (years)	21.0 ± 4.0	20.8 ± 3.2	20.9 ± 3.7	0.992
Smoking, (no), n (%)	264 (77.6)	138 (70.8)	402 (75.1)	1.000
Alcohol consumption, (no), n (%)	308 (90.5)	163 (83.6)	471 (88.0)	0.487
Where they stay, n (%)				
Dormitory	51 (15)	33 (16.9)	84 (15.7)	0.837
House	287 (84.4)	161 (82.6)	448 (83.7)	
Hotel	2 (0.6)	1 (0.5)	3 (0.6)	
Number of main meal, n (%)				
1 meal	29 (8.5)	12 (6.2)	41 (7.7)	0.013*
2 meals	213 (62.6)	100 (51.3)	313 (58.5)	
3 meals	82 (24.1)	67 (34.4)	149 (27.9)	
4 meals	16 (4.7)	16 (8.2)	32 (6)	
Reason for skipping main meals, n (%)				
Don't skip	44 (12.9)	38 (19.5)	82 (15.3)	< 0.001**
I'm not hungry/I have no appetite	132 (38.8)	47 (24.1)	179 (15.3)	
I have time/I am running late	80 (23.5)	72 (36.9)	152 (28.4)	
To lose weight	26 (7.6)	6 (3.1)	32 (6)	
I don't have the habit	43 (12.6)	21 (10.8)	64 (12)	
Other	15 (4.4)	11 (5.6)	26 (4.9)	
Number of snack meal, n (%)				
None	57 (16.8)	35 (17.9)	92 (17.2)	0.267
1 time	151 (44.4)	86 (44.1)	237 (44.3)	
2 times	101 (29.7)	51 (26.2)	152 (28.4)	
3 times	24 (7.1)	22 (11.3)	46 (8.6)	
More than 3 times	7 (2.1)	1 (0.5)	8 (1.5)	
Reason for skipping snack meal, n (%)				
None	39 (11.5)	35 (17.9)	74 (13.8)	0.009**
I'm not hungry	116 (34.1)	62 (31.8)	170 (33.8)	
I don't have time	41 (12.1)	38 (19.5)	80 (14.8)	
To lose weight	31 (9.1)	8 (4.1)	39 (7.3)	
I don't have the habit	65 (19.1)	23 (11.8)	93 (16.4)	
Because it's not prepared/Didn't prepare it	23 (6.8)	13 (6.7)	36 (6.7)	
Other	25 (7.4)	16 (8.2)	41 (7.7)	
Frequency of eating out, n (%)				
None	12 (3.5)	13 (6.7)	25 (4.7)	0.005**
Every Day	23 (6.8)	20 (10.3)	43 (8)	
3–4 times a week	75 (22.1)	59 (30.3)	134 (25)	
1–2 times a week	133 (39.1)	70 (35.9)	203 (37.9)	
1–2 times a month	97 (28.5)	33 (16.9)	130 (24.3)	
Preferred food when dining out, n (%)				
None	12 (3.5)	13 (6.7)	25 (4.7)	0.336
Fast-Food	277 (81.5)	152 (77.9)	429 (80.2)	
Home Cooked Meal	37 (10.9)	24 (12.3)	61 (11.4)	
Other (kebab. iskender etc.)	14 (4.1)	6 (3.1)	20 (3.7)	
Exercise frequency, n (%)				
Everyday	18 (5.3)	25 (12.8)	43 (8)	< 0.001**
4–5 times a week	18 (5.3)	31 (15.9)	49 (9.2)	
2–3 times a week	74 (21.8)	48 (24.6)	122 (22.8)	
Once a week	88 (25.9)	40 (20.5)	128 (23.9)	
None	142 (41.8)	51 (26.2)	193 (36.1)	
Anthropometric measures				
BMI (kg/m^2)	22.5 ± 4.5	24.2 ± 4.5	23.1 ± 4.6	< 0.001**

Table 1 (continued)

