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# Evaluation of the Dietary Carbon Footprint as a Sustainable Diet Marker in Adults: A Cross-Sectional Study

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## ABSTRACT

This study planned to investigate the characteristics of the diet and its contribution to the carbon footprint-the greenhouse gas (GHG) emissions. Data were collected through face-to-face interview methods via a questionnaire including socio-demographic information, anthropometric measurements, the Three-Factor Eating Questionarre-21, and 24-hour recall food consumption record. This cross-sectional study was conducted with 619 adults (M = 266 (43.0%), F = 353 (%57.0)) aged 18-64 years. The carbon footprint value of the overall diet was 3.84 ± 0.1 kg $CO_2$-eq per person per day and 2.10 ± 1.2 kg $CO_2$-eq per 1,000 kcal per day. Meat and dairy groups are the major contributors to carbon footprint (34.8%, and 18.9%, respectively). Uncontrolled eating scores were higher in the highest quantile (Q5) group for the carbon footprint ($CO_2$-eq $kg^{-1}$) group ($p$ = 0.048), and according to the multiple regression model, uncontrolled eating scores significantly affecting the increase of carbon footprint (ß = 0.122, $p$ = 0.006). While high carbon footprint groups have higher dietary protein intake (43.30±0.8 g per day, 29.0±0.7 g per day, respectively, $p$ = 0.048), low carbon footprint groups have higher carbohydrate intake (103.75±3.7 g per day, 85.86±3.4 g per day, respectively, $p$ <0.001). The results of this study provide important knowledge on the contribution of diet patterns and eating behaviour to the carbon footprint and draw attention to the importance of developing sustainable nutrition recommendations in parallel with healthy nutrition recommendations.

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# Yetişkin Bireylerde Diyet Karbon Ayak İzinin Sürdürülebilir Bir Diyet Belirteci Olarak Değerlendirilmesi: Kesitsel Bir Çalışma

## ÖZET

Bu çalışmada, diyetin karbon ayak izi-sera gazı emisyonuna katkısını değerlendirmek amaçlandı. Araştırmanın verileri, sosyo-demografik bilgiler, antropometrik ölçümler, Üç Faktörlü Yeme Anketi-21 ve 24 saatlik geriye dönük besin tüketim kaydını içeren bir anket aracılığıyla toplandı. Bu kesitsel çalışma, 18-64 yaş aralığındaki 619 yetişkin (E = 266 (%43.0), K=353 (%57.0)) ile gerçekleştirilmiştir. Toplam diyet karbon ayak izi değeri kişi başına günlük 3.84±0.1 kg $CO_2$-eq ve 1.000 kcal başına 2.10±1.2 kg $CO_2$-eq olarak belirlenmiştir. Et ve süt ürünleri gruplarının karbon ayak izine en büyük katkıyı sağladığı belirlenmiştir (sırasıyla %34.8 ve %18.9). Kontrolsüz Yeme puanları, karbon ayak izi ($CO_2$-eq $kg^{-1}$) en yüksek kantil (Q5) grubunda daha yüksek bulunmuştur ($p$ = 0.048). Çoklu regresyon modeline göre Kontrolsüz Yeme puanları artan karbon ayak izi ile ilişkili bulunmuştur (ß = 0.122, $p$ = 0.006). Yüksek karbon ayak izi grubunda diyetle protein alımı daha yüksek (sırasıyla 43.30±0.8 g $gün^{-1}$, 29.0±0.7 g/gün, $p$=0.048) iken düşük karbon ayak izi grubunda karbonhidrat alımı daha yüksektir (103.75±3.7 g $gün^{-1}$, 85.86±3.4 g $gün^{-1}$, $p$<0.001). Bu çalışmanın sonuçları, diyet modelinin ve yeme davranışının karbon ayak izine katkısı konusunda önemli veriler sunmakta ve ayrıca sağlıklı beslenme önerilerine paralel olarak sürdürülebilir beslenme önerilerinin geliştirilmesinin önemine dikkat çekmektedir.

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## INTRODUCTION

Dramatic changes in the world's climate have attracted attention in recent years. The activities of humans and those mediated by humans are the most significant factors in these changes, including the food production process (Huseinovic et al., 2017). Food production and human food systems substantially contribute to global environmental footprints (Heller et al., 2018; Laine et al., 2021). In the past 50 years, agriculture, forestry, and fishing production processes have significantly increased their carbon footprint - the greenhouse gas (GHG) emissions (Aydın Eryılmaz & Kılıç, 2018; Huseinovic et al., 2017; Smith P. et al., 2014). Nearly, 19–29% of GHG emissions produced worldwide at every stage of the food life cycle are related to food production (Hjorth et al., 2020; Huseinovic et al., 2017). On the other hand, food production systems need to meet the increasing food demands of a growing population. Regulation of this scenario should take into account the Sustainable Development Goals (SDGs) (Binns et al., 2021).

