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## Aims and Scope

*Clinical Nutrition Research* (Clin Nutr Res or CNR), which was launched in 2012 as the official journal of the Korean Society of Clinical Nutrition (KSCN), strives for academic advancement by stimulating research activities in the clinical nutrition research field. The CNR is published quarterly on the last day of January, April, July, and October, one volume per year. The CNR aims to contribute to human health and nutrition by exerting education effect, which can be practically applied in clinical nutrition care. Total or a part of the articles in this journal are abstracted in Science Central, Directory of Open Access Journal, Google Scholar, and Crossref.

The journal features original research articles, reviews, case reports, and notes related to the field of clinical nutrition, human nutrition, and public health nutrition. It publishes manuscripts on nutrition interventions contributing to disease prevention and health promotion, nutrient physiology and metabolism, human nutrition related to growth and development, nutritional assessments, and quality management of clinical nutrition, community nutrition, dietary behavior, nutritional epidemiology, nutrition education, food culture and other studies related to the promotion of human health. It also publishes animal experiments of which findings are applicable to human nutrition or diseases.

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# Editorial Board

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Original Article

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# Estimating added sugars intake among South Koreans: results from the 2023 Korea National Health and Nutrition Examination Survey

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**Objective:** This study aimed to adapt a systematic methodology for estimating the added sugars content of South Korean foods and to assess added sugars intake among South Koreans using data from the 2023 Korea National Health and Nutrition Examination Survey.

**Methods:** The estimation procedure developed for Australian foods was modified and applied to South Korean foods. Added sugars content was estimated for 2,314 food items using the modified 7-step estimation procedure, and these estimates were applied to dietary intake data. Mean contents of total sugars and estimated added sugars were summarized by food group. Mean intakes of total sugars and added sugars, the percentage of energy from added sugars, and the prevalence of excessive added sugars intake were estimated.

**Results:** According to the modified estimation procedure, 53.0% of food items were assigned to step 1 (total sugars=0) or step 2 (non-added sugars food groups) and therefore assigned added sugars content of zero, while 20.9% were assigned to step 3, in which all total sugars were classified as added sugars. Mean added sugars intake was 30.7 g/day, accounting for about half of total sugars intake (58.3 g/day). Overall, 21.2% of the population had energy intake from added sugars exceeding 10% of total energy intake, with the highest proportion observed among adolescent girls (37.9%).

**Conclusion:** This study provides the first nationally representative estimates of added sugars intake among South Koreans by adapting a systematic methodology. These findings provide a robust foundation for monitoring population-level added sugars intake and informing the development of targeted policies and interventions to reduce added sugars intake.

**Keywords:** Sugars; Dietary sugars; Nutrition surveys; Republic of Korea

## INTRODUCTION

Added sugars are associated with an increased risk of various adverse health outcomes, including obesity [1], hypertension [2], cardiovascular disease [3], and dental caries [4]. Thus, overconsumption of added sugars is a significant global public health con-

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cern that has prompted initiatives to reduce their intake. The 2025–2030 Dietary Guidelines for Americans state that no amount of added sugars is recommended and advise that each meal contain no more than 10 g of added sugars [5]. The 2025 Korean Dietary Reference Intakes (KDRIs) recommend limiting added sugars to no more than 10% of total energy intake [6]. Added sugars include sugars that are added during the processing of foods, foods packaged as sweeteners, sugars from syrups and honey, and sugars from concentrated fruit or vegetable juices [7].

Reliable and current data on added sugars intake are essential for informing evidence-based public health policy decisions. However, monitoring population-level intake remains challenging despite recommendations to limit added sugars intake. In South Korea, as in many other countries, added sugars content is not declared on food labels. Therefore, added sugars content is not included in the publicly available South Korean food composition database. Although the Ministry of Food and Drug Safety (MFDS) reports sugars intake from processed foods [8], the reported intake does not directly correspond to added sugars intake. The Korea National Health and Nutrition Examination Survey (KNHANES) reports only total sugars intake without distinguishing added sugars.

Various methods have been developed to estimate added sugars content of foods, most of which involve subtracting natural sugars from total sugars to derive estimates of added sugars. In 2015, Louie et al. [9] proposed a systematic methodology for estimating added sugars content of foods. This methodology consists of a 10-step procedure for estimating added sugars from the total sugars content of Australian foods. The approach demonstrated good replicability and has since been widely adopted in the Australian Food and Nutrient Database (AUSNUT) and in studies adapting the methodology for other countries, enabling the estimation of both food-level added sugars content and population-level added sugars intake [10-14].

This study aimed to adapt a systematic methodology to estimate the added sugars content of South Korean foods and to estimate added sugars intake among South Koreans using data from the 2023 KNHANES. The estimation procedure proposed by Louie et al. [9], which was not directly applicable to South Korean foods, was modified to estimate the added sugars content of food items reported in KNHANES. These estimates were then applied to the dietary intake data to estimate population-level added sugars intake.

## METHODS

### Ethics statement

The Institutional Review Board of the Korea Disease Control and Prevention Agency (KDCA) approved the KNHANES protocol (No. 2022-11-16-R-A), and written informed consent was obtained from all participants. As this study used publicly available KNHANES data, it qualified for exemption from additional Institutional Review Board approval. All procedures were conducted in accordance with the principles of the Declaration of Helsinki.

### Definition of added sugars

Despite the consistent public health guidance to limit sugar intake, recommendations differ in the type of sugars they address. The World Health Organization (WHO) focuses on free sugars, whereas many national dietary guidelines emphasize added sugars or total sugars [15]. Some countries, including the United States and Brazil, also require added sugars to be declared separately on food labels [7,16]. WHO defines free sugars as all monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook, or consumer, as well as sugars naturally present in honey, syrups, fruit juices, and fruit juice concentrates [17]. Within this framework, added sugars are a subset of free sugars and exclude naturally occurring sugars. The 2025 KDRIs describe added sugars as sugars that are added during food processing and preparation [6], aligning conceptually with the subset of free sugars.

However, several limitations have been identified when sugars are classified from a health perspective [15,18,19]. The distinction between added sugars and free sugars is primarily determined by whether sugars in juiced or pureed fruits and vegetables are included in the definition [18,20]. Added sugars are defined based on whether sugars are intentionally added during food processing or preparation [6,7,21], whereas free sugars are defined according to whether they are present outside the cellular matrix [21]. As a result, sugars naturally occurring in a food may be classified as added sugars when extracted or concentrated and used as sweetening ingredients in other foods, such as syrups, honey, or fruit juice concentrates [15]. Processing methods such as blending and pureeing may partially disrupt the cellular structure of fruits and vegetables, producing intermediate forms in which intrinsic sugars and free sugars coexist [18,19]. Consequently, in foods such as fruit and vegetable juices, purées, and smoothies, distinguishing intrinsic sugars from free sugars can be difficult [15,22]. In this study, added sugars were defined as sugars intentionally incorporated during food processing or preparation, consistent with the common definitions used by the WHO [21], United States Food and Drug Administration (FDA) [7], and KDRIs [6].

The added sugars content of foods was estimated based on this definition. Honey, sugar, and syrups were considered added sugars because they are generally used as sweetening ingredients added to foods or beverages. In contrast, unsweetened 100% fruit or vegetable juices, purées, and smoothies were considered to contain no added sugars. For sweetened versions of these products, added sugars content was estimated by subtracting the total sugars content of the corresponding unsweetened product from that of the sweetened product. Thus, the definition used in this study was consistent with the concept of added sugars as sugars intentionally incorporated during food processing or preparation, while remaining distinct from the broader concept of free sugars.

## Data source and participants

This study analyzed data from the 2023 KNHANES, an annual nationwide survey that provides nationally representative information on the health and nutritional status of the South Korean population. A total of 6,786 participants aged ≥ 1 year who completed a 24-hour dietary recall were included in the analysis.

## Estimation of added sugars content of foods

The methodology proposed by Louie et al. [9] was the first systematic approach developed to estimate added sugars content, using a structured protocol that assesses reliability and transferability [23]. In South Korea, a database on the added sugars content of processed foods was developed in 2015 using manufacturer-provided information and ingredient formulation data [20]; however, this database has not been made publicly available. In this study, Louie's methodology was adapted to estimate the added sugars content of South Korean food items reported in the 2023 KNHANES. This approach enables added sugars content to be estimated in the absence of preexisting data on added sugars content or ingredient formulation information.

Louie's methodology consists of a 10-step procedure for estimating the added sugars content of individual food items, comprising six objective decision steps (steps 1–6) and four subjective decision steps (steps 7–10) [9]. The procedure operates in a stepwise manner, with each step defining specific food groups. Food items move sequentially to the next step if the criteria of the previous step are not met. In the final step, for food items whose added sugars content cannot be estimated through the preceding steps (steps 1–9), 50% of the total sugars content is assigned as added sugars. As each step uses a different estimation method, the resulting added sugars content may differ depending on the step used [23].

Because the original procedure was developed for Australian foods, it was modified in this study to fit the KNHANES data and to estimate the added sugars content of South Korean foods. This adaptation of the original procedure is consistent with previous studies that adapted the 10-step procedure according to country-specific food characteristics and data availability [10-14]. In the present study, steps requiring detailed recipe information and ingredient formulation data (steps 4, 8, and 9) were excluded because of data limitations. As a result, a modified 7-step procedure was used, with the original stepwise logic retained. The modified procedure comprised five objective decision steps (steps 1–5) and two subjective decision steps (steps 6–7).