	(Mean ± SD)			
Variables	**Women (*n* = 340)**	**Men (*n* = 195)**	**Overall (*n* = 535)**	***p*-value**
BMI classification (n%)				
Underweight	49 (14.4)	17 (8.7)	66 (12.3)	< 0.001**
Normal	212 (62.4)	102 (52.3)	314 (58.7)	
Overweight	54 (15.9)	55 (28.2)	109 (20.4)	
Obesity	25 (7.4)	21 (10.8)	46 (20.4)	
Waist (cm)	71.7 ± 9.7	81.0 ± 10.1	75.1 ± 10.8	< 0.001**
Waist/Height	0.4 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	< 0.001**
Waist/Hip	0.7 ± 0.1	0.8 ± 0.1	0.8 ± 0.7	< 0.001**
Fat Percentages (%)	23.2 ± 8.4	17.0 ± 7.5	20.9 ± 8.6	< 0.001**
Food Consumption				
UPF consumption (% ±)	36.7 ± 28.7	32.5 ± 28.4	35.2 ± 28.6	0.081
Energy (kcal/day)	1230.9 ± 514.1	1323.8 ± 595.0	1264.7 ± 546.2	0.112
Protein (g/day)	48.8 ± 23.4	63.5 ± 32.6	54.2 ± 28.0	< 0.001**
Fat (g/day)	56.9 ± 27.2	57.7 ± 30.8	57.2 ± 28.5	0.893
Carbohydrates (g/day)	127.4 ± 66.4	133.9 ± 77.8	129.8 ± 70.8	0.537
Cholesterol (mg/day)	239.7 ± 175.8	351.3 ± 267.4	280.4 ± 220.2	< 0.001**
Saturated fatty acids (g/day)	24.3 ± 16.9	24.1 ± 13.2	24.2 ± 15.6	0.796
Fiber (g/day)	11.3 ± 6.9	11.4 ± 8.2	11.3 ± 7.4	0.556
Sodium (mg/day)	2297.9 ± 1177.4	2512.8 ± 1341.1	2376.2 ± 1242.6	0.830
Potassium (mg/day)	1446.9 ± 656.9	1455.1 ± 777.9	1449.6 ± 702.7	0.730
Water (L/day)	1.6 ± 0.7	1.8 ± 0.7	1.7 ± 0.7	< 0.001**
AGE (AU)	1.49	1.45	1.48	0.041*

AGE Advanced glycation end products, *AU* Arbitrary units, *BMI* Body mass index, *UPF* Ultra-processed food

Categorical variables are presented as frequency (%), and continuous variables as mean ± standard deviation (SD). *p*-values were calculated using the Mann-Whitney U test

* $p < 0.05$, ** $p < 0.01$

In the present study, the mean UPF consumption was 35.19%. This proportion appears to be lower than that reported in a nationally representative study conducted among Turkish adults, in which 44.8% of participants were identified as having high UPF intake [18]. Interestingly, despite targeting a younger population, our findings also indicate a substantially lower prevalence compared to a previous study conducted among Turkish university students, where 69.3% of participants were classified as high UPF consumers [19]. Furthermore, Morino et al.'s systematic review examines global UPF consumption patterns and highlights significant variations across countries and regions. Their analysis revealed that the United States and the United Kingdom had the highest percentages of energy intake from UPFs-generally exceeding 50%-while Italy reported the lowest levels, at approximately 10% [20]. In comparison, the UPF consumption rate observed in the present study was around 30%, placing it within this international range and reflecting a moderate level of UPF intake among the study population. These findings underscore considerable differences in dietary habits and food processing practices worldwide, which may be attributed to variations in sample size, sociodemographic characteristics, dietary assessment tools, or the criteria used to define "high" UPF consumption.

Skin AGE levels, another key variable examined in our study, have attracted growing interest in recent years due to their potential role as non-invasive biomarkers for aging and metabolic health. This increasing research focus reflects the importance of understanding how lifestyle and dietary factors influence AGE accumulation in the skin. Although studies specifically focused on university students are limited, several investigations involving young adults have reported comparable skin AGE levels measured via SAF method. In the current study, the mean skin AGE level among Turkish university students was 1.47 AU. This finding is consistent with a recent study by Erim and Ersoy (2024), who reported a mean level of 1.48 AU among 300 university students (mean age: 22.92 years) in Türkiye [21]. Similarly, studies from Europe have reported slightly higher SAF values among young adults. According to the results of a systematic review and meta-analysis conducted in Spain, skin AGE levels among young adults aged 20–29 ranged between 1.56 and 1.70 AU [22]. In a reference-based study conducted in China, mean skin AGE levels among individuals in the same age group were reported to range between 1.54 and 1.62 AU [23]. Differences in reported skin AGE