Meat and dairy products are two food groups that produce high GHG and have a high dietary carbon footprint (Binns et al., 2021). Plant-based foods such as cereals, pulses, fruit, and vegetables are less likely to cause GHG emissions than meat, fish, and dairy products (Huseinovic et al., 2017). This means that consumers' food choices significantly impact the diet's effect on climate and public health interventions provide an opportunity to reduce global GHG emissions (Binns et al., 2021). It is crucial to appreciate the environmental impact to create sustainable public health policies and improve global health (Laine et al., 2021). The most basic dietary approach within the scope of sustainability is to increase plant sources by reducing animal sources. However, although sugar and starchy foods have low carbon emissions, it is known that their nutritional values are low. For this reason, sustainable nutrition recommendations should be in line with dietary recommendation guidelines.

Eating behaviour can affect individuals' food choices and dietary patterns (Telleria-Aramburu &Arroyo-Izaga, 2022). Individuals' food choices and eating habits also significantly affect their carbon footprint (Gonzalez-Garcia et al., 2018; Kause et al., 2019). Evaluating the contribution of individuals' nutritional behaviour, dietary patterns, and food choices to the carbon footprint may be necessary for supporting and developing strategies to reduce the carbon footprint.

To achieve the global 2 °C climate objective, emissions from agriculture, food production, and consumption must be decreased, especially in wealthier economies (Hjorth et al., 2020). In this instance, it is necessary to take quick action at the national and global levels. Plans and policies that will be developed to address this issue must take into account people's dietary preferences and nutritional practices. However, research focuses on nutrition and health, ignoring environmental health. With this background, this study aimed to evaluate the dietary carbon footprint of Turk adults living in the east region (Erzurum city); the relationship between eating behaviour, and develop population-based recommendations.

## MATERIAL and METHODS

### Participants

This cross-sectional study was conducted with adults aged between 18 and 64 years in Erzurum/Turkiye. At an 80% power probability and a 5% type 1 error level in the Power analysis, the sample size goal for the correlation analysis is at least 416 individuals. The inclusion criteria met the age criteria and did not follow a special diet or eating model. Exclusion criteria were the inability or reluctance to complete the surveys, not meeting the age criteria, being pregnant or breastfeeding, and following a special diet or eating model. The potential volunteers were either contacted by researchers in person or invited to Erzurum Technical University Department of Nutrition and Dietetics via email. At the end of the study, 619 participants had been enrolled. Ethical permission was obtained from the Erzurum Technical University Ethics Committee (Meeting Number: 11, Decision Number: 02, 2023). The research was carried out in line with the Helsinki Declaration. Participants were informed about the study and asked to volunteer after receiving their declarations.

### Tools

In this study, data were collected through face-to-face interview methods through a questionnaire including socio-demographic information, the Three-Factor Eating Questionarre-21 (TFEQ-21), and a 24-hour recall food consumption record form.

### Three-Factor Eating Questionnaire

The Three-Factor Eating Questionnaire-21 (TFEQ-21) is one of the scales that gives a prediction about the eating behaviour of individuals and provides data on the nutritional patterns of individuals (Kıraç et al.

2015, Koksal et al. 2021, Kruger et al. 2016). The TFEQ-21 is one of the widest-used instruments for assessing eating behaviour (Engstrom et al., 2015). The TFEQ-21 measures eating behaviours with a score between 0-100. A high score on any of the sub-factors of the scale indicates that the eating behaviour related to that factor is high. TFEQ-21 evaluates eating behaviour with three sup-groups: cognitive restraint, uncontrolled eating questionnaire and emotional eating (Engstrom et al., 2015). Reliability and validity of the Turkish version of the scale were conducted by Karakuş, Yıldırım and Büyüköztürk (2016), and it was described as a reliable tool for the Turkish population (Karakus et al., 2016). Although the questionnaire was developed for obese individuals, it was reported that it would be appropriate to use it in the whole population (Kıraç et al., 2015).

### Anthropometric measurements

The researchers measured the participant's height and weight according to the techniques explained by Lohman et al. (1988). Body Mass Index (BMI) was calculated by dividing weight (in kilograms) by height (in meters) squared. For the BMI classification individuals with a BMI below 18.50 kg/m$^2$ are underweight, between 18.50–24.99 kg/m$^2$ normal weight, 25.00–29.99 kg/m$^2$ overweight, and 30 kg/m$^2$ and above were classified as obese according to the World Health Organization (WHO, 2000).

