Nutr Res Pract. 2023 Oct;17(5):1028-1041
https://doi.org/10.4162/nrp.2023.17.5.1028
pISSN 1976-1457·eISSN 2005-6168

Nutrition Research and Practice

Original Research

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# What is on plates for school meals: focusing on animal- vs. plant-based protein foods

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**Received:** Apr 19, 2023
**Revised:** May 29, 2023
**Accepted:** Jul 26, 2023
**Published online:** Aug 25, 2023

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**Funding**
This work was supported by the research grant of the Kongju National University in 2021.
This work was supported by the Soonchunhyang University Research Fund.

**Conflict of Interest**
The authors declare no potential conflicts of interests.

## ABSTRACT

**BACKGROUND/OBJECTIVES:** This study aimed to analyze the potential of school meals in South Korea as a sustainable tool to reduce carbon emissions by focusing on animal- vs. plant-based protein foods.
**MATERIALS/METHODS:** By using a stratified proportional allocation method, 536 out of the 11,082 schools nationwide were selected including 21 kindergartens, 287 elementary-, 120 middle- and 108 high schools. A total of 2,680 meals served for 5 consecutive days (June 21–25, 2021) were collected. We analyzed the average serving amounts of protein foods (animal- vs. plant-based) per meal and then, calculated the estimated average amounts of carbon emission equivalents per meal by applying the conversion coefficients. The *t*-test and analysis of variance were used for statistical analyses ($\alpha = 0.05$).
**RESULTS:** The average serving amount of animal-based protein foods per meal was 12.5 g, which was approximately 3 times higher than that of plant-based ones (3.8 g) ($P < 0.001$); the Meat-group had the highest average amount of 17.0 g, followed by Egg-group (9.6 g), Fish-group (7.6 g), and Beans-and-Nuts-group (3.8 g) ($P < 0.05$). Specifically, pork (25.1 g) was ranked first, followed by poultry (19.6 g), processed meat products (18.0 g). The estimated average amount of carbon emission equivalents of animal-based protein foods per meal was 80.1 g $CO_2e$, which was approximately 31 times higher than that of plant-based ones (2.6 g $CO_2e$) ($P < 0.001$); the Meat-group had the highest average amount of 120.3 g $CO_2e$, followed by Fish-group (44.5 g $CO_2e$), Egg-group (25.9 g $CO_2e$), and Beans-and-Nuts-group (2.6 g $CO_2e$) ($P < 0.05$). Specifically, processed meat products (270.8 g $CO_2e$) were ranked first, followed by pork (91.7 g $CO_2e$), and processed fish products (86.6 g $CO_2e$).
**CONCLUSIONS:** The results implied that school meals with plant-based alternatives could be a sustainable tool to improve carbon footprint.

**Keywords:** School lunches; protein sources; sustainable diets; plant-based diets; climate change

## INTRODUCTION

In response to climate change, worldwide efforts are being made to reduce carbon emissions through various means and avenues. Notably, one-third of global greenhouse gas (GHG)

**Author Contributions**
Conceptualization: Kim M, Kim SY; Formal analysis: Kim M; Investigation: Kim M; Methodology: Kim M, Kim SY; Supervision: Kim SY; Validation: Kim M; Writing - original draft: Kim M, Kim SY; Writing - review & editing: Kim M, Kim SY.

emissions are generated from food production to consumption [1,2]. Consequently, achieving sustainable food systems has garnered significant interest.

A considerable portion of these GHG emissions, in particular, is related to livestock farming and consumption. The Food and Agriculture Organization of the United Nations has also pointed out that livestock is a significant contributor to GHG emissions, which lead to global warming [3]. Furthermore, Smith *et al.* [4] highlighted that globally, agriculture-related GHG emissions are dominated by livestock, which is a primary source of methane and nitrous oxide.

Despite projections that methane emissions from livestock will increase by an estimated 60% by 2030 [4], it is expected that livestock farming will increase by approximately 70% by 2050, owing to the growing demand for meat, a typical animal-based protein food [5]. However, there are concerns that such a diet, which is primarily animal-based and low in fruits and vegetables, is consistently identified as a major contributor to GHG emissions and an increased risk of obesity and chronic diseases [6,7].

Springmann *et al.* [8] have demonstrated that transitioning from animal-based to plant-based diets could potentially reduce global food-related GHG emissions by approximately 70% by 2050. Hence, there is a growing emphasis on adopting plant-based diets that can contribute to human and planetary health, both in individual diets and public food services. Particularly, school meals, which can be provided to all children and represent a significant portion of their dietary intake during critical periods of growth, have been identified as a potentially useful tool to address health and sustainability issues [9]. Therefore, introducing low-carbon school meals, which consist of environmentally sustainable and nutritious alternatives, to children presents an excellent opportunity to foster lifelong eating habits for human and planetary health.

As a result, recent studies on low-carbon school meals have been conducted worldwide, which focused on various aspects related to the environmental and nutritional benefits of low-carbon school meals [10]; the successful implementation of climate-friendly, nutritious, and acceptable school meals in practice [11,12]; and the promotion of sustainable school meals [13]. However, no similar studies have been reported in South Korea, whilst most have focused on menu preferences for or customer satisfaction with vegetarian meals as an extension of low-carbon school meals [14-17].

Therefore, this study, as a first attempt in South Korea, aimed to compare and analyze the current status of providing animal- and plant-based protein foods for school meals, and to identify the potential of school meals as a sustainable tool for reducing carbon emissions. The results of this study, based on scientific evidence, will serve as basic data for the establishment of relevant policies for the introduction and implementation of low-carbon school meals in South Korea, and to draw social consensus on their urgent need and importance.

## MATERIALS AND METHODS

### Data collection

The stratified proportional allocation method was employed to select 550 schools in South Korea. These schools represent approximately 5% of the 11,082 schools nationwide that use the ‘NEIS’ School Lunch System. The selection process considered the school types, regional distributions, and meal types. Data from 536 eligible schools, including 21 kindergartens (3.9%), 287 elementary schools (53.5%), 120 middle schools (22.4%), and 108 high schools (20.1%), were collected for analyses. Urban schools accounted for 66.8%, while rural and remote schools accounted for 29.3% and 3.9%, respectively.

## Data analyses

*Classification of protein foods (animal- vs. plant-based) per meal*

Among the various types of foods provided in school meals, protein foods were selected and classified as animal- and plant-based protein foods. The 2020 Korean dietary reference intake guidelines [18] were utilized to classify these protein foods into different food groups and sub-food groups. Animal-based protein foods were divided into Meat, Fish, and Egg groups, with further sub-categorization of the 'Meat' group into beef, pork, poultry, and processed meat products. The 'Fish' group was sub-divided into fish, shellfish, and processed fish products. In contrast, plant-based protein foods were all classified into the 'Beans-and-Nuts-group' group, which was further sub-categorized into beans, processed bean products, and nuts.

When the amount of each protein food was unknown, as school meals were identified only by the name of the menu, estimations were made using the corresponding food recipes from CAN-Pro 5.0. This database, developed by the Korean Nutrition Information Center, consists of food recipes and nutritional information used for menu planning.