Table 2 Frequency of ultra-processed food consumption

UPFs	Every day	Every other day	1–2 times a week	Every 15 days	Once a month	None
Ultra-processed milk and milk product, *n* (%)						
Flavored milk (banana, strawberry, chocolate, etc.)	19 (3.6)	16 (3)	137 (25.6)	74 (13.8)	135 (25.2)	154 (28.8)
Ready-made yogurts (chocolate, fruity)	22 (4.1)	17 (3.2)	96 (17.9)	63 (11.8)	108 (20.2)	229 (42.8)
Ultra-processed meat and meat product, n (%)						
Salami	19 (3.6)	13 (2.4)	132 (24.7)	87 (16.3)	108 (20.2)	176 (32.9)
Chicken nuggets	6 (1.1)	15 (2.8)	117 (21.9)	109 (20.4)	121 (22.6)	167 (31.2)
Ultra-processed bread and bread derivates, n (%)						
Mass-produced packaged bread	59 (11)	20 (3.7)	85 (15.9)	53 (9.9)	61 (11.4)	257 (48)
Noodles	15 (2.8)	25 (4.7)	73 (13.6)	62 (11.6)	94 (17.6)	266 (49.7)
Sugary breakfast cereals	17 (3.2)	16 (3)	77 (14.4)	43 (8)	76 (14.2)	306 (57.2)
Ultra-processed oil derivatives, n (%)						
Margarine	29 (5.4)	21 (3.9)	90 (16.8)	51 (9.5)	71 (13.3)	273 (51)
Spreadable breakfast oil	28 (5.2)	39 (7.3)	94 (17.6)	64 (12)	30 (11.2)	250 (46.7)
Ultra-processed sweets and confectioneries, n (%)						
Packaged biscuits	50 (9.3)	65 (12.1)	190 (35.5)	104 (19.4)	67 (12.5)	59 (11)
Packaged cakes	14 (2.6)	40 (7.5)	153 (28.6)	97 (18.1)	81 (15.1)	150 (28)
Chocolate	91 (17)	87 (16.3)	192 (35.9)	79 (14.8)	46 (8.6)	40 (7.5)
Ultra-processed beverages, n (%)						
Ready-made fruit juices	30 (5.6)	40 (7.5)	126 (23.6)	101 (18.9)	84 (15.7)	154 (28.8)
Carbonated beverages	63(11.8)	60 (11.2)	170 (31.8)	85 (15.9)	74 (13.8)	83 (15.5)
Ready to eat and snacks, n (%)						
Potato chips	26 (4.9)	26 (4.9)	234 (43.7)	81 (15.1)	99 (18.5)	69 (12.9)
Cereal/Granola bars/Energy bars (with nuts, dried fruits, etc.)	12 (2.2)	16 (3)	95 (17.8)	59 (11)	68 (12.7)	285 (53.3)
Ready-made sauces (ketchup, mayonnaise, hot sauce, etc.)	50 (9.3)	53 (9.9)	190 (35.5)	88 (16.4)	79 (14.8)	75 (14)

UPF Ultra-processed food

Categorical variables are presented as frequency (%)

Table 3 Correlation between anthropometric measures and skin AGE levels by gender

Anthropometric measures	AGE (AU)	
	r-value	*p*-value
BMI (kg/m^2)	−0.003	0.949
Weight (kg)	−0.053	0.218
Fat Percentage (%)	0.037	0.391
Waist (cm)	−0.055	0.200
Hip (cm)	−0.074	0.086
Waist/Hip	−0.007	0.879
Waist/Height	−0.015	0.735
UPF consumption percentage (%)	0.060	0.168

AGE Advanced glycation end products, *AU* Arbitrary units, *BMI* Body mass index, *UPF* Ultra-processed food, *r* Spearman's rank correlation coefficient

levels across international studies may be attributed to various factors such as age distribution, ethnic and genetic background, dietary habits, lifestyle factors (e.g., smoking, physical activity), metabolic health status, and technical differences in measurement devices. Additionally, the sensitivity and calibration of SAF measurement devices may vary across studies, potentially contributing to discrepancies in reference values. Moreover, in our study, women exhibited significantly higher skin AGE levels, which is consistent with several studies in the existing literature [24, 25]. Various physiological factors, such as higher body fat percentage in women, hormonal influences, and differences in oxidative stress responses, could contribute to this disparity. Lifestyle factors and dietary habits also differ between men and women may further impact AGE levels.