### Calculation of carbon footprint

The carbon footprint was calculated from 24-hour food consumption with the Nutrition Information System program (BeBis). This program calculates macronutrients and micronutrients and also reports food groups. From the results of the food group analysis of the program, foods were divided into 10 main groups and 39 subgroups. The carbon footprint ($CO_2$-eq kg$^{-1}$) of different foods was specified in the unit of carbon dioxide-equivalent and each subgroup was given a carbon footprint ($CO_2$-eq kg$^{-1}$) based on results from life cycle analyzes. For the $CO_2$-eq kg$^{-1}$ values of the food groups, DataFIELD version 1.0 was used (DataField). The DataFIELD was constructed through a comprehensive literature search of Life Cycle Assessment studies from 2005 to 2016, and from GHG emission values ($CO_2$-equivalent per kg of commodity [$CO_2$-equivalent]), most to the farm gate for entities to the processor gate for processed ingredients such as flour and oil (Willits-Smith et al., 2020). Life cycle analysis is an ISO-standard approach for evaluating a product's environmental impact from "cradle to grave," which encompasses all environmental effects. Life cycle assessment data obtained from relevant articles were used for food subgroups not included in the DataFIELD database (Hjorth et al., 2020, Huseinovic et al., 2017). Finally, some foods (beer, offal meats etc.) were excluded due to their low amount of consumption or not belonging to the major food groups. Carbon footprint is presented by quantiles (Q1 = 0.320-1.092, Q2 = 1.093-1.567, Q3 = 1.568-2.142, Q4 = 2.142-2.910, and Q5 = 2.192-7.160). Macronutrient and micronutrient intake obtained from the Nutrition Information System program and TFEQ-scores were analyzed according to the carbon footprint quantiles with the ANOVA test. According to the quantiles for carbon footprint, the Q1 group was accepted as the low carbon footprint group, and the Q5 group as the high carbon footprint group. The carbon footprint ($CO_2$-eq kg$^{-1}$) of diets was both calculated for the overall diet and also calculated after adjustment for 1000 kcal. The subgroups were ranked based on their respective contribution to GHG emissions associated with total diet (Supplementary Table 1). The current carbon footprint ($CO_2$-eq kg$^{-1}$) was for foods as they were bought at the shop and did not account for customer transportation from a retail location to their homes, preparation at home, disposal at home, or trash. According to estimates of consumer-specific GHG emissions, home preparation, storage, and removal may account for 2.7% of all GHG emissions and 16% of all food-related emissions (Drewnowski et al., 2015).

### Data analyzes

Statistical analyses were conducted with the SPSS 21.0 program. The purpose of the normality test was to ascertain whether the assumptions of the parametric test were fulfilled. Independent sample t-test and One-Way ANOVA were used in independent groups for comparison. Chi-square analysis was used to compare qualitative data. Descriptive variables are given as mean ± standard error ($\chi \pm$ SE), and nominal variables as frequency and percentage. Relationships between TFEQ-scores and carbon footprint values were presented by correlation test and multiple regression models. The variables BMI, gender, energy (kcal), and age (years) were used as adjustment variables in the multivariate analysis. $p < 0.05$ was considered significant for the differences.

## RESULTS and DISCUSSION

This cross-sectional study was conducted with adults (M = 266 (43%), F = 353 (57.0%)) aged from 18 to 64 years. Study participant characteristics are presented by the study group in Table 1. The majority of respondents were not working (68.8%), graduate (56.5%), and single (59.6%). A greater proportion of participants (49.6%) have normal BMI (kg/m$^2$) values. There is no statistical significance for age (years), body weight (kg), and BMI (kg/m$^2$) between low and high carbon footprint ($CO_2$-eq kg$^{-1}$) groups ($p$>0.05) (data not shown in the table).

Dietary carbon footprint ($CO_2$-eq $kg^{-1}$) among Turkish adults was 3.84 ± 0.1 kg $CO_2$-eq per person per day and 2.10 ± 1.2 $CO_2$-eq $kg^{-1}$ per 1000 kcal (data not shown in the table). High carbon footprint ($CO_2$-eq $kg^{-1}$) diet respondents (Q5) had a carbon footprint seven-fold that of low carbon footprint ($CO_2$-eq $kg^{-1}$) diet respondents (Q1) (7.47 ± 0.55 vs. 1.63 ± 0.08 $CO_2$-eq) for total dietary intake and five-fold for dietary intake adjusted for 1000 kcal (4.0 ± 0.09 vs. 0.83 ± 0.01 $CO_2$-eq per 1000 kcal).

Table 1. Demohgraphic characteristics and BMI classification of participants
*Çizelge 1. Katılımcıların demografik özellikleri ve BKİ sınıflaması*

| | N (%) | Carbon footprint ($CO_2$-eq $kg^{-1}$) | P-value |
|---|---|---|---|
| **Working status** | | | |
| Yes | 193 (31.2%) | 2.21±1.2 | 0.128 |
| No | 426 (68.8%) | 2.05±1.1 | |
| **Educational status** | | | |
| Literate | 5 (0.8%) | 2.44±1.1 | 0.195 |
| Primary school | 59 (9.5%) | 2.18±1.1 | |
| Middle School | 45 (7.3%) | 1.83±0.7 | |
| High school | 138 (22. 3%) | 2.12±1.1 | |
| University | 350 (56.5%) | 2.06±1.2 | |
| Higher education | 22 (3.6%) | 2.83±1.8 | |
| **Marital status** | | | |
| Married | 250 (40.4%) | 2.09±1.2 | 0.922 |
| Single | 369 (59.6%) | 2.10±1.2 | |
| **BMI classification** | | | |
| Underweight | 45 (7.3%) | 1.93±1.02 | 0.339 |
| Normal | 307 (49.6%) | 2.11±1.22 | |
| Overweight | 192 (31.0%) | 2.06±1.24 | |
| Obese | 75 (12.1%) | 2.24±1.14 | |

BMI: Body Mass Index, Data are given as mean, standard error, number (N) and percent (%). Independent sample t-test, One way ANOVA (Burası daha çıklayıcı olmalı, eksik yazılmış)

Three-Factor Eating Questionnaire scores, age, body weight (kg), and BMI ($kg/m^2$) are presented according to carbon footprint ($CO_2$-eq $kg^{-1}$) quantile in Table 2. Accordingly, uncontrolled eating differed between quantiles, and uncontrolled eating scores were higher Q5 group than Q1 and Q2 groups. The difference was statistically significant ($p$= 0.048).