The modified procedure was subsequently applied to all 2,314 food items reported in the 2023 KNHANES to systematically estimate the added sugars content of each item according to the stepwise procedure. Food items were assigned to the appropriate step according to the food groups defined at each step of the procedure. For each item, the ingredient information and the total sugars content of its main ingredients were reviewed where available to support step assignment. Food items not explicitly covered in the original procedure, mainly traditional South Korean foods, were assigned to the most appropriate steps based on their characteristics.

For example, unsweetened rice cakes, such as garaetteok and jeolpyeon, were assigned to step 2, which includes food groups considered to contain no added sugars. In contrast, foods were assigned to step 3, in which total sugars were assumed to be 100% added sugars, when they did not contain ingredients generally containing naturally occurring sugars—such as fruits, chocolate, dairy products, or milk solids—and when their main ingredients contained less than 1 g of total sugars per 100 g. Accordingly, powdered sweetened tea products, such as ginger tea and red ginseng tea, and fishery processed products, such as fish sausage and jeotgal, were assigned to step 3 because their main ingredients contain little or no naturally occurring sugars. This approach was applied to minimize potential overestimation due to naturally occurring sugars.

After the added sugars content had been estimated for all food items by one researcher, the initial step assignments were independently reviewed by a second researcher. When discrepancies in step assignments were identified, the ingredient information of the food item and the total sugars content of its main ingredients were re-examined, and the final step assignment was determined by consensus between the two researchers. Details of each step in the modified 7-step procedure are provided in Table 1.

**Table 1.** Modified procedure for estimating added sugars content in food items reported in 2023 KNHANES

| Procedure[a] |
|---|
| Step 1. Assign 0 g added sugars to foods with 0 g total sugars. |
| Step 2. Assign 0 g added sugars to foods in the following food groups: |
| (a) Fresh or minimally processed fruits, vegetables, legumes, nuts, and seeds (including boiled, blanched, dried, or frozen forms). |
| (b) Fresh or minimally processed meat and seafood (including boiled, blanched, dried, or frozen forms). |
| (c) All plain cereal grains, rice, flours, noodles, and pasta. |
| (d) All spices and herbs. |
| (e) All fats and oils. |
| (f) Eggs and egg products (except egg-based desserts). |
| (g) Plain breads (such as English muffins, bagels, pizza bases, and naan). |
| (h) Plain pastries without filling. |
| (i) Plain rice cake (such as Garaetteok and Jeolpyeon). |
| (j) 100% fruit/vegetable juice and juice/cordial base sweetened with artificial sweeteners only. |
| (k) Non-sweetened alcoholic beverages, coffee, and tea. |
| (l) Non-sugar-sweetened milk and dairy products. |
| (m) Intensely sweetened jam and beverage base (without added sugar). |
| Step 3. Assign 100% of total sugars as added sugars for foods in the following food groups: |
| (a) Breakfast cereals and cereal bars that do not contain fruit, chocolate, or dairy products. |
| (b) Savory biscuits, sweet biscuits, cakes and buns, donuts and batter-based products that do not contain fruit, chocolate or dairy products. |
| (c) Processed meat (such as bacon and sausages) and seafood (such as fish sausages and fermented seafood including Jeotgal) |
| (d) Crumbed/battered meat and seafood. |
| (e) All confectionery except those containing dairy products such as fudge and chocolate. |
| (f) Frozen desserts that do not contain fruit, chocolate, or dairy products. |
| (g) Regular soft drinks, sports drinks, flavored water and non-fruit-based energy drinks. |
| (h) Coffee and beverage base with no milk solids, dry or made up with water. |
| (i) Soy beverages and soy yogurt without added fruits. |
| (j) Honey, sugar and syrups. |
| (k) Sauces, seasonings, dressings, stock powder and broths that do not contain fruit, chocolate, or dairy products. |
| Step 4. Calculation based on comparison with values from the unsweetened variety. |
| The amount of added sugars needed per 100 g ($AS_{100\ g}$) to sweeten the unsweetened product to achieve the final listed sugars content ($S_{Total}$) is given by the following formula: |
| $AS_{100g} = \frac{100\ (S_{us} - S_{\text{total}})}{S_{us} - 100}$ |
| where $S_{us}$ is the total sugars content per 100 g of the unsweetened variety of the food. |
| Step 5. Calculation based on analytical data from the KFCT[b]. |
| When the target food item is available in the KFCT, its analytical values for total sugars, lactose, and maltose are used to estimate the added sugars content. If the target food item is not available in the KFCT, a similar food is selected for estimation. The added sugars content estimated using analytical data of the similar food must not exceed the total sugars content of the target food item. Based on the selected food (identical or similar), added sugars content was calculated as follows: |
| (a) If analytical data for lactose are available and the ingredients do not include dried fruits or malted cereals, added sugars content is calculated as total sugars minus lactose. |
| (b) If the food contains malted cereals and analytical data for both lactose and maltose are available, added sugars content is calculated as total sugars minus lactose and maltose. |
| Step 6. Use borrowed values from similar products from steps 1–5 or from overseas databases. |
| (a) The added sugars value is directly borrowed from a similar food identified in steps 1–5. |
| (b) In the absence of a similar food from steps 1–5, the added sugars value is estimated using data from similar foods identified in the USDA Global Branded Food Products Database (GBFPD)[c] and the Australian Food and Nutrient Database (AUSNUT)[d]. The added sugars content of the target food item is calculated as total sugars multiplied by the proportion of added sugars in a similar food. |
| Step 7. Assign 50% of total sugars as added sugars. |
| If estimation of added sugars content is impossible from Steps 1–6, then added sugars is assumed to be 50% of total sugars. |

KNHANES, Korea National Health and Nutrition Examination Survey.
[a]The 7-step procedure developed by adapting the original procedure proposed by Louie et al. [9] to enhance its applicability to the KNHANES data, with modifications specifically applied to steps 2, 3, and 5. [b]National Institute of Agricultural Sciences (NAS); Rural Development Administration. Korean Food Composition Table (KFCT), version 10.2. [c]United States Department of Agriculture (USDA). Global Branded Food Products Database, release date June 2025. [d]Food Standards Australia New Zealand (FSANZ). Australian Food and Nutrient Database 2023, release date September 2025.

### Estimation of population-level added sugars intake

The added sugars content of individual food items was applied to 24-hour dietary recall data from the 2023 KNHANES to estimate added sugars intake. The mean intakes of total sugars and estimated added sugars were presented by sex and age group. The percentage of total energy intake contributed by added sugars was derived using an energy conversion factor of 4 kcal/g. In addition, based on the 2025 KDRIs recommendation to limit added sugars intake to no more than 10% of total energy intake, the prevalence of added sugars intake exceeding 10% of total energy intake was estimated.

### Statistical analysis

Mean contents of total sugars and estimated added sugars in foods were presented by food group as means with standard deviations, along with estimated added sugars as a percentage of total sugars. The energy, total sugar, and added sugars intakes were presented as the weighted means with standard errors. The percentage of energy intake from added sugars and the prevalence of excessive intakes were presented as the weighted percentages with standard errors. Sampling weights were applied to account for the complex sampling design of the 2023 KNHANES. All data analyses were conducted using SAS ver. 9.4 (SAS Institute Inc.).

## RESULTS

### Application of the added sugars content estimation procedure

Fig. 1 illustrates the distribution of food items according to the modified 7-step procedure. Of the total food items, 87.4% were assigned to objective steps (steps 1–5), while 12.6% were assigned to subjective steps (steps 6–7). Added sugars were estimated for 73.9% of food items using the most straightforward steps (steps 1–3). Of all food items, 53.0% were assigned to step 1 (total sugars content = 0) or step 2 (non-added sugars food groups) and were therefore estimated to contain no added sugars. In contrast, 20.9% were assigned to step 3 as foods in which 100% of total sugars were considered added sugars.

### Added sugars content of the South Korean foods

Table 2 shows the mean contents of total sugars and estimated added sugars by food group, based on estimates for individual food items obtained using the modified procedure presented in Table 1. Food groups were classified according to the Korean Food Code classification system for processed foods established by the MFDS [24]. Excluding 'Saccharides' (68.3 g/100 g) and 'Honey and Pollen Products' (63.5 g/100 g), the food groups with

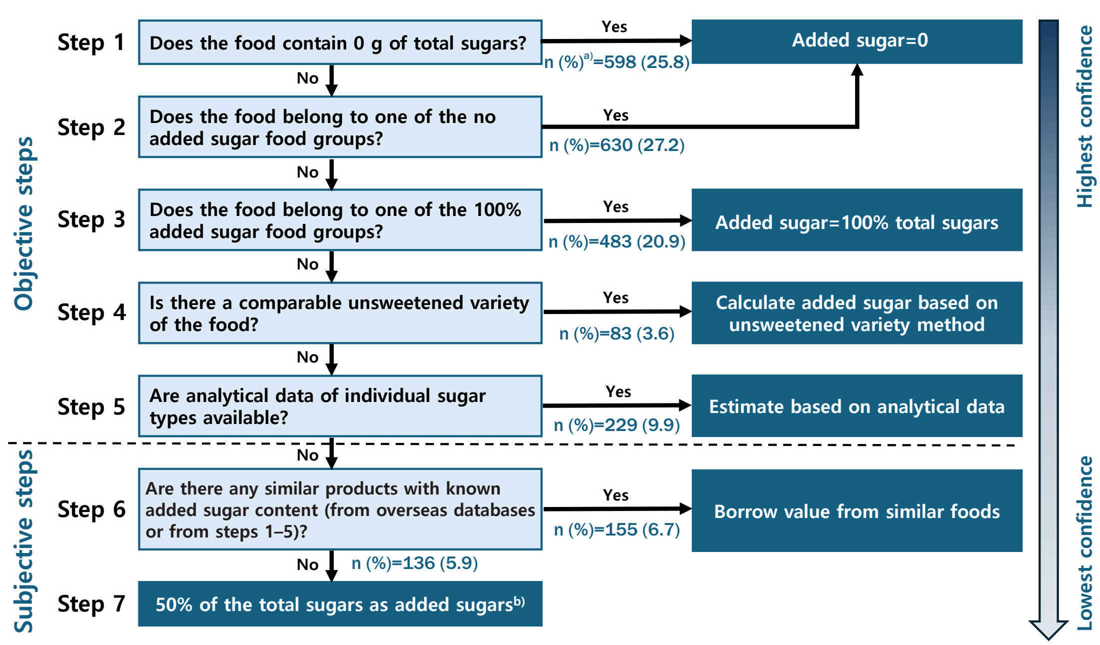


**Fig. 1.** Decision-making flowchart for estimating added sugars content in food items. [a)]Number (%) of food items assigned to each step according to the National Food Code in the food intake data from 2023 Korea National Health and Nutrition Examination Survey. [b)]The proportion of total energy intake contributed by food items classified in step 7 was 1.7% from all food items.