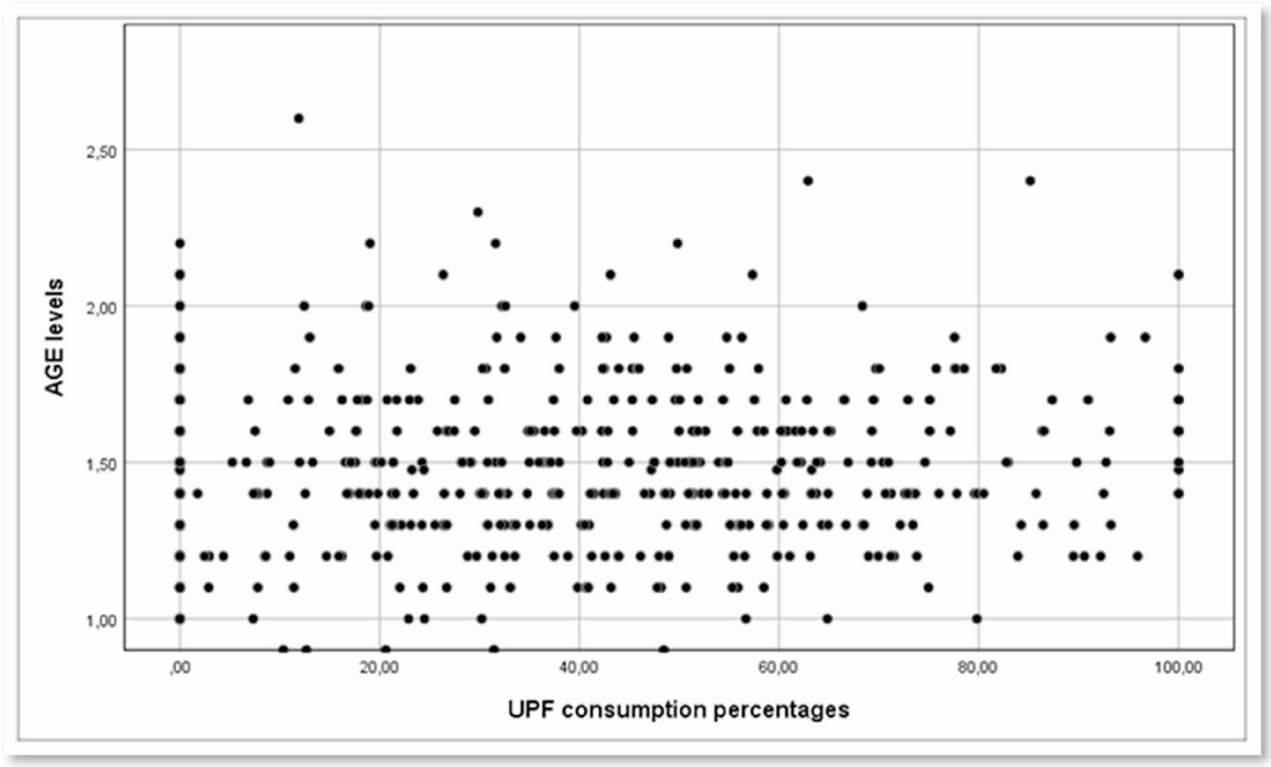

Fig. 2 Scatterplot of UPF Intake vs. SAF-Measured AGEs

In line with our hypothesis, we anticipated that higher frequencies of UPF consumption would be associated with elevated levels of skin AGEs. However, our findings did not support this expectation, as no statistically significant relationship was observed between UPF consumption frequency and skin AGE levels. UPFs are considered a major dietary source of dAGEs due to the industrial processes involving high-temperature cooking, prolonged shelf life, and added sugars and fats. In the large-scale Rotterdam Study, which investigated the association between dAGE intake and skin AGE levels, no significant relationship was found in the general population-a finding that, although focused on direct dAGE intake, is indirectly in line with our results, given that UPFs are a major dietary source of AGEs [26]. Kellow et al. reported that processed meat consumption was positively correlated with higher SAF in healthy adults, though this finding was not UPF-specific [10]. The only available study directly linking UPF consumption to skin AGE levels was conducted in a pediatric population, in which higher UPF intake was significantly associated with increased SAF in children with obesity [27]. The absence of a significant association between UPF consumption and skin AGE accumulation in our study may be attributed to several factors. Firstly, skin AGE levels reflect long-term accumulation and are influenced not only by dietary intake but also by endogenous metabolic processes, individual differences in AGE absorption and clearance, and other lifestyle factors such as sun exposure and smoking, which were not fully controlled for in our study. Secondly, the heterogeneity and variability of UPF products make it challenging to establish a direct link between overall UPF intake and skin AGE levels. Therefore, further longitudinal studies with more comprehensive control of confounding factors are needed to clarify the relationship between UPF consumption and skin AGE accumulation.