Table 2. TFEQ scores, age (years) and BMI ($kg/m^2$) according to carbon footprint quantile
*Çizelge 2. Karbon ayak izi kantiline göre TFEQ skorları, yaş (yıl) ve BKİ ($kg/m^2$)*

| | Q1 (n=123) | Q2 (n=124) | Q3 (n=124) | Q4 (n=124) | Q5 (n=124) | |
|---|---|---|---|---|---|---|
| | Mean±SE | Mean±SE | Mean±SE | Mean±SE | Mean±SE | P-value |
| **Cognitive restriction** | 14.79±1.9 | 14.44±2.1 | 14.27±2.1 | 14.50±2.1 | 14.32±2.4 | 0.411 |
| **Emotional eating** | 18.28±5.3 | 18.52±5.1 | 18.71±5.3 | 18.37±4.9 | 19.09±4.6 | 0.841 |
| **Uncontrolled eating** | 20.06±3.9[a] | 20.08±3.4[a] | 20.76±3.8[ab] | 20.51±3.3[ab] | 21.41±3.7[b] | 0.048 |
| **Age (years)** | 29.0±11.6 | 30.48±12.5 | 30.44±12.2 | 31.45±12.6 | 30.15±12.3 | 0.880 |
| **BMI ($kg/m^2$)** | 24.85±4.6 | 24.67±4.63 | 24.24±4.5 | 24.77±4.4 | 24.38±4.8 | 0.487 |

Data are given as mean, standard error, number (N), and percent (%). $p$<0.05
[a, b, c]: There is difference between groups that share the different letter. One way ANOVA, SE: Standart error

Table 3 provides the multiple regression model for carbon footprint prediction ($CO_2$-eq $kg^{-1}$). In the results of the statistical analysis, cognitive restriction and emotional eating scores had no significant effect on the development of carbon footprint ($p$ = 0.120, $p$ = 0.832). However, across TFEQ subgroups, the uncontrolled eating scores were examined to considerably influence the increase of carbon footprint (ß = 0.122, $p$ = 0.006).

Figure 1 represents the distribution of the contribution of food groups to the carbon footprint. Meat and dairy groups are the major contributors to carbon footprint (34.8%, and 18.9%, respectively). The distribution of the food groups between low and high carbon footprint ($CO_2$-eq $kg^{-1}$) groups is demostrated in Figure 2. Meat ($p$ < 0.001), dairy ($p$<0.001), vegetable, drink and beverages ($p$ < 0.001) consumption is higher in high carbon footprint ($CO_2$-eq $kg^{-1}$) groups.

Table 3. Multiple regression model for the prediction of carbon footprint ($CO_2$-eq $kg^{-1}$, adjusted for 1000 kkal) (Bu tablonun doğru olduğunu düşünmüyorum)
*Çizelge 3. Karbon ayak izi tahmini için çoklu regresyon modeli ($CO_2$-eşd $kg^{-1}$, 1000 kkal'a göre ayarlanmıştır)*

| Model | Unstandardized Coefficients | | Standardized Coefficients | t | p-value | $R^2$ | Adjusted $R^2$ | F-value |
|---|---|---|---|---|---|---|---|---|
| | B | SE | Beta | | | | | |
| (Constant) | 1.637 | .569 | | 2.874 | .004 | .022 | .011 | 1.997 |
| Cognitive restriction | -.035 | .023 | -.063 | -1.555 | .120 | | | |
| Emotional eating | .002 | .011 | .009 | .212 | .832 | | | |
| Uncontrolled eating | .040 | .014 | .122 | 2.763 | .006 | | | |

a. Dependent Variable: Carbon footprint eq/kg/1000 kkal
b. Predictors: (Constant), Cognitive restriction, Emotional eating, Uncontrolled eating, Adjusted for: BMI, Gender, Energy (kcal), Age (years)
SE: standard error