*Average serving frequency and amount of protein foods (animal- vs. plant-based) per meal*

We investigated 1) the average serving frequency and 2) the average serving amount of protein foods (animal- vs. plant-based) per meal. The serving frequency and amount of each protein food per meal were calculated, summed, and then divided by the total number of meals to obtain the averages, respectively. They were then further analyzed according to subsequent food- and sub-food groups.

*Estimated average amount of carbon emission equivalents of protein foods (animal- vs. plant-based) per meal*

The estimated average amount of carbon emission equivalents of protein foods (animal- vs. plant-based) were calculated by referring to the mean data points of GHG emissions from representative food products (kg $CO_2$e/kg of product), which were suggested by Ferrari *et al.* [19]. In this study, more than 50 scientific articles were considered to extract GHG emission values for each of the representative food products.

Specifically, the mean data points of the representative food products, which were partly identical to or similar to those of the protein foods in our study, were used to calculate the estimated conversion coefficients for the carbon emission contribution of each protein food (**Table 1**). Subsequently, we used these estimated conversion coefficients to investigate the estimated average amounts of carbon emission equivalents for protein foods (animal- vs. plant-based) per meal. We further analyzed these carbon emission equivalents for subsequent food- and sub-food groups.

*Statistical analyses*

An independent *t*-test was conducted to analyze the differences between protein foods (animal- vs. plant-based). Furthermore, the differences between the subsequent food- and sub-food groups were analyzed using analysis of variance with Duncan's *post-hoc* test. For all statistical analyses, SPSS was used, with a significance level of 0.05.


https://doi.org/10.4162/nrp.2023.17.5.1028

**Table 1.** The estimated conversion coefficients for the carbon emission contribution of protein foods

| Classification | Estimated conversion coefficients (kg $CO_2e$/kg of product) | Category/sub-category[1)] | Food items consumed[1)] | Representative food product[1)] | Mean of data points (kg $CO_2e$/kg of product)[1)] |
|---|---|---|---|---|---|
| Animal-based protein foods | | | | | |
| Meat | | | | | |
| Beef | 15.45 | Meat, meat products and substitutes/beef & veal, not preserved, excl. offal | Beef, veal, industrial meat sauce | Beef | 15.45 |
| Pork | 3.65 | Meat, meat products and substitutes/pork, not preserved, excl. offal | Pork meat, pork meat roasted (porchetta), foot pork raw, excl. offal | Pork | 3.65 |
| Poultry | 1.88 | Meat, meat products and substitutes/poultry and game, not preserved, excl. offal | Pheasant, chicken, roast chicken, goose, quail, turkey, ostrich, incl. offal | Poultry | 1.88 |
| Processed meat products | 15.03 | Meat, meat products and substitutes/processed meat | Ham, salami, sausages and other preserved meats, excl. offal | Processed meat | 15.03 |
| Fish | | | | | |
| Fish | 2.67[2)] | Fish and seafood/fish, fresh | All other types of fresh fish (fresh or frozen or preserved) | Small pelagics | 2.27 |
| | | | | Cod | 3.10 |
| | | | | Salmon | 3.03 |
| | | | | Ground fish | 2.27 |
| Shellfish | 4.85[3)] | Fish and seafood/crustaceans, shellfish, mussels | All types of fish, molluscs, crustaceans, raw (fresh or frozen or preserved) and fish fingers | Shrimps | 3.00 |
| | | | | Mussels | 6.70 |
| Processed fish products | 8.08[4)] | Fish and seafood/fish, fresh | All other types of fresh fish (fresh or frozen or preserved) | Mean of small pelagics, Cod, Salmon, and Ground fish | 2.67 |
| | | Fish and seafood/crustaceans, shellfish, mussels | All types of fish, molluscs, crustaceans, raw (fresh or frozen or preserved) and fish fingers | Mean of shrimps and mussels | 4.85 |
| Egg | | | | | |
| Egg | 2.70 | Eggs / Eggs | All types of eggs (chicken, duck, ostrich, etc.) excl. fish egg | Egg | 2.70 |
| Plant-based protein foods | | | | | |
| Beans-and-Nuts | | | | | |
| Bean | 0.64[5)] | Pulses/pulses, fresh or processed | All types of pulses (fresh and processed): lentils, peas, chickpeas, all types of beans excl. green beans, soybeans | Green bean | 0.78 |
| | | | | Dried legumes | 0.50 |
| Processed bean products | 0.64[4)] | Pulses/pulses, fresh or processed | All types of pulses (fresh and processed): lentils, peas, chickpeas, all types of beans excl. green beans, soybeans | Green bean | 0.78 |
| | | | | Dried legumes | 0.50 |
| Nuts | 1.79 | Fruit/nuts, seeds, dried fruit, olives and their products | Nuts roasted, dried, in powder or in puree (almond, chestnut, walnut, coconut, pine nut, peanut, pistachio), seeds (pumpkin seed), olives | Walnut, hazelnut | 1.79 |

[1)]Sauce: Ferrari *et al.* (2020) [19].
[2)]Mean of small pelagics, cod, salmon, and ground fish.
[3)]Mean of shrimps and mussels.
[4)]2.15 [ratio of processed meat products for meat (mean of beef, pork, and poultry)] × fish (mean of fish and shellfish).
[5)]Mean of green bean and dried legumes.

## RESULTS

### General characteristics of school meals

In total, 2,680 meals were served over 5 consecutive days (from June 21 to June 25, 2021) in the 536 eligible schools (**Table 2**). Among the different menus comprising these meals, 4,668 menus included protein foods. Furthermore, the serving frequency of the different protein foods in these menus totaled 12,395, with animal- and plant-based protein foods accounting for 87.4% and 12.6%, respectively.

 https://doi.org/10.4162/nrp.2023.17.5.1028 

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**Table 2.** General characteristics of school meals