**Table 2.** Mean contents of total sugars and added sugars by food group in this study

| Food group[a)] | No. of food items[b)] | Total sugars (g/100 g) | Added sugars (g/100 g)[c)] | Added sugars as a percentage of total sugars (%) |
|---|---|---|---|---|
| Saccharides | 21 | 68.3±32.9 | 68.3±32.9 | 100 |
| Honey and pollen products | 7 | 63.5±21.3 | 63.5±21.3 | 100 |
| Cocoa products or chocolates | 38 | 49.2±14.5 | 44.6±14.8 | 88.1 |
| Jams | 11 | 50.5±6.8 | 43.8±10.5 | 86.9 |
| Confectioneries, breads, or rice cakes | 302 | 21.9±18.3 | 20.7±18.2 | 91.7 |
| Frozen confectioneries | 77 | 17.0±5.3 | 13.4±5.7 | 77.7 |
| Processed agricultural foods | 92 | 13.6±13.2 | 10.9±12.9 | 61.3 |
| Beverages | 263 | 13.9±17.6 | 10.5±15.6 | 73.7 |
| Pickled foods or boiled foods | 42 | 9.8±14.8 | 8.9±14.7 | 73.1 |
| Soy sauces and pastes | 37 | 8.0±11.0 | 7.7±11.1 | 88.8 |
| Seasoning foods | 106 | 9.2±9.0 | 7.6±7.9 | 79.2 |
| Milk products | 120 | 10.2±9.8 | 6.0±7.3 | 52.7 |
| Prepared meals | 22 | 6.7±9.6 | 4.3±7.2 | 59.9 |
| Processed fishery foods | 81 | 2.9±5.8 | 2.8±5.8 | 95.2 |
| Processed meat products and packaged meats | 35 | 2.4±5.1 | 2.2±5.1 | 95.7 |
| Alcoholic beverages | 56 | 1.4±3.5 | 0.8±2.0 | 43.6 |
| Soybean curds or muk (starch jellies) | 14 | 0.2±0.3 | 0.0±0.1 | 12.5 |
| Noodles | 31 | 0.9±1.7 | 0.0±0.0 | 0 |
| Egg products | 10 | 0.1±0.1 | 0.0±0.0 | 0 |
| Edible fats and oils | 30 | 0.0±0.0 | 0.0±0.0 | NA |

Total sugars and added sugars contents are presented as mean±standard deviation.
NA, not calculated because the total sugar content was zero.
a)Food groups were classified according to the Korean Food Code classification system for processed foods established by the Ministry of Food and Drug Safety [24]. Raw food ingredients and prepared dishes were excluded. Food groups with fewer than five food items were also excluded: foods for special dietary uses (n=4), processed animal food products (n=1), and other foods (n=2). b)National Food Code in the food intake data from 2023 National Health and Nutrition Examination Survey. c)Added sugars were estimated for each food item using the modified procedure for estimating added sugars content described in Table 1, and mean values were calculated by food group.

the highest mean added sugars content were 'Cocoa Products or Chocolates' (44.6 g/100 g) and 'Jams' (43.8 g/100 g), with added sugars accounting for 88.1% and 86.9% of total sugars, respectively. 'Confectioneries, Breads or Rice Cakes' contain 20.7 g/100 g of added sugars, corresponding to 91.7% of total sugars. 'Frozen Confectioneries' (13.4 g/100 g), 'Processed Agricultural Foods' (10.9 g/100 g), and 'Beverages' (10.5 g/100 g) also contained more than 10 g/100 g of added sugars.

## Added sugars intake among the South Korean population

Table 3 presents the mean daily intakes of total sugars and added sugars by sex and age group. In the overall population, mean total sugars intake was 58.3 g/day, while mean estimated added sugars intake was 30.7 g/day, accounting for more than half of total sugars intake. Total sugars intake was consistent with the intake reported by the MFDS using the same 2023 KNHANES data [8], but it differed from that reported by the KDCA, which applied standardization in its analysis [25].

The mean intake of added sugars was higher in men (34.3 g/day) than in women (27.2 g/day). The highest mean intake of added sugars was observed among adolescents aged 12–18 years (45.3 g/day), followed by young adults aged 19–29 years (40.7 g/day). Across all sex and age subgroups, the highest mean intakes of both total sugars and added sugars were observed in adolescent boys aged 12–18 years, at 73.9 g/day and 49.3 g/day, respectively.

Table 4 shows the percentage of total energy intake from added sugars and the prevalence of excessive added sugars intake by sex and age group. Added sugars contributed 6.8% of total energy intake in the overall population. The percentage of total energy intake from added sugars was comparable between men (6.7%) and women (6.8%). The percentage of total energy intake from added sugars exceeded 8% among children, adolescents, and young adults, specifically those aged 6–11 years (8.6%), 12–18 years (9.1%), and 19–29 years (8.7%). Notably, the percentage of energy intake from added sugars was highest among adolescent girls aged 12–18 years (9.7%), approaching the 10% limit recommended by the 2025 KDRIs [6].

Excessive added sugars intake was defined as consuming more than 10% of total energy from added sugars, in accordance with

**Table 3.** Mean intakes of total sugars and added sugars by sex and age group among South Koreans (2023 KNHANES)

| Age group (yr) | No. of participants[a] | | | Total sugars (g/day) | | | Added sugars (g/day)[b] | | |
|---|---|---|---|---|---|---|---|---|---|
| | All | Men | Women | All | Men | Women | All | Men | Women |
| All | 6,786 | 3,016 | 3,770 | 58.3±0.7 | 60.8±1.0 | 55.8±0.8 | 30.7±0.5 | 34.3±0.7 | 27.2±0.6 |
| 1–2 | 87 | 40 | 47 | 49.8±3.3 | 54.6±5.6 | 44.6±2.9 | 15.6±2.7 | 18.3±5.0 | 12.6±1.6 |
| 3–5 | 129 | 64 | 65 | 58.5±3.5 | 61.0±5.1 | 56.1±4.5 | 26.9±2.1 | 29.0±3.3 | 24.8±2.5 |
| 6–11 | 403 | 204 | 199 | 66.4±2.7 | 69.7±4.0 | 62.9±3.0 | 38.3±1.8 | 39.5±2.3 | 37.1±2.3 |
| 12–18 | 386 | 197 | 189 | 68.5±2.8 | 73.9±4.3 | 62.5±3.5 | 45.3±2.5 | 49.3±3.6 | 40.8±2.8 |
| 19–29 | 600 | 284 | 316 | 60.6±2.2 | 62.4±2.8 | 58.6±2.8 | 40.7±1.8 | 42.2±2.4 | 39.0±2.3 |
| 30–49 | 1,625 | 715 | 910 | 59.0±1.2 | 61.3±1.7 | 56.5±1.5 | 34.1±0.9 | 37.8±1.4 | 30.2±1.0 |
| 50–64 | 1,758 | 720 | 1,038 | 57.7±1.2 | 58.0±1.8 | 57.4±1.4 | 25.9±0.7 | 29.2±1.1 | 22.5±0.7 |
| ≥65 | 1,798 | 792 | 1,006 | 50.9±1.2 | 54.8±1.6 | 47.9±1.3 | 18.7±0.5 | 22.3±0.8 | 15.9±0.5 |

Values for total sugars and added sugars intake are presented as weighted mean±standard error. All weighted models accounted for the complex sampling design of the 2023 Korea National Health and Nutrition Examination Survey (KNHANES).
[a]Numbers of participants are unweighted. [b]Mean intake of added sugars was estimated using the modified procedure for estimating added sugars content described in Table 1.