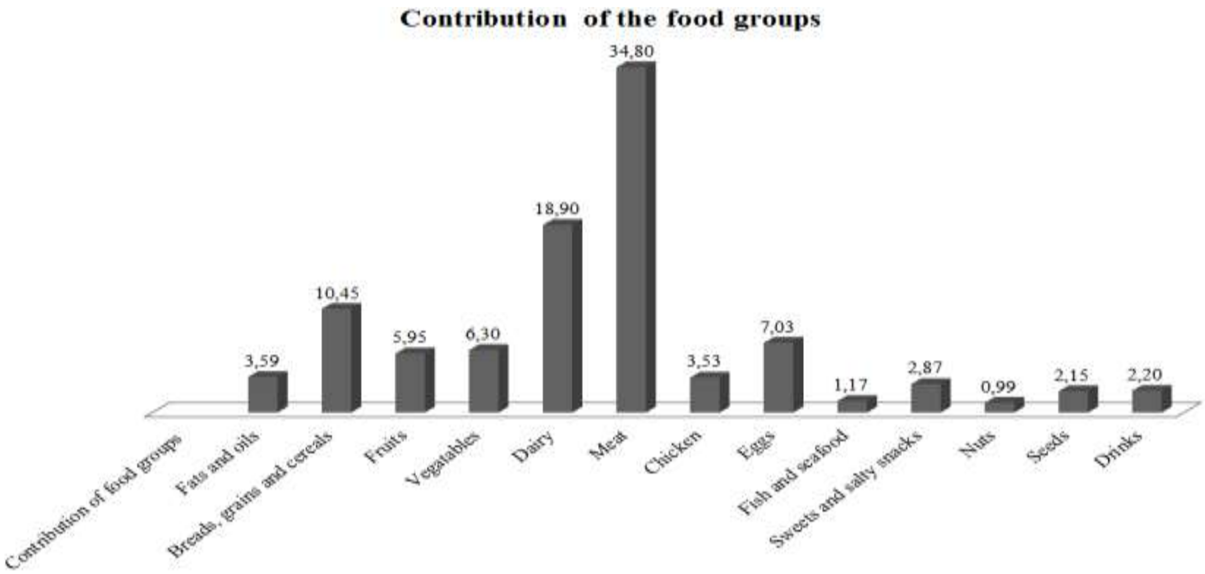


Figure 1. The distribution of the contribution of food groups to the carbon footprint
*Şekil 1. Besin gruplarının karbon ayak izine katkısının dağılımı*

Table 4 displays participants' macro and micronutrient intake according to carbon footprint ($CO_2$-eq $kg^{-1}$) quantiles. Dietary intake of protein (g), carbohydrate (g), potassium (mg), calcium (mg), zinc (mg), and iron (mg) are statistically significantly different between quantiles according to carbon footprint ($CO_2$-eq $kg^{-1}$) groups ($p$ < 0.001). While the high carbon footprint group has higher dietary protein intake (43.30 ± 0.8 g per day, 29.0 ± 0.7 g per day, respectively, $p$ < 0.001), the low carbon footprint group has higher carbohydrate intake (103.75 ± 3.7 g per day) than Q4 and Q5 groups ($p$ = 0.001). The carbon footprint ($CO_2$-eq $kg^{-1}$) of individuals consuming a higher protein diet (protein intake >20%) is statistically significantly higher (2.82 ± 0.2, 2.01 ± 0.04, $p$ = 0.048 respectively, data not shown in the table).

The main purpose of this study is to evaluate the carbon footprint of the diets in a Turkish population. Hence, this study provides important data on the carbon footprint (3.84 ± 0.1 $CO_2$-eq $kg^{-1}$) of diets in adults living in the east region (Erzurum city) of Turkiye. The carbon footprint can vary according to the countries' nutritional culture, traditional habits, and socioeconomic status. According to in a study evaluated results from Turkey Nutrition and Health Survey 2017, the $CO_2$-eq value was found to be 3.21 ± 2.07 kg $CO_2$-eq/person/day (Ilhan et al., 2023). Canadian self-selected diets' carbon footprint was 3.98 ± 0.06 $CO_2$-eq $kg^{-1}$, the Netherlands diets' was 3.9 kg $CO_2$-eq $kg^{-1}$ (Temme et al., 2015), which were similar to this study's results, the US diet' was 4.72 $CO_2$-eq $kg^{-1}$ (Heller et al., 2018, Rose et al., 2019), and France diets was 4.092 $CO_2$-eq $kg^{-1}$ (Drewnowski et al., 2015). After calorie consumption was adjusted for 1000 kcal, the Canadian and US estimations were similar (2.15 vs. 2.21 $CO_2$-eq/1000 kcal, respectively) (Rose et al., 2019).