| Classification | Kindergarten (n = 21) | Elementary school (n = 287) | Middle school (n = 120) | High school (n = 108) | Total (n = 536) |
|---|---|---|---|---|---|
| Number of meals provided | 105 (3.9) | 1,435 (53.5) | 600 (22.4) | 540 (20.1) | 2,680 (100.0) |
| Number of menus with protein foods included in meals | 149 (3.2) | 2,430 (52.1) | 1,091 (23.4) | 998 (21.4) | 4,668 (100.0) |
| Serving frequency of the different protein foods included in menus | 444 (100.0) | 6,635 (100.0) | 2,786 (100.0) | 2,530 (100.0) | 12,395 (100.0) |
| Animal-based protein foods | 388 (87.4) | 5,770 (87.0) | 2,440 (87.6) | 2,234 (88.3) | 10,832 (87.4) |
| Meat | 142 (32.0) | 2,241 (33.8) | 1,008 (36.2) | 985 (38.9) | 4,376 (35.3) |
| Beef | 45 (10.1) | 518 (7.8) | 143 (5.1) | 108 (4.3) | 814 (6.6) |
| Pork | 36 (8.1) | 764 (11.5) | 357 (12.8) | 380 (15.0) | 1,537 (12.4) |
| Poultry | 27 (6.1) | 433 (6.5) | 186 (6.7) | 182 (7.2) | 828 (6.7) |
| Processed meat products | 34 (7.7) | 526 (7.9) | 322 (11.6) | 315 (12.5) | 1,197 (9.7) |
| Fish | 204 (45.9) | 2,872 (43.3) | 1,130 (40.6) | 1,000 (39.5) | 5,206 (42.0) |
| Fish | 19 (4.3) | 193 (2.9) | 79 (2.8) | 67 (2.6) | 358 (2.9) |
| Shellfish | 66 (14.9) | 890 (13.4) | 338 (12.1) | 312 (12.3) | 1,606 (13.0) |
| Processed fish products | 119 (26.8) | 1,789 (27.0) | 713 (25.6) | 621 (24.5) | 3,242 (26.2) |
| Egg | 42 (9.5) | 657 (9.9) | 302 (10.8) | 249 (9.8) | 1,250 (10.1) |
| Egg | 42 (9.5) | 657 (9.9) | 302 (10.8) | 249 (9.8) | 1,250 (10.1) |
| Plant-based protein foods | 56 (12.6) | 865 (13.0) | 346 (12.4) | 296 (11.7) | 1,563 (12.6) |
| Beans-and-Nuts | 56 (12.6) | 865 (13.0) | 346 (12.4) | 296 (11.7) | 1,563 (12.6) |
| Bean | 5 (1.1) | 118 (1.8) | 52 (1.9) | 33 (1.3) | 208 (1.7) |
| Processed bean products | 39 (8.8) | 524 (7.9) | 220 (7.9) | 201 (7.9) | 984 (7.9) |
| Nuts | 12 (2.7) | 223 (3.4) | 74 (2.7) | 62 (2.5) | 371 (3.0) |

Values are presented as frequency, n (%), (per week).

## Average serving frequency of protein foods (animal- vs. plant-based) per meal

**Tables 3** and **4** show the average serving frequencies of the different protein foods (animal- vs. plant-based) per meal by food and sub-food groups. The average serving frequency of animal-based protein foods per meal was 0.51, which was approximately 2.7 times higher than that of plant-based protein foods (0.19) ($P < 0.001$). When categorized by food groups, the Fish-group (0.65) had the highest serving frequency, followed by the Egg-group (0.47), Meat-group (0.41), and Beans-and-Nuts-group (0.19) ($P < 0.05$). A closer examination of the Meat group showed that the average serving frequency of pork (0.57) was significantly higher than that of processed meat products (0.45), poultry (0.31), and beef (0.30) ($P < 0.05$). The Fish group had a higher serving frequency of processed fish products (1.21) > shellfish (0.60) > and fish (0.13) ($P < 0.05$), while the Legume group had a higher serving frequency of processed bean products (0.37) > nuts (0.14) > and beans (0.08) ($P < 0.05$).

## Average serving amount of protein foods (animal- vs. plant-based) per meal

**Tables 5** and **6** show the average serving amount of different protein foods (animal- vs. plant-based) per meal by food and sub-food groups. The average serving amount of animal-based protein foods per meal was 12.5 g, which was approximately 3 times higher than that of plant-based protein foods (3.8 g) ($P < 0.001$). By food group, the Meat-group (17.0 g) was ranked highest, followed by the Egg-group (9.6 g), Fish-group (7.6 g), and Beans-and-Nuts-group (3.8 g) ($P < 0.05$).

Specifically, the Meat-group had an average serving amount of pork (25.1 g), followed by poultry (19.6 g), processed meat products (18.0 g), > and beef (5.3 g) ($P < 0.05$). For the Fish-group, processed fish products had the highest average serving amount (10.7 g), followed by shellfish (6.8 g) > and fish (5.2 g) ($P < 0.05$). For the Beans-and-Nuts-group, processed bean products had the highest average serving amount (10.4 g), followed by beans (0.5 g) and nuts (0.4 g) ($P < 0.05$).

**Table 3.** Average serving frequency of protein foods (animal- vs. plant-based) per meal by food group

| School type | Animal-based protein foods | | | | Plant-based protein foods | *P*-value[1)] | *P*-value[2)] |
|---|---|---|---|---|---|---|---|
| | Sub mean | Meat-group | Fish-group | Egg-group | Beans-and-Nuts-group | | |
| Kindergarten (n = 105) | 0.46 ± 0.68 | 0.34 ± 0.57[b] | 0.65 ± 0.79[c] | 0.40 ± 0.57[b] | 0.18 ± 0.45[a] | < 0.001 | < 0.001 |
| Elementary school (n = 1,435) | 0.50 ± 0.75 | 0.39 ± 0.62[b] | 0.67 ± 0.91[d] | 0.46 ± 0.64[c] | 0.20 ± 0.47[a] | < 0.001 | < 0.001 |
| Middle school (n = 600) | 0.51 ± 0.73 | 0.42 ± 0.64[b] | 0.63 ± 0.85[d] | 0.50 ± 0.61[c] | 0.19 ± 0.44[a] | < 0.001 | < 0.001 |
| High school (n = 540) | 0.52 ± 0.79 | 0.46 ± 0.70[b] | 0.62 ± 0.93[c] | 0.46 ± 0.62[b] | 0.18 ± 0.46[a] | < 0.001 | < 0.001 |
| Total (n = 2,680) | 0.51 ± 0.75 | 0.41 ± 0.64[b] | 0.65 ± 0.90[d] | 0.47 ± 0.63[c] | 0.19 ± 0.46[a] | < 0.001 | < 0.001 |

Values are presented as mean ± SD.
[1)]*P*-value by analysis of variance among Meat-, Fish-, Egg-, Beans-and-Nuts-groups.
[2)]*P*-value by *t*-test between animal- and plant-based protein foods.
[a-d]Different letters within the same rows are significantly different at $P < 0.05$ by Duncan's multiple range test.