**Table 4.** Percentage of energy intake from added sugars and prevalence of excessive added sugars intake by sex and age group among South Koreans (2023 KNHANES)

| Age group (yr) | No. of participants[a] | | | Percentage of energy intake from added sugars (%)[b] | | | Prevalence of excessive added sugars intake (%)[c] | | |
|---|---|---|---|---|---|---|---|---|---|
| | All | Men | Women | All | Men | Women | All | Men | Women |
| All | 6,786 | 3,016 | 3,770 | 6.8±0.1 | 6.7±0.1 | 6.8±0.1 | 21.2±0.6 | 21.1±0.9 | 21.3±0.8 |
| 1–2 | 87 | 40 | 47 | 5.2±0.8 | 5.5±1.4 | 4.8±0.6 | 16.2±4.6 | 16.5±7.2 | 15.8±5.5 |
| 3–5 | 129 | 64 | 65 | 7.8±0.5 | 8.2±0.8 | 7.3±0.6 | 30.0±4.7 | 33.1±7.2 | 27.0±5.7 |
| 6–11 | 403 | 204 | 199 | 8.6±0.4 | 8.3±0.5 | 8.9±0.5 | 32.0±3.1 | 29.4±3.6 | 34.7±4.2 |
| 12–18 | 386 | 197 | 189 | 9.1±0.4 | 8.6±0.6 | 9.7±0.6 | 34.5±2.7 | 31.4±3.8 | 37.9±3.5 |
| 19–29 | 600 | 284 | 316 | 8.7±0.3 | 7.9±0.4 | 9.6±0.5 | 33.8±2.3 | 30.9±2.9 | 37.0±3.0 |
| 30–49 | 1,625 | 715 | 910 | 7.2±0.2 | 7.1±0.2 | 7.4±0.2 | 23.7±1.3 | 24.0±1.7 | 23.4±1.6 |
| 50–64 | 1,758 | 720 | 1,038 | 5.7±0.1 | 5.8±0.2 | 5.6±0.1 | 14.1±0.9 | 14.6±1.4 | 13.5±1.1 |
| ≥65 | 1,798 | 792 | 1,006 | 4.7±0.1 | 4.9±0.1 | 4.5±0.1 | 9.6±0.8 | 9.4±1.2 | 9.7±1.0 |

Values for the percentage of energy intake from added sugars and the prevalence of excessive added sugars intake are presented as weighted percentage±standard error. All weighted models accounted for the complex sampling design of the 2023 Korea National Health and Nutrition Examination Survey (KNHANES).
[a]Number of participants are unweighted. [b]Percentage of total energy intake contributed by added sugars estimated using the modified procedure for estimating added sugars content described in Table 1. [c]Prevalence of South Koreans consuming >10% of total energy from added sugars (The 2025 Korean Dietary Reference Intakes recommendation).

the 2025 KDRIs recommendation [6]. In the overall population, 21.2% of participants consumed more than 10% of their total energy from added sugars. More than one-third of adolescents aged 12–18 years (34.5%) and young adults aged 19–29 years (33.8%) exceeded the recommended limit. Within these age groups, women had a higher prevalence of excessive added sugars intake than men, with a prevalence greater than 37.0% among women aged 12–18 years (37.9%) and 19–29 years (37.0%).

## DISCUSSION

In the present study, the methodology proposed by Louie et al. [9] was applied to estimate added sugars intake among South Koreans using data from the 2023 KNHANES. Because nationally representative estimates of added sugars intake in the South Korean population have never been reported before, the sugars intake from processed foods reported by the MFDS [8] was used as a reference for comparison. However, the sugars content of processed foods is inherently higher than their added sugars content, as processed foods contain both added and naturally occurring sugars. For example, flavored strawberry yogurt contains lactose from milk, sugars derived from strawberries, most of which are present as free sugars because of cellular disruption during processing, and sugars added during processing; therefore, its total sugars content exceeds its added sugars content. Accordingly, the estimated added sugars intake in this study was lower than the total sugars intake from processed foods reported by the MFDS [8]. In the overall population, the mean estimated added sugars intake was 30.7 g/day, which was somewhat lower than the reported sugars intake from processed foods (35.5 g/day).

This study revealed that the prevalence of excessive added sugars intake was 21.2%, indicating that one in five South Koreans exceeds the recommended upper limit of 10% of total energy intake from added sugars. Excessive intake was particularly prevalent among school-aged children (6–11 years), adolescents (12–18 years), and young adults (19–29 years), among whom approximately one-third were classified as excessive consumers of added sugars. The highest prevalence was observed in adolescent girls (37.9%). A previous study using data from the 2019–2024 KNHANES examined the proportion of the population whose sugar intake from processed foods exceeded the WHO recommendation of less than 10% of total energy intake [26]. The study reported higher proportions of excessive sugar intake from processed foods among children, adolescents, and young adults, with the highest proportion observed among school-aged girls (41.4%), consistent with the findings of the present study. In the United States and the United Kingdom, adolescents and young adults also exhibit higher added sugars intake than other age groups [27,28].

The primary sources of sugar intake from processed foods among the South Korean population are beverages, confectionery, and bakery products [8,26], which likely contribute to the high intake of added sugars among children and adolescents. In particular, beverages are a major source of added sugars, with the highest intake observed among adolescents and young adults [29,30]. In the present study, the estimated added sugars content was relatively high in these food groups, and added sugars accounted for a substantial proportion of total sugars. Therefore, these food groups may contribute considerably to added sugars intake, reflecting both their high added sugars content and their larger consumption among children and adolescents.

These findings indicate the need for targeted nutrition strategies for population subgroups with high added sugars intake, particularly adolescent girls. For these groups, nutrition education should focus on identifying the major dietary sources of added sugars, including sugar-sweetened beverages, confectionery, and bakery products, rather than simply emphasizing the reduction of total sugar intake. Practical strategies may include replacing sugar-sweetened beverages with water or unsweetened beverages and substituting sweetened snacks with healthier alternatives, such as fresh fruits. School-based nutrition education programs tailored to adolescents may also help promote healthier food choices and reduce the habitual consumption of snacks and beverages high in added sugars. These approaches may support more effective clinical nutrition guidance and targeted strategies to reduce added sugars intake among high-risk groups.

In the present study, a modified 7-step procedure based on the methodology proposed by Louie et al. [9] was applied to estimate added sugars intake among South Koreans. Several studies have examined Louie's methodology, and it has been demonstrated to be reliable and valid [10-14]. When Louie's methodology was applied by two independent researchers to estimate the added sugars content of foods, a high level of inter-rater agreement was observed [23]. Furthermore, the estimated values derived using Louie's methodology demonstrated excellent agreement with the added sugars values declared on food labels [13]. However, selecting the most appropriate step for each food item inherently involves a degree of subjective judgment [23].

This issue may be particularly relevant when adapting the original Australian procedure to South Korean food items, because some South Korean foods are not covered in the original procedure and require contextual interpretation based on their ingredients and processing methods. For example, unsweetened rice cakes were assigned to step 2, which includes non-added sugars food groups, because they are considered to contain no added sugars. In contrast, fishery processed products, such as fish sausage and jeotgal, were assigned to step 3, in which total sugars are assumed to be 100% added sugars, because their main ingredients contain little or no naturally occurring sugars.

To reduce potential bias in assigning food items to certain steps, assignments were based on available ingredient information and the total sugars content of the main ingredients, and were systematically reviewed. Nevertheless, because the procedure was modified to reflect both data availability and South Korean dietary culture, further validation is needed to assess its reliability. In particular, inter-rater reliability was not quantitatively assessed in the present study, although discrepancies were resolved by consensus between the two researchers. Therefore, future studies should evaluate the reliability, reproducibility, and validity of the modified procedure.

It should be noted that added sugars intake in the present study was estimated using data from a single 24-hour dietary recall and therefore may not reflect individuals' usual intake. Although the 24-hour dietary recall method is widely used in national dietary surveys, it captures dietary intake for only one day and may be subject to recall bias. In particular, for items that are frequently consumed but may be easily omitted during recall, such as snacks and beverages, the amounts consumed may be systematically under- or over-reported. If added sugars intake was under- or overestimated, the proportion of individuals exceeding 10% of total energy intake from added sugars, which was calculated based on these estimates, may also have been affected. Considering these limitations, the estimates presented in this study should be interpreted as daily intake estimates based on 1-day dietary data, and the prevalence of excessive added sugars intake should be interpreted with caution.

To the best of our knowledge, this is the first study to estimate added sugars intake among South Koreans using nationally representative data from the KNHANES. Unlike previous studies that focused on total sugars or sugars derived from processed foods, this study specifically estimated added sugars intake, which constitutes the primary target of sugar reduction policies. This distinction is significant because evidence-based policies for sugar reduction require population-level monitoring of added sugars intake. The mandatory declaration of added sugars on food labels, as implemented in the United States [7], could provide a foundation for effective sugar reduction policies, including regulatory measures targeting the added sugars content of processed foods. Moreover, further research identifying the major dietary sources of added sugars across population subgroups would contribute to the development of targeted sugar reduction strategies. At a time when the introduction of a sugar tax is being actively debated in South Korea, the findings of this study provide timely, policy-relevant evidence on the current status of added sugars intake in the South Korean population, offering an important scientific basis for public health decision-making.

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### Conflict of interest

None.

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### Data availability

The datasets analyzed in this study are available in the Korea National Health and Nutrition Examination Survey (KNHANES) repository, https://knhanes.kdca.go.kr/knhanes.