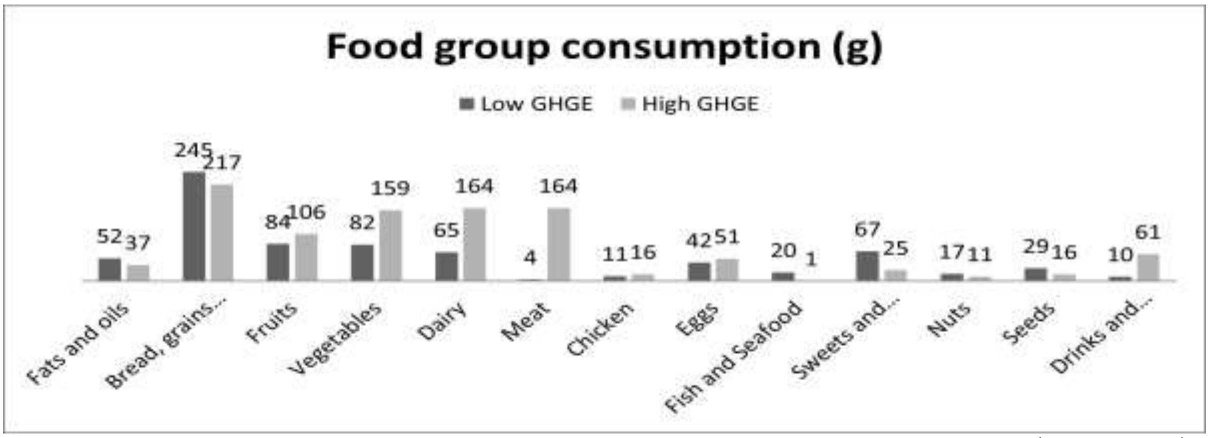


Figure 2. The distribution of the food groups between low and high carbon footprint groups ($CO_2$-eq $kg^{-1}$)
*Şekil 2. Besin gruplarının düşük ve yüksek karbon ayak izi grupları arasındaki dağılımı ($CO_2$-eşd $kg^{-1}$)*

Table 4. Macro and micronutrient intake of participants according to carbon footprint quantiles ($CO_2$-eq $kg^{-1}$)
*Çizelge 4. Katılımcıların karbon ayak izi kantillerine göre makro ve mikro besin alımları ($CO_2$-eşd $kg^{-1}$)*

| | Q1 (n=123) | Q2 (n=124) | Q3 (n=124) | Q4 (n=124) | Q5 (n=124) | p-valua |
|---|---|---|---|---|---|---|
| | Mean±SE | Mean±SE | Mean±SE | Mean±SE | Mean±SE | |
| Protein (g) | 29.0±0.7$^{a}$ | 33.86±0.8$^{a}$ | 37.34±1.1a$^{b}$ | 39.52±1.1$^{ab}$ | 43.30±0.8$^{b}$ | <0.001 |
| Protein (%) | 15.07±0.4 | 14.73±0.3 | 15.25±0.4 | 14.99±0.4 | 15.16±0.4 | 0.110 |
| CHO (g) | 103.75±3.7$^{abc}$ | 105.5±4.0$^{b}$ | 97.56±3.9ab$^{cd}$ | 96.63±3.7$^{d}$ | 85.86±3.4$^{e}$ | 0.001 |
| CHO (%) | 38.82±0.9 | 39.56±1.0 | 38.45±0.9 | 38.31±1.0 | 38.52±1.0 | 0.111 |
| Fat | 41.35±1.3 | 38.47±1.3 | 38.57±1.2 | 38.97±1.1 | 41.94±1.2 | 0.186 |
| Fat % | 46.09±1.0 | 45.65±1.0 | 46.31±1.0 | 46.66±1.1 | 46.31±1.1 | 0.603 |
| Fiber (g) | 9.12±0.4 | 10.32±0.5 | 10.20±0.4 | 9.42±0.4 | 9.01±0.4 | 0.110 |
| Saturated fat (g) | 12.21±0.6 | 12.41±0.6 | 11.65±0.6 | 12.62±0.6 | 13.05±0.7 | 0.429 |
| Polyunsaturated | 10.45±0.7 | 8.45±0.5 | 7.86±0.5 | 8.19±0.5 | 7.59±0.5 | 0.216 |
| Monounsaturated | 13.18±0.7 | 12.71±0.6 | 11.78±0.7 | 12.52±0.6 | 13.04±0.7 | 0.767 |
| Vitamin A (mcg) | 434.41±117.26 | 479.80±86.1 | 668.89±122.1 | 402.54±32.1 | 387.2±34.4 | 0.064 |
| Vitamin D (mcg) | 3.05±0.4 | 2.55±0.5 | 2.92±0.4 | 2.39±0.6 | 2.36±0.3 | 0.556 |
| Vitamin E (mg) | 8.94±0.6 | 8.36±0.6 | 8.07±0.5 | 7.49±0.5 | 8.40±0.4 | 0.504 |
| Sodium (mg) | 912.55±816 | 989.56±44.3 | 1030.00±60.0 | 988.20±51.2 | 1031.46±55.2 | 0.068 |
| Potassium(mg) | 809.10±39.9$^{a}$ | 1024.94±44.8$^{b}$ | 1091.92±56.2$^{b}$ | 1170.69±46.7$^{b}$ | 1071.83±43.2$^{b}$ | <0.001 |
| Calcium (mg) | 210.74±9.1$^{a}$ | 269.85±11,.3$^{b}$ | 303.23±5.3$^{b}$ | 322.17±5.5$^{b}$ | 268.07±6.2$^{b}$ | <0.001 |
| Zinc (mg) | 3.13±0.1$^{a}$ | 3.79±0.1$^{b}$ | 4.07±0.1$^{b}$ | 4.71±0.1$^{c}$ | 6.03±0.3$^{d}$ | <0.001 |
| Iron (mg) | 4.71±0.1$^{a}$ | 5.42±0.2$^{a}$ | 5.35±0.1$^{a}$ | 5.58±0.1$^{b}$ | 6.29±0.1$^{b}$ | <0.001 |

Data are given as mean, standard error, number (N), and percent (%). p<0.05, p<0.001
[a, b, c, d, e]: There is a difference between groups that share different letters. One way ANOVA test, SE:Standart error