**Table 4.** Average serving frequency of protein foods (animal- vs. plant-based) per meal by sub-food group

| School type | Animal-based protein foods | | | | | | | | | | | Plant-based protein foods | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Meat-group | | | | | Fish-group | | | | Egg-group | | Beans-and-Nuts-group | | | |
| | Beef | Pork | Poultry | Processed meat products | *P*-value[1)] | Fish | Shellfish | Processed fish products | *P*-value[1)] | Egg | *P*-value | Bean | Processed bean products | Nuts | *P*-value[1)] |
| Kindergarten (n = 105) | 0.43 ± 0.57 | 0.34 ± 0.59 | 0.26 ± 0.48 | 0.32 ± 0.64 | 0.189 | 0.18 ± 0.39[a] | 0.63 ± 0.90[b] | 1.13 ± 0.67[c] | < 0.001 | 0.40 ± 0.57 | N/A | 0.05 ± 0.21[a] | 0.37 ± 0.49[b] | 0.11 ± 0.53[a] | < 0.001 |
| Elementary school (n = 1,435) | 0.36 ± 0.59[b] | 0.53 ± 0.71[c] | 0.30 ± 0.52[a] | 0.37 ± 0.61[b] | < 0.001 | 0.13 ± 0.36[a] | 0.62 ± 0.96[b] | 1.25 ± 0.92[c] | < 0.001 | 0.46 ± 0.64 | N/A | 0.08 ± 0.28[a] | 0.37 ± 0.54[c] | 0.16 ± 0.50[b] | < 0.001 |
| Middle school (n = 600) | 0.24 ± 0.48[a] | 0.60 ± 0.75[c] | 0.31 ± 0.53[b] | 0.54 ± 0.69[c] | < 0.001 | 0.13 ± 0.37[a] | 0.56 ± 0.86[b] | 1.19 ± 0.85[c] | < 0.001 | 0.50 ± 0.61 | N/A | 0.09 ± 0.29[a] | 0.37 ± 0.53[b] | 0.12 ± 0.41[a] | < 0.001 |
| High school (n = 540) | 0.20 ± 0.45[a] | 0.70 ± 0.83[d] | 0.34 ± 0.57[b] | 0.58 ± 0.75[c] | < 0.001 | 0.12 ± 0.33[a] | 0.58 ± 1.00[b] | 1.15 ± 0.97[c] | < 0.001 | 0.46 ± 0.62 | N/A | 0.06 ± 0.24[a] | 0.37 ± 0.55[c] | 0.11 ± 0.46[b] | < 0.001 |
| Total (n = 2,680) | 0.30 ± 0.54[a] | 0.57 ± 0.75[c] | 0.31 ± 0.53[a] | 0.45 ± 0.66[b] | < 0.001 | 0.13 ± 0.35[a] | 0.60 ± 0.94[b] | 1.21 ± 0.91[c] | < 0.001 | 0.47 ± 0.63 | N/A | 0.08 ± 0.27[a] | 0.37 ± 0.53[c] | 0.14 ± 0.48[b] | < 0.001 |

Values are presented as mean ± SD.
N/A, not available.
[1)]*P*-value by analysis of variance.
[a-d]Different letters within the same rows are significantly different at $P < 0.05$ by Duncan's multiple range test.


https://doi.org/10.4162/nrp.2023.17.5.1028

**Table 5.** Average serving amount of protein foods (animal- vs. plant-based) per meal by food group

| School type | Animal-based protein foods | | | | Plant-based protein foods | $P$-value[1)] | $P$-value[2)] |
|---|---|---|---|---|---|---|---|
| | Sub mean | Meat-group | Fish-group | Egg-group | Beans-and-Nuts-group | | |
| Kindergarten (n = 105) | 8.1 ± 16.45 | 10.1 ± 19.42[c] | 6.0 ± 12.69[b] | 6.7 ± 12.05[b] | 2.6 ± 8.47[a] | < 0.001 | < 0.001 |
| Elementary school (n = 1,435) | 10.0 ± 21.08 | 13.1 ± 25.72[d] | 6.5 ± 14.08[b] | 8.3 ± 15.41[c] | 3.4 ± 11.73[a] | < 0.001 | < 0.001 |
| Middle school (n = 600) | 15.3 ± 31.04 | 21.2 ± 38.58[d] | 8.6 ± 19.13[b] | 11.8 ± 19.27[c] | 3.8 ± 13.55[a] | < 0.001 | < 0.001 |
| High school (n = 540) | 17.1 ± 35.74 | 24.2 ± 43.56[c] | 9.7 ± 24.62[b] | 11.1 ± 20.33[b] | 4.9 ± 17.14[a] | < 0.001 | < 0.001 |
| Total (n = 2,680) | 12.5 ± 27.05 | 17.0 ± 33.30[d] | 7.6 ± 17.84[b] | 9.6 ± 17.37[c] | 3.8 ± 13.31[a] | < 0.001 | < 0.001 |

Values are presented as mean ± SD (g).
[1)]$P$-value by analysis of variance among Meat-, Fish-, Egg-, Beans-and-Nuts-groups.
[2)]$P$-value by $t$-test between animal- and plant-based protein foods.
[a-d]Different letters within the same rows are significantly different at $P < 0.05$ by Duncan's multiple range test.

**Table 6.** Average serving amount of protein foods (animal- vs. plant-based) per meal by sub-food group

| School type | Animal-based protein foods | | | | | | | | | | | Plant-based protein foods | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Meat-group | | | | | Fish-group | | | | Egg-group | | Beans-and-Nuts-group | | | |
| | Beef | Pork | Poultry | Processed meat products | $P$-value[1)] | Fish | Shellfish | Processed fish products | $P$-value[1)] | Egg | $P$-value | Bean | Processed bean products | Nuts | $P$-value[1)] |
| Kindergarten (n = 105) | 7.4 ± 13.06 | 11.6 ± 22.60 | 11.2 ± 21.03 | 10.2 ± 19.63 | 0.393 | 5.6 ± 14.39 | 4.7 ± 9.25 | 7.6 ± 13.74 | 0.231 | 6.7 ± 12.05 | N/A | 0.1 ± 0.68[a] | 7.5 ± 13.36[b] | 0.3 ± 1.34[a] | < 0.001 |
| Elementary school (n = 1,435) | 5.6 ± 12.05[a] | 19.0 ± 29.37[d] | 15.7 ± 27.93[c] | 12.0 ± 27.61[b] | < 0.001 | 4.9 ± 14.28[a] | 5.7 ± 12.87[a] | 8.9 ± 14.71[b] | < 0.001 | 8.3 ± 15.41 | N/A | 0.5 ± 4.18[a] | 9.2 ± 18.48[b] | 0.5 ± 1.74[a] | < 0.001 |
| Middle school (n = 600) | 4.7 ± 14.00[a] | 31.8 ± 47.71[c] | 23.7 ± 42.20[b] | 24.4 ± 36.14[b] | < 0.001 | 5.6 ± 17.09[a] | 7.0 ± 16.06[a] | 13.1 ± 22.76[b] | < 0.001 | 11.8 ± 19.27 | N/A | 0.5 ± 3.03[a] | 10.5 ± 21.71[b] | 0.5 ± 1.98[a] | < 0.001 |
| High school (n = 540) | 4.6 ± 15.02[a] | 36.7 ± 51.97[c] | 27.0 ± 48.88[b] | 28.5 ± 41.41[b] | < 0.001 | 5.6 ± 17.28[a] | 9.9 ± 28.70[b] | 13.6 ± 25.81[c] | < 0.001 | 11.1 ± 20.33 | N/A | 0.5 ± 2.44[a] | 13.7 ± 27.49[b] | 0.3 ± 1.47[a] | < 0.001 |
| Total (n = 2,680) | 5.3 ± 13.19[a] | 25.1 ± 39.98[c] | 19.6 ± 36.60[b] | 18.0 ± 33.36[b] | < 0.001 | 5.2 ± 15.58[a] | 6.8 ± 17.83[b] | 10.7 ± 19.44[c] | < 0.001 | 9.6 ± 17.37 | N/A | 0.5 ± 3.55[a] | 10.4 ± 21.23[b] | 0.4 ± 1.73[a] | < 0.001 |

Values are presented as mean ± SD (g).
N/A, not available.
[1)]$P$-value by analysis of variance.
[a-d]Different letters within the same rows are significantly different at $P < 0.05$ by Duncan's multiple range test.


https://doi.org/10.4162/nrp.2023.17.5.1028

### Estimated average amount of carbon emission equivalents of protein foods (animal- vs. plant-based) per meal

**Tables 7** and **8** show the estimated average amounts of carbon emission equivalents of protein foods (animal-vs. plant-based) per meal by food and sub-food groups. According to the application of conversion coefficients for the carbon emission contribution of each protein food, animal-based protein foods were estimated to produce an average amount of 80.1 g $CO_2e$ per meal, which was approximately 31 times higher than that of plant-based ones (2.6 g $CO_2e$) ($P < 0.001$). Based on food groups, the Meat-group had the highest average amount of 120.3 g $CO_2e$, followed by the Fish-group (44.5 g $CO_2e$), the Egg-group (25.9 g $CO_2e$), and the Beans-and-Nuts-group (2.6 g $CO_2e$) ($P < 0.05$).