## REFERENCES

1. Te Morenga L, Mallard S, Mann J. Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies. BMJ 2012;346:e7492.
2. Te Morenga LA, Howatson AJ, Jones RM, Mann J. Dietary sugars and cardiometabolic risk: systematic review and meta-analyses of randomized controlled trials of the effects on blood pressure and lipids. Am J Clin Nutr 2014;100:65-79.
3. Vos MB, Kaar JL, Welsh JA, et al. Added sugars and cardiovascular disease risk in children: a scientific statement from the American Heart Association. Circulation 2017;135:e1017-34.
4. Moynihan PJ, Kelly SA. Effect on caries of restricting sugars intake: systematic review to inform WHO guidelines. J Dent Res 2014;93:8-18.
5. United States Department of Agriculture. Dietary guidelines for Americans, 2025-2030 [Internet]. United States Department of Agriculture; 2026 [cited 2026 Jun 9]. Available from: https://www.dietaryguidelines.gov/
6. Ministry of Health and Welfare; The Korean Nutrition Society. Dietary reference intakes for Koreans 2025. Ministry of Health and Welfare; 2025.
7. United States Food and Drug Administration. Added sugars on the nutrition facts label [Internet]. U.S. Food and Drug Administration; 2023 [cited 2026 Jun 9]. Available from: https://www.fda.gov/food/nutrition-facts-label/added-sugars-nutrition-facts-label
8. Ministry of Food and Drug Safety. 2025 Report on the intake status of health-sensitive nutrients: sodium and sugars. Ministry of Food and Drug Safety; 2025.
9. Louie JC, Moshtaghian H, Boylan S, et al. A systematic methodology to estimate added sugar content of foods. Eur J Clin Nutr 2015;69:154-61.
10. Kibblewhite R, Nettleton A, McLean R, et al. Estimating free and

added sugar intakes in New Zealand. Nutrients 2017;9:1292.
11. Wanselius J, Axelsson C, Moraeus L, Berg C, Mattisson I, Larsson C. Procedure to estimate added and free sugars in food items from the Swedish food composition database used in the National Dietary Survey Riksmaten Adolescents 2016-17. Nutrients 2019;11:1342.
12. Liu S, Munasinghe LL, Ohinmaa A, Veugelers PJ. Added, free and total sugar content and consumption of foods and beverages in Canada. Health Rep 2020;31:14-24.
13. Scapin T, Louie JC, Pettigrew S, et al. The adaptation, validation, and application of a methodology for estimating the added sugar content of packaged food products when total and added sugar labels are not mandatory. Food Res Int 2021;144:110329.
14. Coyle DH, Davies T, Taylor F, Howes K, Pettigrew S, Jones A. Assessing the policy implications of different definitions for added sugars: an analysis across the Australian packaged food and beverage supply. Curr Dev Nutr 2024;8:102058.
15. Scapin T, Fernandes AC, Proenca RP. Added sugars: definitions, classifications, metabolism and health implications. Rev Nutr 2017;30:663-77.
16. Brazilian Health Regulatory Agency. Collegiate Board Resolution - RDC No. 429 of 8 October 2020: provides for the nutritional labeling of packaged foods. Brazilian Health Regulatory Agency; 2020.
17. World Health Organization. Guideline: sugars intake for adults and children [Internet]. World Health Organization; 2015 [cited 2026 Jun 9]. Available from: https://www.who.int/publications/i/item/9789241549028
18. Mela DJ, Woolner EM. Perspective: total, added, or free?: what kind of sugars should we be talking about? Adv Nutr 2018;9:63-9.
19. Swan GE, Powell NA, Knowles BL, Bush MT, Levy LB. A definition of free sugars for the UK. Public Health Nutr 2018;21:1636-8.
20. Korea Health Industry Development Institute. Sugar database compilation for commonly consumed foods. Korea Health Industry Development Institute; 2015.
21. World Health Organization. Sugars factsheet [Internet]. World Health Organization Regional Office for Europe; 2022 [cited 2026 Jun 15]. Available from: https://cdn.who.int/media/docs/librariesprovider2/euro-health-topics/obesity/sugars-factsheet.pdf
22. Padovan M, Ares G, Scapin T, et al. Declaration of free sugars from fruits on food labels: a scoping review. Br Food J 2024;126:4342-56.
23. Louie JC, Lei L, Rangan AM. Reliability of a systematic methodology to estimate added sugars content of foods when applied to a recent Australian food composition database. J Food Compos Anal 2016;46:36-42.
24. Ministry of Food and Drug Safety. Korean food code [Internet]. Ministry of Food and Drug Safety; [cited 2026 Jun 13]. Available from: https://www.foodsafetykorea.go.kr/foodcode/
25. Yeon S, Lee J, Yun S, Oh K. Intake of dietary sugar in the Republic of Korea: data from the Korea National Health and Nutrition Examination Survey. Jugan Geongang Gwa Jilbyeong 2026;19:253-67.
26. Kwon SO, Kim C. Sugar intake from processed foods among Koreans and levy on excessive sugar use: a cross-sectional study. Korean J Community Nutr 2026;31:287-96.
27. Park S, Zhao L, Lee SH, et al. Children and adolescents in the United States with usual high added sugars intake: characteristics, eating occasions, and top sources, 2015-2018. Nutrients 2023;15:274.
28. Whitton C, Nicholson SK, Roberts C, et al. National Diet and Nutrition Survey: UK food consumption and nutrient intakes from the first year of the rolling programme and comparisons with previous surveys. Br J Nutr 2011;106:1899-914.
29. Powell ES, Smith-Taillie LP, Popkin BM. Added sugars intake across the distribution of US children and adult consumers: 1977-2012. J Acad Nutr Diet 2016;116:1543-50.
30. Jeong Y, Lee H, Oh J, Kim Y. Major food groups and dishes contributing to sugar intake in Korea: Korea National Health and Nutrition Examination Survey 2016-2018. J Korean Soc Food Cult 2021;36:474-83.

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CLINICAL NUTRITION RESEARCH

# Secular trends in dietary patterns among South Korean primary school–aged children based on the 2007–2022 Korea National Health and Nutrition Examination Survey

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**Objective:** This study aimed to identify dietary patterns and examine their associations with sociodemographic and lifestyle characteristics among South Korean primary school–aged children.
**Methods:** Data from 10,173 children aged 6–12 years who participated in the 2007–2022 Korea National Health and Nutrition Examination Survey were analyzed. Their dietary intake was assessed using a 24-hour dietary recall, and dietary patterns were derived from the energy contributions of 26 food groups through cluster analysis.
**Results:** Three patterns were identified: rice-based pattern (47.3%), flour-based pattern (17.7%), and diversified type (35.1%). From 2007 to 2022, the prevalence of the rice-based pattern declined substantially (56.6% to 32.6%), whereas that of the diversified type markedly increased (27.3% to 47.0%). Survey-weighted analyses revealed that the dietary patterns were significantly associated with age, household income, vigorous physical activity, meal-skipping, eating-out frequency, and dietary supplement use (all, P<0.05). Children following the flour-based pattern tended to be older, skip breakfast more often, and engage in less vigorous physical activities. The rice-based pattern included a higher proportion of children from low-income households, whereas the diversified type showed more favorable socioeconomic characteristics and family breakfast practices. Overall, the rice-based and flour-based patterns were associated with less favorable lifestyle behaviors than the diversified type.
**Conclusion:** Dietary patterns among South Korean primary school–aged children appear to be closely related to socioeconomic status and daily health behaviors. Nutrition education and public health interventions promoting balanced diets, reduced meal skipping, and healthier lifestyles during childhood are needed.

**Keywords:** Primary school–aged children; Dietary patterns; Secular trends; Cluster analysis; Korea National Health and Nutrition Examination Survey

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## INTRODUCTION

Dietary habits established during childhood considerably impact physical growth, cognitive development, and long-term health outcomes [1]. Childhood is a sensitive period during which food preferences and eating behaviors are formed, and these behaviors often persist into adolescence and adulthood [2]. Unhealthy dietary habits developed during childhood are associated with increased risks of obesity and other chronic health problems later in life [1,2]. Therefore, understanding childhood dietary behaviors is essential for developing effective nutrition policies and early-life interventions aimed at promoting lifelong health.

In recent decades, rapid socioeconomic development and food environment changes have substantially altered dietary behaviors worldwide, including in South Korea [3]. Traditional South Korean diets comprising rice, vegetables, legumes, and fermented foods have gradually shifted toward more Westernized dietary patterns commonly involving processed and convenience foods, particularly among children and adolescents [3,4]. Recent studies based on the Korea National Health and Nutrition Examination Survey (KNHANES) have also reported changes in dietary behaviors among South Korean youth [4]. These dietary transitions have raised public health concerns, considering that Westernized dietary patterns have been linked to poorer dietary quality and undesirable health effects among children and adolescents [5].

Traditional nutritional epidemiology often focuses on individual nutrients or specific food items [6]. However, given that foods are consumed in combination rather than independently, analyses focusing solely on single nutrients may not adequately reflect overall eating behaviors [7]. Thus, dietary pattern analysis has been widely used to evaluate overall dietary intake by considering food combinations that are habitually consumed within populations [7,8]. Empirical methods, including factor and cluster analyses, have been extensively applied to identify major dietary patterns and examine their associations with nutritional status, obesity, and socioeconomic characteristics [8].

KNHANES is a nationally representative cross-sectional survey that provides comprehensive information on the South Korean population's dietary intake, health behaviors, and socioeconomic characteristics [9]. Previous KNHANES-based studies have identified distinct dietary patterns, including traditional and Westernized dietary patterns, among South Korean children and adolescents [4]. However, the Westernized dietary patterns have been associated with poorer dietary quality and unfavorable health outcomes among younger populations [5]. Additionally, socioeconomic disparities in dietary behaviors have consistently been observed, suggesting the substantial influence of household income, parental environment, and lifestyle behaviors on children's dietary patterns [10,11].

Although dietary patterns among South Korean children and adolescents have already been widely studied, less attention has been given to primary school–aged children. This age period may be crucial because children gradually become more independent in food selection while still remaining influenced by family environments and parental dietary practices. Furthermore, dietary behaviors established during the early school-age may be applied into later stages of life and contribute to future health inequalities [2]. Therefore, dietary patterns and related socioeconomic and lifestyle factors during this developmental stage must be identified to establish effective early nutritional interventions.

Accordingly, this study aimed to identify major dietary patterns among South Korean primary school–aged children included in the 2007–2022 KNHANES database and to examine differences in nutrient intake, sociodemographic characteristics, and lifestyle behaviors according to dietary patterns.

## METHODS

### Ethics statement

All participants provided written informed consent. The Institutional Review Board (IRB) of the Korea Disease Control and Prevention Agency reviewed and approved the protocols of KNHANES. This study was exempted from additional IRB approval, given the use of de-identified, publicly available KNHANES data.