Additionally, our findings revealed that skin AGE levels were not significantly associated with anthropometric measures such as BMI, body fat percentage, or WHR is in agreement with several previous studies conducted in healthy adult populations [10, 26]. Furthermore, the ILERVAS Project-a prospective study investigating the prevalence of subclinical atheromatous and kidney disease in individuals with moderate cardiovascular risk, affirm that simple anthropometric measures like BMI are not reliable predictors of skin AGE accumulation in middle-aged adults. Instead, cardiometabolic risk factors appear to play a more decisive role in influencing SAF levels. In line with our results, these data emphasize the importance of considering metabolic health status over anthropometry alone when interpreting AGE deposition [28]. However, contrasting evidence comes from Apaydın and Yavuz (2022), who found significantly higher SAF levels in a large cohort of morbidly obese individuals

compared to controls, independent of the presence of metabolic syndrome or type 2 diabetes. Their findings suggest that in cases of extreme obesity, excess adiposity alone may contribute to increased tissue AGE accumulation [29]. Nevertheless, given the inconsistent findings across studies and the potential influence of confounding factors, the precise role of adiposity in skin AGE accumulation remains unclear and warrants further investigation in diverse populations and clinical settings.

Conclusion

In conclusion, this study offers original insights into the potential relationship between UPF consumption and skin AGE accumulation in a young adult population, utilizing a non-invasive technique (SAF) to assess tissue AGE levels. Although no direct association was found between UPF intake and skin AGE accumulation, the findings still carry important clinical implications. Skin AGE levels have been linked to the pathophysiology of several chronic diseases such as type 2 diabetes, CVD, and renal dysfunction. Therefore, the absence of a relationship in a healthy, young population does not undermine the clinical relevance of AGE monitoring; instead, it underscores the complexity of early AGE accumulation and suggests that other nutritional, metabolic, or environmental factors may be more influential at this life stage. These results highlight the need for longitudinal and intervention-based research to further explore the role of diet in AGE accumulation and to determine whether skin AGE levels could serve as a non-invasive biomarker for long-term metabolic risk.

One of the key strengths of this study lies in its focus on a relatively understudied demographic, university students, and its use of a validated, non-invasive method for assessing tissue AGE accumulation in a real-life setting. Moreover, by examining UPF consumption in detail, the study contributes to the limited body of literature addressing the impact of food processing on health risk indicators. However, the cross-sectional design limits its causal inference, and the homogeneity of the study population may reduce the generalizability of findings. In addition, dietary intake data were collected using self-reported 24-hour recalls, a method that is inherently subject to recall bias and may not accurately capture participants' habitual dietary patterns over time. This limitation could lead to misclassification of dietary exposure, potentially attenuating or exaggerating observed associations. Furthermore, although we aimed to control for confounding variables, key factors such as physical activity levels, psychological stress, and other lifestyle habits that can influence skin AGE accumulation were not measured or adjusted for in the analysis. The absence of these controls may have introduced residual confounding, which could affect the interpretation of the results and limit the ability to draw definitive conclusions.

Despite these limitations, this study contributes valuable insights to the expanding body of evidence regarding the influence of diet quality on AGE accumulation. It also emphasizes the critical need for future longitudinal and well-controlled intervention studies to elucidate the specific dietary determinants of skin AGE levels across larger, more diverse, and representative populations.

Ethics declarations

All of the data was collected using a face-to-face data collection method. This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Research Ethics Committee of Istanbul Esenyurt University (Date: 01.12.2022; Approval No: 2022/11–17). Written informed consent was obtained from all participants prior to their inclusion in the study.

Abbreviations

AGEs	Advanced glycation end products
AU	Arbitrary units
BEBIS	Nutrition information systems package program
BMI	Body mass index
CVD	Cardiovascular disease
dAGE	Dietary advanced glycation end products
MR	Maillard reaction
MRPs	Maillard reaction products
NCDs	Non-communicable diseases
SAF	Skin autofluorescence
SD	Standard deviation
SPSS	Statistical package for the social sciences
UPF	Ultra-processed food
WHO	World Health Organization
WHR	Waist to hip ratio

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

All authors (AGÇ, and GDB) contributed to the conceptualization, AGÇ and GDB contributed to the formal analysis, and writing of the original draft. GDB was involved in the review and editing process, and all authors approved the final draft.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare no competing interests.

Conflict of interest
The authors declare that they have no conflict of interest.

Consent to publish
Not applicable.

Author details
[1]Faculty of Health Sciences, Department of Nutrition and Dietetics, İstanbul Sabahattin Zaim University, Halkalı Cad. 34303 Küçükçekmece, İstanbul, Türkiye
[2]Institute of Health Sciences, Department of Nutrition and Dietetics, Selcuk University, Alaeddin Keykubat Kampüsü Akademi Mah. Yeni İstanbul Cad, 42130 Konya, Türkiye
[3]Faculty of Health Sciences, Department of Nutrition and Dietetics, Yeditepe University, İnönü Mah. Kayışdağı Cad, 34755 İstanbul, Türkiye

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