A detailed analysis revealed that within the Meat group, processed meat products had the highest estimated average amount of carbon emission equivalents (270.8 g $CO_2e$), followed by pork (91.7 g $CO_2e$), beef (81.6 g $CO_2e$), > and poultry (36.8 g $CO_2e$) ($P < 0.05$). Similarly, within the Fish-group, processed fish products had the highest estimated average amount of carbon emission equivalents (86.6 g $CO_2e$), followed by shellfish (32.9 g $CO_2e$) > and fish (14.0 g $CO_2e$) ($P < 0.05$). For the Beans-and-Nuts-group, processed bean products had the highest estimated average amounts of carbon emission equivalents (6.6 g $CO_2e$), followed by nuts (0.8 g $CO_2e$) > and beans (0.3 g $CO_2e$) ($P < 0.05$).

Finally, **Fig. 1** shows the average serving amounts and estimated average amounts of carbon emission equivalents of protein foods (animal- vs. plant-based) per meal.

## DISCUSSION

This study aimed to compare and analyze the current status of providing animal- and plant-based protein foods for school meals and to identify the potential for reducing carbon emissions from school meals in South Korea.

The protein foods with the lowest average serving frequency and amount per meal were in the plant-based 'Beans-and-Nuts-group'. In contrast, the Fish and Meat groups, which were all animal-based protein foods, had the highest average serving frequencies and amounts. Apart from the serving amount, the highest serving frequency of the Fish-group is presumed to be due to the frequent use of dried anchovies for the broth of a soup served at almost every Korean school meal. Dried anchovies are commonly included in soup recipe but in small quantities.

The average serving amount of animal-based protein foods per meal was 12.5 g, which was more than 3 times higher than that of plant-based ones (3.8 g). Upon applying the conversion coefficients for the carbon emission contribution of each protein food, this difference was further amplified. This highlighted that the estimated average amount of carbon emission equivalents from animal-based protein foods per meal was 80.1 g $CO_2e$, approximately 31 times higher than that of plant-based protein foods (2.6 g $CO_2e$). The top 5 protein foods with the highest estimated average carbon emission equivalents were all animal-based protein foods, namely processed meat products, pork, processed fish products, beef, and poultry. Notably, processed meat and fish products, which ranked first and third, respectively, were ultra-processed foods such as ham, sausage, bacon, fish cake, crab meat, and squid balls. In addition, pork and beef, which ranked second and fourth, respectively, were typical red meats.


https://doi.org/10.4162/nrp.2023.17.5.1028

**Table 7.** Estimated average amount of carbon emission equivalents of protein foods (animal- vs. plant-based) per meal by food group

| School type | Animal-based protein foods | | | | Plant-based protein foods | P-value[1)] | P-value[2)] |
|---|---|---|---|---|---|---|---|
| | Sub mean | Meat-group | Fish-group | Egg-group | Beans-and-Nuts-group | | |
| Kindergarten (n = 105) | 56.0 ± 145.91 | 82.8 ± 191.44[c] | 33.0 ± 75.19[b] | 18.1 ± 32.53[ab] | 1.8 ± 5.54[a] | < 0.001 | < 0.001 |
| Elementary school (n = 1,435) | 62.6 ± 181.32 | 91.4 ± 241.43[d] | 37.5 ± 84.31[c] | 22.4 ± 41.60[b] | 2.4 ± 7.66[a] | < 0.001 | < 0.001 |
| Middle school (n = 600) | 98.4 ± 253.53 | 150.2 ± 332.93[d] | 51.5 ± 124.49[c] | 32.0 ± 52.03[b] | 2.6 ± 8.84[a] | < 0.001 | < 0.001 |
| High school (n = 540) | 110.8 ± 291.29 | 171.0 ± 379.77[d] | 57.6 ± 152.26[c] | 30.0 ± 54.88[b] | 3.2 ± 11.03[a] | < 0.001 | < 0.001 |
| Total (n = 2,680) | 80.1 ± 224.43 | 120.3 ± 296.18[d] | 44.5 ± 110.63[c] | 25.9 ± 46.90[b] | 2.6 ± 8.64[a] | < 0.001 | < 0.001 |

Values are presented as mean ± SD (g $CO_2$e/g of product).
1)P-value by analysis of variance among Meat-, Fish-, Egg-, Beans-and-Nuts-groups.
2)P-value by t-test between animal- and plant-based protein foods.
a-dDifferent letters within the same rows are significantly different at $P < 0.05$ by Duncan's multiple range test.

**Table 8.** Estimated average amount of carbon emission equivalents of protein foods (animal- vs. plant-based) per meal by sub-food group

| School type | Animal-based protein foods | | | | | | | | | | | Plant-based protein foods | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Meat-group | | | | | Fish-group | | | | Egg-group | | Beans-and-Nuts-group | | | |
| | Beef | Pork | Poultry | Processed meat products | P-value[1)] | Fish | Shellfish | Processed fish products | P-value[1)] | Egg | P-value | Bean | Processed Bean products | Nuts | P-value[1)] |
| Kindergarten (n = 105) | 114.3 ± 201.81[b] | 42.2 ± 82.50[a] | 21.1 ± 39.54[a] | 153.6 ± 294.96[b] | < 0.001 | 15.0 ± 38.41[a] | 22.6 ± 44.86[a] | 61.4 ± 111.04[b] | < 0.001 | 18.1 ± 32.53 | N/A | 0.1 ± 0.43[a] | 4.8 ± 8.55[b] | 0.5 ± 2.41[a] | < 0.001 |
| Elementary school (n = 1,435) | 86.9 ± 186.10[c] | 69.2 ± 107.18[a] | 29.5 ± 52.50[b] | 180.0 ± 414.96[d] | < 0.001 | 13.2 ± 38.14[a] | 27.6 ± 62.40[b] | 71.8 ± 118.83[c] | < 0.001 | 22.4 ± 41.60 | N/A | 0.4 ± 2.68[a] | 5.9 ± 11.83[b] | 0.8 ± 3.12[a] | < 0.001 |
| Middle school (n = 600) | 72.9 ± 216.31[a] | 116.2 ± 174.13[b] | 44.6 ± 79.33[a] | 367.2 ± 543.19[c] | < 0.001 | 15.0 ± 45.63[a] | 33.9 ± 77.90[b] | 105.5 ± 183.92[c] | < 0.001 | 32.0 ± 52.03 | N/A | 0.3 ± 1.94[a] | 6.7 ± 13.90[b] | 0.8 ± 3.54[a] | < 0.001 |
| High school (n = 540) | 71.2 ± 232.12[a] | 134.1 ± 189.71[b] | 50.7 ± 91.89[a] | 427.9 ± 622.42[c] | < 0.001 | 15.1 ± 46.14[a] | 47.9 ± 139.18[b] | 109.8 ± 208.55[c] | < 0.001 | 30.0 ± 54.88 | N/A | 0.3 ± 1.56[a] | 8.8 ± 17.60[b] | 0.6 ± 2.63[a] | < 0.001 |
| Total (n = 2,680) | 81.6 ± 203.76[b] | 91.7 ± 145.94[b] | 36.8 ± 68.80[a] | 270.8 ± 501.47[c] | < 0.001 | 14.0 ± 41.60[a] | 32.9 ± 86.50[b] | 86.6 ± 157.10[c] | < 0.001 | 25.9 ± 46.90 | N/A | 0.3 ± 2.27[a] | 6.6 ± 13.59[c] | 0.8 ± 3.10[b] | < 0.001 |