### Study design and participants

This study used data from KNHANES, which is conducted annually by the Korea Disease Control and Prevention Agency. This survey targets the noninstitutionalized civilian population of South Korea, with informed consent obtained from all participants. Although KNHANES was initially conducted in 1998, 2001, and 2005, it has been conducted annually since 2007. To evaluate long-term, continuous secular trends in dietary patterns among primary school–aged children in South Korea, this study used data collected between 2007 and 2022.

The initial sample included 10,233 children aged 6–12 years who completed all three KNHANES components, namely, the health interview/health behavior survey, health examination, and nutrition survey. Of these participants, 60 were excluded because of having implausible total daily energy intake (≤ 500 kcal or

>5,000 kcal). Ultimately, 10,173 primary school–aged children (5,286 boys and 4,887 girls) were included in the analysis.

### Dietary assessment

Dietary intake was assessed using a standardized 24-hour dietary recall method. In this method, information on the time, type, and quantity of all foods and beverages consumed by participants during the previous 24 hours was collected by trained interviewers. Visual aids, including food models and photographs, were also used to enhance recall accuracy. Between 2007 and 2021, dietary data were obtained at participants' homes, and the day before the survey served as the reference day. From 2022 onward, the reference day was defined as 2 days before the survey, and interviews were conducted in mobile examination units, in accordance with the procedures specified by KNHANES.

### Dietary pattern analysis

Dietary patterns were identified by classifying food items into 26 groups according to the KNHANES food classification system. Grouping was mainly based on similarities in nutrient composition, as well as culinary use and the food processing level [8].

Grain and grain-based foods contribute substantially to total daily energy intake; hence, staple foods were further divided into six subgroups: whole grains, refined white rice, refined grains, wheat flour and bread, processed white rice, and flour-based foods.

Salted vegetables, including kimchi, contribute substantially to sodium intake; thus, they were classified separately from fresh vegetables. Furthermore, meat products were subdivided into red meat, poultry, and processed meat, while beverages were categorized as fruit juices, tea and coffee, and sugar-sweetened beverages.

In total, 26 food groups were defined: whole grains, refined white rice, refined grains, wheat flour and bread, processed white rice, flour-based foods, potatoes, sweets, legumes and tofu (including soymilk), nuts, unsalted vegetables, kimchi and salted vegetables, seasonings, fruits, red meat, poultry, processed meat, eggs, fish and seafood, seaweed, milk and dairy products, plant oils, animal oils, fruit juices, tea and coffee, and sugar-sweetened beverages.

Moreover, the proportion of energy derived from each group was calculated to evaluate each food group's contribution to total energy intake while standardizing intake across individuals with differing total energy consumption and accounting for weight and volume differences between solid and liquid items. This energy-based approach is widely used in dietary pattern analysis because it expresses each food group's contribution relative to an individual's overall diet rather than in absolute terms, enabling comparison across participants with different total intake levels. However, given that energy-dense food groups inherently contribute a larger share of total energy, high-energy food groups (e.g., grains, meat, and oils) may be given a proportionally greater weight by this approach than low-energy but nutritionally relevant food groups (e.g., vegetables and seaweed), indicating a limitation of this study. Subsequently, dietary patterns were identified using K-means cluster analysis based on these proportions across the 26 food groups. The optimal number of clusters, determined using Ward's method, was three. These clusters were selected according to the dendrogram structure and the clinical interpretability of the resulting dietary patterns. Each dietary pattern was assigned a descriptive name that reflected the dominant food groups consumed within each cluster. The clustering procedures (PROC CLUSTER and PROC FASTCLUS) do not support complex survey sampling weights; hence, sampling weights were not applied during the clustering procedure itself.

### Nutrient intake

Total daily energy intake was calculated from all reported foods and beverages. To calculate the percentage of energy derived from carbohydrates and protein, we multiplied carbohydrate or protein intake (g) by 4 kcal, divided by total energy intake (kcal), and then multiplied by 100. For the percentage of energy derived from fat, we multiplied fat intake (g) by 9 kcal, divided by total energy intake (kcal), and multiplied by 100.

Nutrient intake was evaluated using 14 components: total energy (kcal), protein (g), fat (g), carbohydrate (g), calcium (mg), phosphorus (mg), iron (mg), potassium (mg), vitamin A (retinol activity equivalents [RAE]), carotene (μg), thiamin (mg), riboflavin (mg), niacin (mg), and vitamin C (mg).

All values were standardized to a single metric, considering that the unit used for vitamin A intake changed following revisions to the Korean Dietary Reference Intakes (KDRI). Vitamin A intake was calculated as retinol equivalents (retinol+1/6×β-carotene) until 2015, and since 2016, it has been calculated as RAE (retinol+1/12×β-carotene). Accordingly, data from 2007 to 2015 were recalculated using the RAE standard and included in the final analysis.

### Demographic and lifestyle information

Data on age, residential area, household income, and vigorous physical activity were collected by trained interviewers through face-to-face interviews. Residential areas were classified into urban and rural. Household income was calculated as equivalized monthly income by dividing the total household income by the number of household members and then categorized into four levels: low, lower-middle, upper-middle, and high. Vigorous physical activity, which referred to participation in high-intensity physical activity for at least 10 minutes per week, was classified as yes or no.

Weight status was determined using age- and sex-specific body mass index (BMI) percentiles based on the 2017 Korean National Growth Charts and then categorized into the following: underweight (BMI < 5th percentile), normal weight (BMI 5th to < 95th percentile), and obesity (BMI ≥ 95th percentile).

To assess dietary behaviors, we determined the frequency of skipping breakfast, lunch, and dinner and whether meals were consumed with family members. In addition, eating-out frequency was classified into three: none, 1 to 6 times per week, and at least once per day. Criteria for dietary supplement use varied according to the survey year; therefore, participants were classified as supplement users according to the corresponding survey definitions.

### Statistical analysis

KNHANES employs a complex, multistage, stratified, and clustered sampling design. To obtain nationally representative estimates and appropriate variance estimates, we considered the survey design in all statistical analyses by incorporating sampling weights, stratification variables, and primary sampling units. Furthermore, all analyses were conducted separately for boys and girls, reflecting sex-related differences in dietary and behavioral characteristics.

Hierarchical cluster analysis based on Ward's method, followed by K-means clustering, was applied for identifying dietary patterns. We present continuous variables as weighted means and standard errors, and categorical variables as weighted percentages and standard errors. For evaluating group differences, the Rao-Scott chi-square test and survey-weighted linear regression models were employed. As mentioned, sampling weights were not applied during the clustering procedure itself; nonetheless, all subsequent descriptive and inferential analyses incorporated the complex survey design, which included the sampling weights, stratification, and primary sampling units, to obtain nationally representative estimates. Moreover, we conducted post hoc pairwise comparisons among the three dietary patterns through unadjusted pairwise t-tests (linear contrasts) derived from the survey-weighted linear regression models for each nutrient variable, without correction for multiple comparisons. The following three pairs of dietary patterns were compared: rice-based vs. flour-based, rice-based vs. diversified-type, and flour-based vs. diversified type.

To examine the associations between dietary patterns and nutrient intake, we used survey-weighted linear regression models adjusted for age, total energy intake, household income level, and BMI category. Meanwhile, weighted Rao-Scott chi-square tests were applied for assessing sex-specific secular trends in dietary pattern distribution. All statistical data were analyzed using SAS ver. 9.4 (SAS Institute Inc.), and a P-value below 0.05 was considered statistically significant.

## RESULTS

### Dietary pattern characteristics

Cluster analysis revealed three distinct dietary patterns (Table 1). Participants were grouped according to similarities in dominant food group consumption. The largest group (n = 4,807, 47.3%) showed a markedly higher proportion of energy derived from refined white rice relative to the other groups, thereby labeled as the rice-based pattern. The second group (n = 1,800, 17.7%) displayed a distinctly higher proportion of energy derived from flour-based foods, thereby designated as the flour-based pattern. The remaining group (n = 3,566, 35.1%) exhibited a more even distribution of energy intake across food groups without a single dominant source, thereby classified as the diversified type.

### Secular trends in dietary patterns by sex

Secular trends in the distribution of the three dietary patterns (rice-based pattern, flour-based pattern, and diversified type) from 2007 to 2022 were examined overall and by sex (Fig. 1). The proportion of children classified into the rice-based pattern steadily declined from 56.6% in 2007 to 32.6% in 2022. Conversely, the diversified type showed a marked increase, rising from 27.3% to 47.0%, suggesting that the participants gradually shifted toward a more diversified dietary pattern. Meanwhile, the flour-based pattern increased modestly over time, from 16.1% to 20.4%, with 2020 showing the highest proportion.