This study also presents a close carbon footprint ($CO_2$-eq $kg^{-1}$) (2.10 ± 1.2) to the Canadian and US self-selected diets after adjustment for 1000 kcal. Carbon footprint ($CO_2$-eq $kg^{-1}$) values were also reported according to demographic and anthropometric characteristics (Table 1). High carbon footprint ($CO_2$-eq $kg^{-1}$) diet respondents (Q5) had a carbon footprint seven-fold that of low carbon footprint ($CO_2$-eq $kg^{-1}$) diet respondents (Q1) (7.47 ± 0.55 vs. 1.63 ± 0.08 $CO_2$-eq $kg^{-1}$) for total dietary intake and five-fold for dietary intake adjusted for 1000 kcal (4.0 ± 0.09 vs. 0.83 ± 0.01 $CO_2$-eq per 1000 kcal). Similar to these findings, high- GHG emissions diets in the US also had an energy-adjusted carbon footprint 5-fold that of low-GHG emission diets (Rose et al. 2019). In a study comparing Mediterranean, Atkins (20/40/100), Ornish, Zone diets, and Turkey Dietary Guidelines-2015 recommendations' according to the $CO_2$-eq levels. Ornish and Mediterranean diet models had less harmful environmental impacts, contributing to sustainable nutrition (Kemaloglu et al., 2023).

Individuals' food choices are among the crucial determinants of the carbon footprint and their effects on health (Gonzalez-Garcia et al., 2018; Kause et al., 2019). In this article, as a second purpose, the effects of eating behaviour on the carbon footprint were evaluated by considering its possible impact on the food choice. There are several studies in the literature examining the association between eating behaviour and food choice in different aspects (Cecchini &Warin , 2016; Dressler &Smith, 2013; Scully et al., 2012; Segura-Garcia et al., 2014; Vilaro et al., 2016). Impaired eating behavior affects the food choice of individuals and might cause adverse effects on general health (Nagata et al., 2018). Although this subject has been defined in detail and frequently researched in the past years, there is no study investigating the relationship between impaired eating behavior, food choice and sustainability, hence, it is a concept of recent years. In this study, eating behavior was evaluated with the TFEQ-21 and accordingly, individuals with high uncontrolled eating behavior had a higher carbon footprint. Cornelis et al. found that uncontrolled eating was positively correlated with energy intake in their study (Cornelis et al., 2014). In another study, similar results were also found and uncontrolled eating was positively associated with energy-dense foods (de Lauzon et al., 2004). We also found a positive correlation between energy intake (kcal) and uncontrolled eating and also for emotional eating. However, it would be more beneficial to interpret this relationship through food choices rather than simple energy intake. Impaired eating behavior is generally associated with increased intake of palatable foods (Robinson et al., 2014), and these foods might have low and high Carbon footprint ($CO_2$-eq $kg^{-1}$) values depending on the product type. It is predicted that uncontrolled eating behavior may lead to unhealthy food choices in the dietary pattern in terms of sustainability. More comprehensive analysis would be beneficial for the dietary patterns of individuals for future research.

Heller et al. (2018) stated that the meat and dairy group made the most significant Carbon footprint ($CO_2$-eq $kg^{-1}$) contribution to diets (Heller et al., 2018). Auclair and Borges (2021) found that the single top contributor was beef (36%), followed by luncheon and other meats (7%), poultry (6%), and milk (6%) (Auclair &Burgos, 2021). Similar to other studies, in this analysis places the meat group top (34.8%), and the dairy group (18.9%) comes in second place as the top carbon footprint ($CO_2$-eq $kg^{-1}$) contributors. Considering the carbon footprint ($CO_2$-eq $kg^{-1}$) values of the meat and dairy group, it is an expected result consistent with the literature due to the high $CO_2$-eq $kg^{-1}$ values of these food groups. Beef, in particular, contributes significantly to global greenhouse gas emissions, and generally speaking, animal goods emit greater emissions than plant items (Willits-Smith et al., 2020). Food groups were additionally split into 39 subgroups to increase and improve understanding of diet-associated GHG emissions from both plant- and animal-based diets. The subgroups were ranked based on their respective contribution to GHG emissions associated with total diet (Supplementary Table 1).