Values are presented as mean ± SD (g $CO_2$e/g of product).
N/A, not available.
1)P-value by analysis of variance.
a-dDifferent letters within the same rows are significantly different at $P < 0.05$ by Duncan's multiple range test.


https://doi.org/10.4162/nrp.2023.17.5.1028

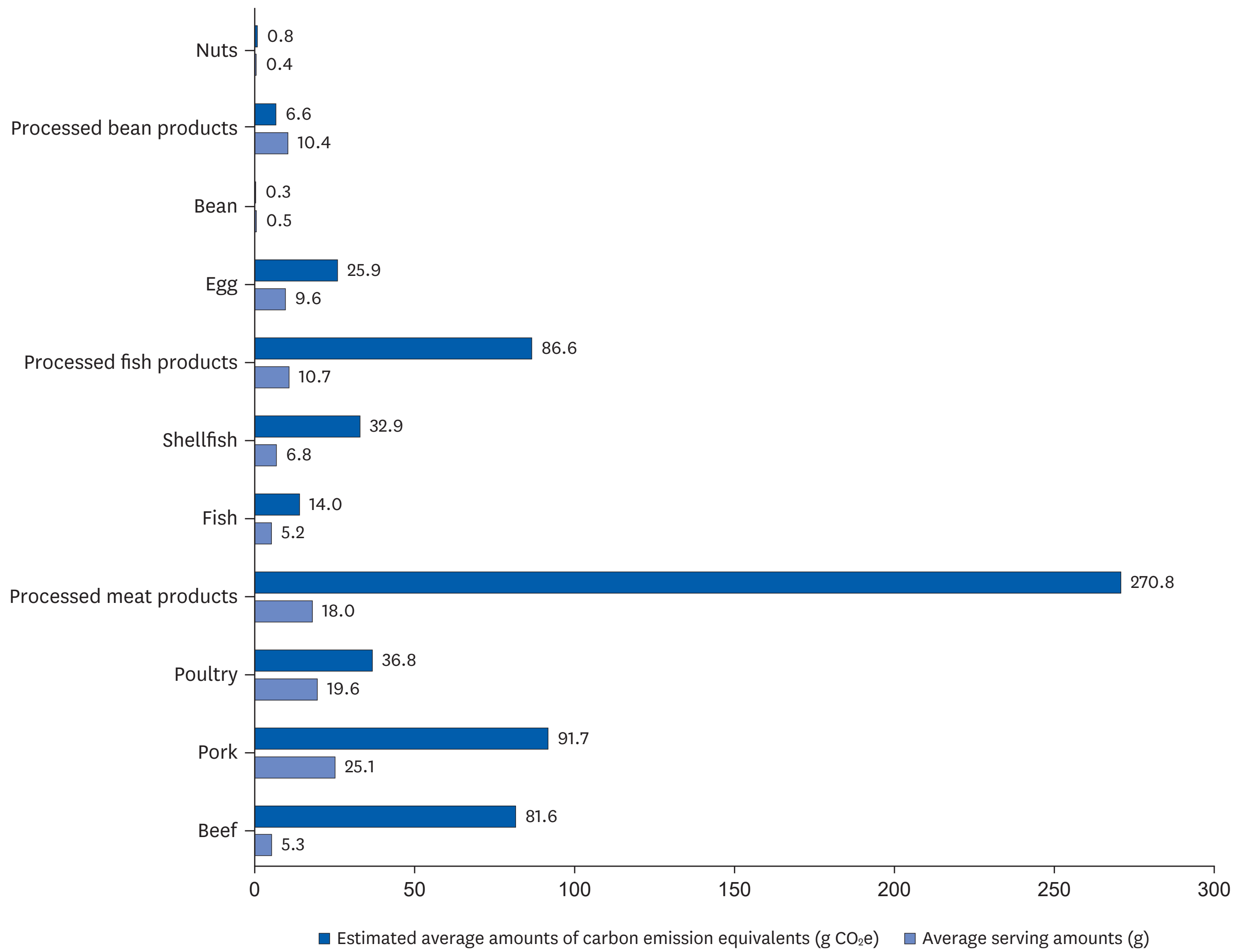


**Fig. 1.** Average serving amount and estimated average amount of carbon emission equivalents of protein foods (animal- vs. plant-based) per meal.

Previous studies have consistently reported that plant-based diets are more environmentally friendly than animal-based diets [20,21]. This is supported by the fact that the estimated conversion coefficients for carbon emissions of each protein food in this study were arranged in descending order as follows: beef, processed meat products, processed fish products, shellfish, pork, fish, eggs, poultry, nuts, beans, and processed bean products. Therefore, replacing animal-based protein foods with plant-based alternatives could significantly reduce carbon emissions [7,22-26]. Reducing the consumption of ultra-processed foods and red meat, particularly, could be beneficial in this regard [27,28]. The EAT-Lancet Commission [7] has reported that if the world's diets shift toward plant-based diets, based on an increase in the consumption of vegetables, fruits, whole grains, legumes, and nuts, and a decrease in the consumption of red meat, sugar, and refined grains, GHG emissions could be substantially reduced by up to 80% by 2050.

There are concerns that plant-based diets may result in nutritional deficiencies and health issues. However, previous research has demonstrated that appropriately planned plant-based diets can positively impact health and protect against chronic illnesses such as obesity [29], heart disease [30,31], diabetes [30,32], and certain cancers [30,33,34]. In addition, earlier studies have consistently reported that an excessive intake of animal-based protein foods can


https://doi.org/10.4162/nrp.2023.17.5.1028

have a negative effect on health and is related to the development of various diseases, including type 2 diabetes [35,36], metabolic syndrome [37], and breast cancer [38]. Furthermore, a diet high in red meat is associated with an increased risk of cardiovascular disease [39].