When stratified by sex, similar trends were observed. Among boys, the proportion of those classified into the rice-based pattern decreased from 56.8% to 35.4%, whereas the diversified type demonstrated an increase, from 25.9% to 45.5% between 2007 and 2022. The proportion of those displaying the flour-based pat-

**Table 1.** Mean percentage of energy intake from food groups according to dietary patterns among South Korean primary school–aged children

| Food group (% energy) | Rice-based pattern | Flour-based pattern | Diversified type | P-value |
|---|---|---|---|---|
| Whole grains | 2.4±4.0 | 2.4±5.1 | 3.8±7.2 | <0.001 |
| Refined white rice | 45.6±10.0 | 21.2±10.4 | 22.1±8.2 | <0.001 |
| Refined grains | 1.9±3.2 | 1.7±3.2 | 2.3±4.4 | <0.001 |
| Wheat flour and bread | 4.2±5.9 | 5.1±6.8 | 14.0±12.3 | <0.001 |
| Processed white rice | 0.2±1.5 | 0.4±2.5 | 0.5±3.1 | <0.001 |
| Flour-based foods | 2.4±5.1 | 26.8±10.6 | 2.8±4.7 | <0.001 |
| Potatoes | 1.1±2.7 | 1.4±3.4 | 1.2±3.4 | 0.0012 |
| Sweets | 2.5±4.6 | 3.0±6.0 | 4.6±8.0 | <0.001 |
| Legumes and tofu, soymilk | 1.7±2.7 | 1.1±2.3 | 1.4±2.4 | <0.001 |
| Nuts | 0.5±1.5 | 0.4±1.8 | 0.5±1.8 | 0.059 |
| Unsalted vegetables | 2.3±3.1 | 1.9±3.1 | 2.3±3.9 | <0.001 |
| Kimchi and salted vegetables | 0.9±1.1 | 0.7±0.9 | 0.7±0.9 | <0.001 |
| Seasonings | 2.3±2.9 | 2.4±2.6 | 2.5±2.8 | 0.009 |
| Fruits | 3.7±5.5 | 3.6±5.4 | 4.2±6.0 | <0.001 |
| Red meat | 6.2±7.3 | 5.5±7.2 | 8.7±10.2 | <0.001 |
| Poultry | 1.8±4.4 | 2.1±5.0 | 3.3±7.2 | <0.001 |
| Processed meat | 1.1±2.9 | 1.0±3.2 | 1.3±3.3 | 0.002 |
| Eggs | 2.8±3.7 | 2.5±3.4 | 2.6±3.6 | <0.001 |
| Fish and seafood | 2.8±3.7 | 2.0±3.5 | 2.4±3.7 | <0.001 |
| Seaweed | 0.4±0.8 | 0.2±0.5 | 0.3±0.5 | <0.001 |
| Milk and dairy products | 8.8±7.9 | 8.6±8.5 | 12.0±10.1 | <0.001 |
| Plant oils | 2.8±2.7 | 3.0±3.2 | 3.3±3.4 | <0.001 |
| Animal oils | 0.1±0.4 | 0.1±0.4 | 0.2±0.7 | <0.001 |
| Fruit juices | 0.4±1.7 | 0.5±1.9 | 0.8±2.4 | <0.001 |
| Tea and coffee | 0.0±0.0 | 0.0±0.1 | 0.0±0.0 | 0.037 |
| Sugar-sweetened beverages | 1.2±2.9 | 2.5±4.4 | 2.4±4.4 | <0.001 |

Values are presented as mean±standard deviation. Data examined using cluster analysis. The P-values were derived from survey-weighted general linear models comparing mean percentage energy intake across the three dietary pattern groups.

tern varied yearly but remained higher in the later survey years than at baseline.

Among girls, the rice-based pattern showed a more pronounced decline, from 56.4% in 2007 to 29.7% in 2022. Meanwhile, the diversified-type demonstrated a substantial increase, from 28.7% to 48.5%. The flour-based pattern also exhibited an increase, from 14.9% to 21.8%, although fluctuations were observed across survey years. These findings indicate a long-term reduction in rice-based dietary habits accompanied by an increase in diversified-type, with distinct trajectories observed between sexes.

## Sociodemographic characteristics by dietary pattern

Tables 2 and 3 list the sociodemographic characteristics of dietary pattern groups among boys and girls, respectively. In boys, the mean age was highest in the flour-based pattern group (9.46 years) and lowest in the diversified-type group (8.90 years), demonstrating a significant difference across the dietary pattern groups ($P < 0.001$). Household income also differed according to dietary pattern. The proportion of low-income participants was highest in the rice-based pattern group (28.0%), whereas the proportion of high-income participants was relatively higher in the flour-based pattern and diversified-type groups (24.2% and 24.8%, respectively).

Regarding BMI percentile classification, obesity was most prevalent in the flour-based pattern group (12.28%). Breakfast and dinner skipping was most common in the flour-based pattern group (18.34% and 3.13%, respectively). Daily eating out was most frequent in the diversified-type group (29.74%). Moreover, the rice-based pattern group had the highest proportion of supplement users (16.47%).

Among girls, the mean age was highest in the flour-based pattern group (9.42 years) and lowest in the rice-based pattern group (9.05 years). Household income patterns differed across dietary patterns. The diversified-type group had the highest proportion of high-income participants (26.7%), whereas the rice-based pattern

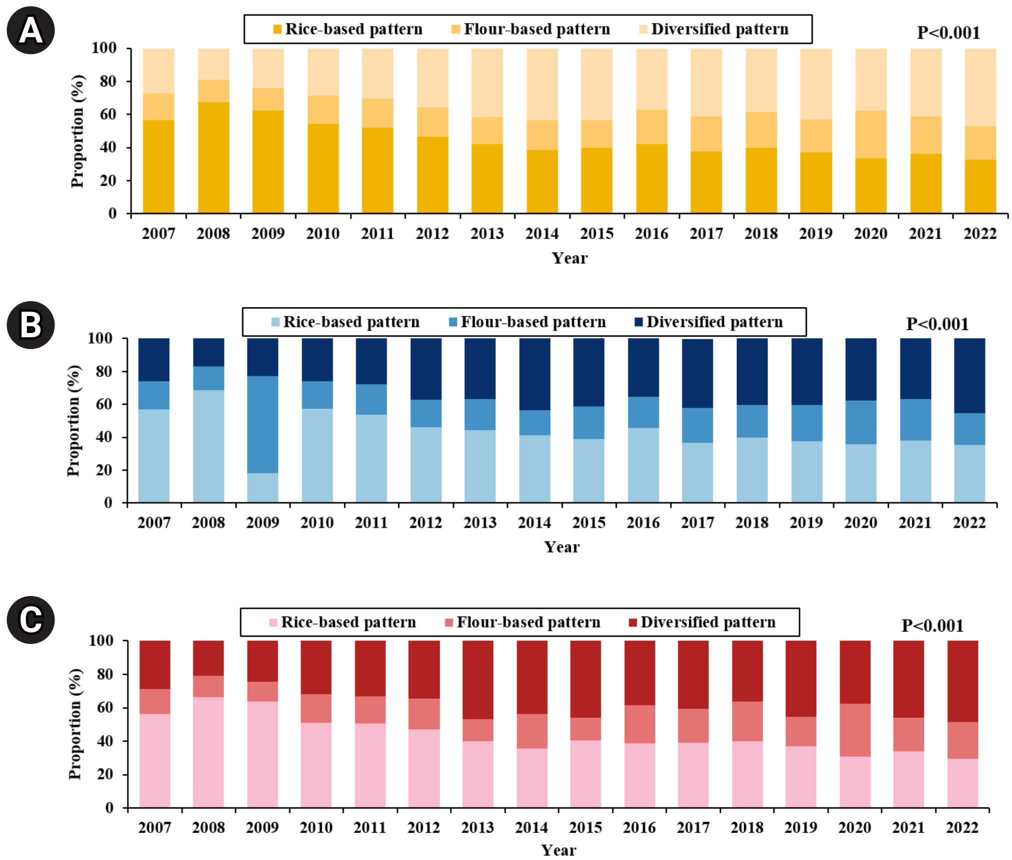


**Fig. 1.** Secular trends in dietary patterns by sex among South Korean primary school–aged children: (A) total, (B) boys, and (C) girls.

group had the highest proportion of low-income participants (28.0%).

BMI percentile classification revealed that obesity was most prevalent in the diversified-type group (10.12%). Breakfast skipping was most frequent in the flour-based pattern group (20.5%), whereas dinner skipping was most prevalent in the diversified-type group (4.15%). Daily eating out was most common in the flour-based pattern group (33.42%). Moreover, the diversified-type group had the highest proportion of dietary supplement users (17.92%).

## Nutrient intake by dietary pattern

Tables 4 and 5 present nutrient intakes across dietary patterns among boys and girls according to multivariable-adjusted models, respectively. Daily energy intake was 1,828.52 to 2,098.61 kcal among boys and 1,567.25 to 1,813.09 kcal among girls, indicating differences across dietary patterns.

In boys, the intake of all nutrients, except for carbohydrate, iron, vitamin A, and carotene, differed significantly according to dietary pattern. The diversified type was associated with relatively higher intakes of both macronutrients and micronutrients. Regarding macronutrient energy distribution, the rice-based pattern group had the highest proportion of energy derived from carbohydrates (65.5%), whereas the diversified-type group had the highest proportions derived from fat (27.0%) and protein (14.7%). A similar trend was observed among girls. The intake of all nutrients, except for vitamin A and thiamin, differed significantly across dietary patterns.

Post hoc pairwise comparisons (Tables 4 and 5) further indicated that for most nutrients (e.g., energy, protein, fat, and calcium intake, and the percentage of energy from carbohydrate, fat, and protein), all three dietary patterns differed significantly. For phosphorus, potassium, and niacin, the diversified type differed significantly from both the rice-based and flour-based patterns, which did not differ significantly from each other. Conversely, for carbohydrate, riboflavin, and vitamin C, differences were less consistent between sexes, with the rice-based pattern generally differing from at least one of the other two patterns.