In this study, individuals consuming a high-protein diet had a higher dietary carbon footprint ($CO_2$-eq $kg^{-1}$). It is recommended that dietary protein intake be between 15-20% or 10-20% in healthy individuals (Cuenca-Sanchez et al., 2015; TUBER, 2022). In the present study, protein intake above the amount of 20% was associated with a higher carbon footprint ($CO_2$-eq $kg^{-1}$). Apart from diet-specific and disease-specific conditions, high protein intake might increase urinary calcium excretion, triggering the development of osteoporosis, and may cause liver and kidney problems (Cuenca-Sanchez et al., 2015, TUBER 2022). In this study, the fact that it has a high carbon footprint ($CO_2$-eq $kg^{-1}$) and health risks shows that it also poses a risk in terms of sustainability. Micronutrient deficiencies, particularly iron, zinc, and vitamins, are of great importance (Binns et al., 2021). On the left side of the curve, insufficient food intake leads to undernutrition, which carries a significant risk of illness and death. On the other end of the scale, obesity and its associated conditions pose a significant threat to the health of the two billion adults who are overweight or obese worldwide (Binns et al., 2021). K, Ca, Zn and Fe consumption were lowest in the lowest quantile according to carbon footprint ($CO_2$-eq $kg^{-1}$). Recommendations must be compatible with both human and planetary health. The definition of a sustainable diet is one that "protects and respects biodiversity and ecosystems, is culturally acceptable, accessible, economically - equitable, and inexpensive; is nutritionally adequate, safe, and healthy; and maximizes natural and human resources." (Binns et al., 2021, Rose et al., 2019). Ending hunger, eliminating food insecurity, enhancing nutrition, and promoting sustainable agriculture are other Sustainable Developmet Goals that strongly emphasize on nutrition; nonetheless, the majority of Sustainable Development Goals have some impact on food production and nutrition (Binns et al., 2021). The majority of food-based dietary recommendations are built on the following tenets: they should address important issues in both acute and chronic public health, be based on food to make them more easily translated into practical dietary recommendations, provide the necessary nutrients, support healthy growth and body weight, and promote overall health. Accordingly, there are opinions that dietary guidelines should emphasize Sustainable Development Goals and GHG emissions (Binns et al., 2021). Auclair and Borges, (2021) stated that the significant variation in GHG emissions associated with diet among Canadians shows the possibility for dietary advice to reduce the country's overall carbon footprint, a soft policy lever that some nations have already incorporated into their food guides (Auclair &Burgos 2021). Turkiye Dietary Guidelines (2022) was published in 2022 and has included sustainable nutrition, and also emphasized the carbon footprint of foods (TUBER, 2022). Accordingly, the Turkiye Dietary Guideline (2022) encourages consumers to purchase more plant-based foods and consume animal-based proteins in the recommended amounts, besides advising the consumption of dairy products with low fat. It is also suggested decrease consumption of meat, animal products, saturated fats, sugar, salt, and alcohol, and increase consumption of fish, grains, nuts, fruits, berries, and vegetables (FAO, 2020).

Heller et al. (2018) drew a framework for the evaluation of individual diets. They claimed that individual-level data are necessary for extra sophisticated modeling of regulations because they permit for knowledge of the variety of effects inside a population and for linking of individual-level features (e.g., age, gender, race-ethnicity, educational level, nutritional knowledge, environmental attitudes, etc.) to the nutritional behaviors and environmental results (Heller et al., 2018). Willits-Smith et al. (2020), also highlighted the significance of individual-level diet studies and reported that comprehension of the consequences of climate policies, such as those that incorporate sustainability information in national dietary guidelines, can be improved by research that considers consumer response variability (Willits-Smith et al., 2020). There is no national study evaluating the dietary carbon footprint at the individual level in the Turkish population. This study provides important data about Turkish adults' dietary carbon footprint values.

## CONCLUSION

In summary, this study provides important data for the carbon footprint ($CO_2$-eq kg$^{-1}$) of Turkish adults living in east region (Erzurum city). Overall carbon footprint ($CO_2$-eq kg$^{-1}$) of diets is lower than the US and higher than the national diet in Turkey (results from Turkey Nutrition and Health Survey, 2017). Beef and dairy groups are the major contributors of carbon footprint ($CO_2$-eq kg$^{-1}$). This study's results show that individuals with high uncontrolled eating behavior had a higher carbon footprint. Uncontrolled eating behaviour can lead to food choices that are unhealthy from a sustainability perspective and have a high carbon footprint. Considering the traditional dietary habits in the region where the study was conducted, we can say that the results may differ regionally.

While reducing the diets' carbon footprint is a very important issue for planetary health, diets with low carbon footprint must be compatible with human health and meet daily recommendations. For this reason, sustainable diets and the concept of sustainable nutrition should be drawn very well and both human and planetary health should be observed. Studies need to evaluate both the carbon footprint and diet quality of individual diets on this subject. It is very important to raise awareness about healthy and sustainable nutrition in people. For this reason, sustainable and healthy nutrition education is necessary for environmental health sustainability and can increase the adaptation of individuals to healthy and sustainable diets to reduce the carbon footprint. It is important that governments/policy makers should pay attention to sustainable nutrition and environmental health.

### Strenghts and limitations

This study provides important data for calculating the carbon footprint of diets in Turkey. It also has important data in terms of being the first study to investigate sustainability and eating behavior. The characteristics of this study reflect part of whole population due to the cross-sectional design. The food consumption record was taken with the 24-hour recall method. It may not present the general habits of individuals. Different regions may contribute to the carbon footprint to varying rates due other traditional dietary habits.

### Contribution of the Authors as Summary

**OB:** conceptualization, data collection, data analysis, writing–original draft, writing–review, and editing. **MSMÇ:** conceptualization, data analysis, writing–original draft, writing–review, and editing.

**BKB:** conceptualization, data collection, writing–review, and editing. All authors have read and approved the final manuscript.

### Statement Of Conflict Of Interest

Authors have declared no conflict of interest.

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