Moreover, a recent study conducted in South Korea found that the protein intake among preschoolers (3–5 yrs), school-aged children (6–11 yrs), and adolescents (12–18 yrs) exceeded the recommended intake by 228.6%, 179.9%, and 145.1%, respectively [40], which is higher than the corresponding rate of the general population (144%) [41]. The Korea Rural Economic Institute [42] reported that as of 2022, meat consumption in South Korea has surpassed that of rice, a staple food, for the first time. The average per capita consumption of pork, beef, and chicken is projected to be 58.4 kg in 2022, a 74% increase from 33.5 kg in 2002, with an annual average growth rate of 2.8%. Similarly, according to a study by the GBD 2017 Diet Collaborators [43], the global consumption of animal-based protein foods exceeded optimal levels, with processed meat products and red meat consumption surpassing optimal levels by 90% and 18%, respectively. In contrast, the consumption of plant-based protein foods (legumes, nuts, seeds, and whole grains) did not even reach the optimal levels.

A growing number of studies on low-carbon school meals and their implementation have been conducted in Western countries, especially in Europe [10-13,44,45]. However, in South Korea, policy and scholarly interest in this topic has only increased in the last year or two. Currently, it is recommended that low-carbon school meals should only be provided 1–2 times a month at the metropolitan or provincial level of education [14,16]. The actual provision of low-carbon school meals on site barely meets this recommendation.

In order to promote the wider adoption of low-carbon school meals in the future, it will be utmost important to plan and provide these meals more regularly and systematically. Simultaneously, efforts to change the perceptions of students who benefit from school meals should also be emphasized. Park [16] conducted a survey of school dietitians (teachers) in the Seoul area and revealed that changing student perceptions was cited as a major obstacle (45.8%) to implementation and acceptance of low-carbon meals. Moreover, there appears to be a lack of on-site education regarding low-carbon school meals. Kang [14] found that 60.8% of upper elementary school students in Jeju had never received education on low-carbon school meals, and Park [16] reported that 39.4% of school dietitians (teachers) had no experience in providing such education to students.

Fortunately, there is a movement to promote low-carbon school meals as an extension of food ecological transformation education, which involves learning and practicing food consumption in response to the climate crisis [46]. In food ecological transformation education, it is crucial to change students' perceptions on low-carbon school meals; they should clearly understand that low-carbon school meals, as defined by the EAT-Lancet Commission, do not consist entirely of vegetables but instead involve restraining from animal-based protein foods and replacing them with more sustainable plant-based alternatives that can contribute to human and planetary health. This importance is illustrated by the fact that low-carbon school meals were once misconstrued as a diet solely composed of vegetables that excluded animal-based protein foods, leading to strong opposition from parents and students.

This study holds significance as it marks the first attempt to compare and analyze the current status of the estimated carbon emissions of protein foods, distinguishing between animal- and plant-based options, served in school meals in South Korea. The results imply that school meals in South Korea could be a sustainable tool to improve carbon footprints, provided that they are appropriately redesigned to replace animal-based protein foods with plant-based alternatives. However, the conversion coefficients, which were used to estimate the carbon emission equivalents in this study, were not derived in consideration of domestic circumstances. Therefore, caution must be applied in interpreting the study results, by understanding the relative magnitude of such differences in the estimated carbon emissions of protein foods. To fill this gap, future research should focus on developing a database of carbon emissions for each major food based on life cycle assessment, and domestic conditions should be factored in.

## REFERENCES


1. Campbell BM, Beare DJ, Bennett EM, Hall-Spencer JM, Ingram JSI, Jaramillo F, Ortiz R, Ramankutty N, Sayer JA, Shindell D. Agriculture production as a major driver of the earth system exceeding planetary boundaries. Ecol Soc 2017;22:8.
CROSSREF
2. Crippa M, Solazzo E, Guizzardi D, Monforti-Ferrario F, Tubiello FN, Leip A. Food systems are responsible for a third of global anthropogenic GHG emissions. Nat Food 2021;2:198-209.
PUBMED | CROSSREF
3. Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, Haan C. Livestock's Long Shadow: Environmental Issues and Options. Rome: Food and Agriculture Organization of the United Nations; 2006.
4. Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA, Haberl H, Harper R, House J, Jafari M, et al. Agriculture, forestry and other land use. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, et al. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; 2014. p.811-922.
5. Alexandratos N, Bruinsma J. World Agriculture Towards 2030/2050: The 2012 Revision (ESA Working Paper No. 12-03). Rome: Food and Agriculture Organization of the United Nations; 2012.
6. IPCC. Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems. Geneva: Intergovernmental Panel on Climate Change; 2019.
7. Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, Garnett T, Tilman D, DeClerck F, Wood A, et al. Food in the anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet 2019;393:447-92.
PUBMED | CROSSREF
8. Springmann M, Mason-D'Croz D, Robinson S, Garnett T, Godfray HCJ, Gollin D, Rayner M, Ballon P, Scarborough P. Global and regional health effects of future food production under climate change: a modelling study. Lancet 2016;387:1937-46.
PUBMED | CROSSREF
9. Oostindjer M, Aschemann-Witzel J, Wang Q, Skuland SE, Egelandsdal B, Amdam GV, Schjøll A, Pachucki MC, Rozin P, Stein J, et al. Are school meals a viable and sustainable tool to improve the healthiness and sustainability of children´s diet and food consumption? A cross-national comparative perspective. Crit Rev Food Sci Nutr 2017;57:3942-58.
PUBMED | CROSSREF
10. Batlle-Bayer L, Bala A, Aldaco R, Vidal-Monés B, Colomé R, Fullana-I-Palmer P. An explorative assessment of environmental and nutritional benefits of introducing low-carbon meals to Barcelona schools. Sci Total Environ 2021;756:143879.
PUBMED | CROSSREF
11. Benvenuti L, De Santis A, Santesarti F, Tocca L. An optimal plan for food consumption with minimal environmental impact: the case of school lunch menus. J Clean Prod 2016;129:704-13.
CROSSREF
12. Elinder LS, Eustachio Colombo P, Patterson E, Parlesak A, Lindroos AK. Successful implementation of climate-friendly, nutritious, and acceptable school meals in practice: the OPTIMAT™ intervention study. Sustainability (Basel) 2020;12:8475.
CROSSREF



https://doi.org/10.4162/nrp.2023.17.5.1028

13. Rossi L, Ferrari M, Martone D, Benvenuti L, De Santis A. The promotions of sustainable lunch meals in school feeding programs: the case of Italy. Nutrients 2021;13:1571.
PUBMED | CROSSREF

14. Kang EJ. A survey on menu preference and satisfaction regarding the vegetarian diet day of school food service among higher grade elementary school children in Jeju area [master's thesis]. Jeju: Jeju National University; 2015.

15. Lee KE, Hong WS, Kim MH. Students' food preferences on vegetarian menus served at middle and high schools. J Korean Diet Assoc 2005;11:320-30.

16. Park SH. Awareness and operation status about green meal service in school nutrition teachers at Seoul area [master's thesis]. Seoul: Kookmin University; 2021.

17. Sim DH. A study on the perception and satisfaction of green lunch among some middle school students in Seoul [master's thesis]. Ansung: Chung-Ang University; 2023.

18. Ministry of Health and Welfare, The Korean Nutrition Society. Dietary Reference Intakes for Korean in 2020. Sejong: Ministry of Health and Welfare; 2020.

19. Ferrari M, Benvenuti L, Rossi L, De Santis A, Sette S, Martone D, Piccinelli R, Le Donne C, Leclercq C, Turrini A. Could dietary goals and climate change mitigation be achieved through optimized diet? The experience of modeling the national food consumption data in Italy. Front Nutr 2020;7:48.
PUBMED | CROSSREF

20. Carlsson-Kanyama A, González AD. Potential contributions of food consumption patterns to climate change. Am J Clin Nutr 2009;89:1704S-1709S.
PUBMED | CROSSREF

21. Reijnders L, Soret S. Quantification of the environmental impact of different dietary protein choices. Am J Clin Nutr 2003;78:664S-668S.
PUBMED | CROSSREF

22. Aleksandrowicz L, Green R, Joy EJM, Smith P, Haines A. The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: a systematic review. PLoS One 2016;11:e0165797.
PUBMED | CROSSREF

23. Fresán U, Sabaté J. Vegetarian diets: planetary health and its alignment with human health. Adv Nutr 2019;10:S380-8.
PUBMED | CROSSREF

24. Gao J, Kovats S, Vardoulakis S, Wilkinson P, Woodward A, Li J, Gu S, Liu X, Wu H, Wang J, et al. Public health co-benefits of greenhouse gas emissions reduction: a systematic review. Sci Total Environ 2018;627:388-402.
PUBMED | CROSSREF

25. Kesse-Guyot E, Fouillet H, Baudry J, Dussiot A, Langevin B, Allès B, Rebouillat P, Brunin J, Touvier M, Hercberg S, et al. Halving food-related greenhouse gas emissions can be achieved by redistributing meat consumption: progressive optimization results of the NutriNet-Santé cohort. Sci Total Environ 2021;789:147901.
PUBMED | CROSSREF

26. Rabès A, Seconda L, Langevin B, Allès B, Touvier M, Hercberg S, Lairon D, Baudry J, Pointereau P, Kesse-Guyot E. Greenhouse gas emissions, energy demand and land use associated with omnivorous, pescovegetarian, vegetarian, and vegan diets accounting for farming practices. Sustain Prod Consum 2020;22:138-46.
CROSSREF

27. Auclair O, Burgos SA. Carbon footprint of Canadian self-selected diets: comparing intake of foods, nutrients, and diet quality between low-and high-greenhouse gas emission diets. J Clean Prod 2021;316:128245.
CROSSREF

28. Garzillo JMF, Poli VFS, Leite FHM, Steele EM, Machado PP, Louzada MLDC, Levy RB, Monteiro CA. Ultra-processed food intake and diet carbon and water footprints: a national study in Brazil. Rev Saude Publica 2022;56:6.
PUBMED | CROSSREF

29. Dunn-Emke S, Weidner G, Ornish D. Benefits of a low-fat plant-based diet. Obes Res 2001;9:731.
PUBMED | CROSSREF

30. Hardman WE. Diet components can suppress inflammation and reduce cancer risk. Nutr Res Pract 2014;8:233-40.
PUBMED | CROSSREF

31. Hu FB. Plant-based foods and prevention of cardiovascular disease: an overview. Am J Clin Nutr 2003;78:544S-551S.
PUBMED | CROSSREF

32. Trapp C, Levin S. Preparing to prescribe plant-based diets for diabetes prevention and treatment. Diabetes Spectr 2012;25:38-44.
CROSSREF
33. Fung TT, Brown LS. Dietary patterns and the risk of colorectal cancer. Curr Nutr Rep 2013;2:48-55.
PUBMED | CROSSREF
34. Link LB, Canchola AJ, Bernstein L, Clarke CA, Stram DO, Ursin G, Horn-Ross PL. Dietary patterns and breast cancer risk in the California teachers study cohort. Am J Clin Nutr 2013;98:1524-32.
PUBMED | CROSSREF
35. Liang Y, Gong Y, Zhang X, Yang D, Zhao D, Quan L, Zhou R, Bao W, Cheng G. Dietary protein intake, meat consumption, and dairy consumption in the year preceding pregnancy and during pregnancy and their associations with the risk of gestational diabetes mellitus: a prospective cohort study in Southwest China. Front Endocrinol (Lausanne) 2018;9:596.
PUBMED | CROSSREF
36. Malik VS, Li Y, Tobias DK, Pan A, Hu FB. Dietary protein intake and risk of type 2 diabetes in us men and women. Am J Epidemiol 2016;183:715-28.
PUBMED | CROSSREF
37. Shang X, Scott D, Hodge A, English DR, Giles GG, Ebeling PR, Sanders KM. Dietary protein from different food sources, incident metabolic syndrome and changes in its components: an 11-year longitudinal study in healthy community-dwelling adults. Clin Nutr 2017;36:1540-8.
PUBMED | CROSSREF
38. Farvid MS, Cho E, Chen WY, Eliassen AH, Willett WC. Dietary protein sources in early adulthood and breast cancer incidence: prospective cohort study. BMJ 2014;348:g3437.
PUBMED | CROSSREF
39. Pan A, Sun Q, Bernstein AM, Schulze MB, Manson JE, Stampfer MJ, Willett WC, Hu FB. Red meat consumption and mortality: results from 2 prospective cohort studies. Arch Intern Med 2012;172:555-63.
PUBMED | CROSSREF
40. Ministry of Health and Welfare, Korea Disease Control and Prevention Agency. Korea Health Statistics 2018. Osong: Korea Disease Control and Prevention Agency; 2019.
41. Ministry of Health and Welfare, Korea Disease Control and Prevention Agency. Korea Health Statistics 2021. Osong: Korea Disease Control and Prevention Agency; 2022.
42. Korea Rural Economic Institute. The 2023 Agricultural Outlook (Vol. 2): Innovation and Future of Agriculture and Rural Areas. Osong: Korea Rural Economic Institute; 2023.
43. GBD 2017 Diet Collaborators. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the global burden of disease study 2017. Lancet 2019;393:1958-72.
PUBMED | CROSSREF
44. Martinez S, Delgado MDM, Marin RM, Alvarez S. Carbon footprint of school lunch menus adhering to the Spanish dietary guidelines. Carbon Manag 2020;11:427-39.
CROSSREF
45. Wickramasinghe KK, Rayner M, Goldacre M, Townsend N, Scarborough P. Contribution of healthy and unhealthy primary school meals to greenhouse gas emissions in England: linking nutritional data and greenhouse gas emission data of diets. Eur J Clin Nutr 2016;70:1162-7.
PUBMED | CROSSREF
46. Seoul Metropolitan Office of Education, Department of Health, Sports, Culture, and Arts. The 2021 SOS! Basic Plan for Revitalization of Green School Meals: Seoul: Seoul Metropolitan Office of Education; 2021. p. 1-13.