**Table 2.** Sociodemographic and lifestyle characteristics of South Korean primary school–aged boys based on dietary patterns

| Characteristic | All (n=5,286) | Rice-based pattern (n=2,535) | Flour-based pattern (n=969) | Diversified type (n=1,782) | P-value |
|---|---|---|---|---|---|
| Age (y) | 9.14±0.03 | 9.19±0.04 | 9.46±0.06 | 8.90±0.05 | <0.001 |
| Region of residence | | | | | 0.423 |
| City | 44.5 (0.79) | 43.8 (1.14) | 46.6 (1.86) | 44.3 (1.35) | |
| Rural | 55.5 (0.79) | 56.2 (1.14) | 53.4 (1.86) | 55.7 (1.35) | |
| Household income status | | | | | 0.005 |
| Low | 25.5 (0.70) | 28.0 (1.05) | 26.3 (1.64) | 21.7 (1.14) | |
| Lower-middle | 25.74 (0.70) | 25.9 (1.03) | 24.2 (1.67) | 26.4 (1.21) | |
| Upper-middle | 25.32 (0.68) | 24.1 (0.98) | 25.3 (1.63) | 27.1 (1.19) | |
| High | 23.44 (0.66) | 22.1 (0.93) | 24.2 (1.57) | 24.8 (1.15) | |
| Vigorous physical activity[a] | | | | | 0.015 |
| No | 14.6 (1.20) | 11.75 (1.38) | 20.5 (3.32) | 17.2 (2.75) | |
| Yes | 85.4 (1.20) | 88.3 (1.38) | 79.5 (3.32) | 82.8 (2.75) | |
| Pediatric BMI percentile | | | | | 0.020 |
| Underweight (<5th percentile) | 7.72 (0.49) | 9.16 (0.85) | 4.76 (0.76) | 7.57 (0.77) | |
| Normal weight (5th to <95th percentile) | 81.35 (0.74) | 78.78 (1.18) | 82.96 (1.53) | 80.82 (1.19) | |
| Obesity (≥95th percentile) | 11.39 (0.68) | 12.06 (0.93) | 12.28 (1.38) | 11.60 (0.99) | |
| Perceived weight status | | | | | 0.320 |
| Underweight | 35.29 (0.76) | 35.56 (1.09) | 32.55 (1.72) | 36.43 (1.30) | |
| Normal weight | 35.70 (0.76) | 35.58 (1.09) | 35.75 (1.81) | 35.87 (1.30) | |
| Overweight | 29.0 (0.74) | 28.86 (1.07) | 31.70 (1.75) | 27.70 (1.23) | |
| Skipping breakfast | 13.11 (0.55) | 10.78 (0.73) | 18.34 (1.47) | 13.47 (0.97) | <0.001 |
| Skipping dinner | 2.15 (0.23) | 1.55 (0.28) | 3.13 (0.66) | 2.44 (0.40) | 0.027 |
| Having breakfast with family | 89.64 (0.57) | 88.56 (0.84) | 90.06 (1.36) | 91.05 (0.95) | 0.150 |
| Having dinner with family | 95.89 (0.33) | 95.81 (0.47) | 95.45 (0.81) | 96.23 (0.57) | 0.709 |
| Eating-out frequency | | | | | 0.007 |
| None | 0.72 (0.11) | 0.71 (0.16) | 0.41 (0.26) | 0.58 (0.15) | |
| 1–6 times/wk | 70.39 (0.72) | 74.80 (1.03) | 70.86 (1.72) | 69.68 (1.26) | |
| Daily | 27.23 (0.72) | 24.49 (1.02) | 28.73 (1.71) | 29.74 (1.25) | |
| Taking dietary supplement | 39.11 (0.78) | 16.47 (0.59) | 7.70 (0.45) | 14.94 (0.56) | <0.001 |

Values are presented as weighted mean±standard error or weighted percentage (standard error). We derived the P-values for categorical variables from the Rao-Scott chi-square test, and the P-value for age (continuous variable) from survey-weighted linear regression.
BMI, body mass index.
[a]Participating in a vigorous physical activity each week.

## Sensitivity analysis

To assess whether the associations between sociodemographic/lifestyle characteristics and dietary patterns remained consistent in more recent years, we reanalyzed such associations in the 2018–2022 survey subsample (n = 2,416) (Table S1). Most variables (household income status, physical activity, and pediatric BMI percentile) showing significant associations in the full 2007–2022 sample were no longer statistically significant in the smaller, more recent subsample. Skipping dinner remained significantly associated with dietary pattern in boys and girls (P = 0.025 and P = 0.014, respectively). Meanwhile, taking dietary supplements remained significantly associated with dietary pattern among girls only (P = 0.016). In the recent subsample, associations for household education and vigorous physical activity could not be estimated because of insufficient cell variation. Overall, while the association between meal-skipping behavior and dietary pattern appeared more robust throughout the entire study period, most of the sociodemographic associations observed over time should be interpreted with some caution when applying them to the current dietary and socioeconomic context.

# DISCUSSION

This study identified three distinct dietary patterns among South Korean primary school–aged children: rice-based, flour-based, and diversified-type patterns. Factors such as age, household income, meal-skipping behaviors, physical activity, eating-out frequency, dietary supplement use, and nutrient intake significantly differed between these three dietary patterns. Overall, children following the diversified type tended to demonstrate more favor-

**Table 3.** Sociodemographic and lifestyle characteristics of South Korean primary school–aged girls based on dietary patterns

| Characteristic | All (n=4,887) | Rice-based pattern (n=2,272) | Flour-based pattern (n=831) | Diversified type (n=1,784) | P-value |
|---|---|---|---|---|---|
| Age (yr) | 9.12±0.03 | 9.05±0.04 | 9.42±0.07 | 9.06±0.05 | <0.001 |
| Region of residence | | | | | 0.912 |
| City | 46.1 (0.82) | 46.2 (1.22) | 45.5 (2.01) | 46.5 (1.35) | |
| Rural | 53.9 (0.82) | 53.8 (1.22) | 54.5 (2.01) | 53.5 (1.35) | |
| Household income status | | | | | 0.005 |
| Low | 24.94 (0.73) | 28.0 (1.13) | 23.9 (1.77) | 21.8 (1.12) | |
| Lower-middle | 25.8 (0.73) | 25.6 (1.07) | 25.9 (1.79) | 26.0 (1.20) | |
| Upper-middle | 24.6 (0.71) | 24.2 (1.04) | 24.1 (1.73) | 25.5 (1.18) | |
| High | 24.66 (0.70) | 22.2 (0.98) | 26.1 (1.74) | 26.7 (1.20) | |
| Vigorous physical activity[a] | | | | | 0.240 |
| No | 22.12 (1.46) | 20.79 (1.95) | 19.76 (3.57) | 25.95 (2.82) | |
| Yes | 77.88 (1.46) | 79.21 (1.95) | 80.24 (3.57) | 74.05 (2.82) | |
| Pediatric BMI percentile | | | | | 0.649 |
| Underweight (<5th percentile) | 9.59 (0.60) | 9.40 (0.90) | 9.65 (1.39) | 9.76 (0.96) | |
| Normal weight (5th to <95th percentile) | 81.35 (0.77) | 82.21 (1.18) | 82.09 (1.76) | 80.12 (1.25) | |
| Obesity (≥95th percentile) | 8.99 (0.56) | 8.39 (0.86) | 8.25 (1.23) | 10.12 (0.93) | |
| Perceived weight status | | | | | 0.920 |
| Underweight | 32.67 (0.77) | 32.55 (1.14) | 32.36 (1.88) | 32.99 (1.27) | |
| Normal weight | 44.02 (0.82) | 44.77 (1.22) | 43.78 (2.01) | 43.24 (1.34) | |
| Overweight | 23.31 (0.70) | 22.68 (1.03) | 23.86 (1.73) | 23.77 (1.15) | |
| Skipping breakfast | 14.80 (0.61) | 10.95 (0.79) | 20.5 (1.67) | 16.67 (1.05) | <0.001 |
| Skipping dinner | 2.90 (0.27) | 1.58 (0.31) | 3.67 (0.67) | 4.15 (0.54) | <0.001 |
| Having breakfast with family | 90.15 (0.55) | 89.21 (0.84) | 89.98 (1.34) | 91.50 (0.88) | 0.178 |
| Having dinner with family | 96.18 (0.33) | 96.29 (0.50) | 95.15 (4.84) | 96.53 (3.47) | 0.318 |
| Eating-out frequency | | | | | 0.002 |
| None | 0.72 (0.15) | 0.85 (0.23) | 0.62 (0.42) | 0.52 (0.21) | |
| 1–6 times/wk | 70.94 (0.76) | 74.12 (1.09) | 65.96 (1.91) | 69.57 (1.25) | |
| Daily | 28.33 (0.75) | 25.03 (1.08) | 33.42 (1.89) | 29.91 (1.24) | |
| Taking dietary supplement | 25.7 (0.9) | 15.25 (0.60) | 7.71 (0.46) | 17.92 (0.64) | <0.001 |

Values are presented as weighted mean±standard error or weighted percentage (standard error). We derived P-values for categorical variables from the Rao-Scott chi-square test, and the P-value for age (continuous variable) from survey-weighted linear regression.
BMI, body mass index.
[a]Participating in a vigorous physical activity each week.

able nutritional profiles and healthier lifestyle behaviors; in contrast, those in the rice-based and flour-based patterns showed relatively less healthy dietary and behavioral characteristics. In secular trend analyses, the rice-based pattern showed a gradual decline, whereas the diversified type exhibited an increase between 2007 and 2022; however, sex-specific differences were observed.

These renamed patterns help clarify the secular trends observed in this study. The rice-based and diversified-type patterns were defined according to the dominant source of dietary energy rather than a broad East-West dietary orientation. Thus, the steady decline in the rice-based pattern and the corresponding rise in the diversified type most plausibly reflect that the dominance of refined white rice gradually declined in children's diets and that energy intake tended to be distributed more evenly across food groups rather than shifting away from "Western" foods per se. This interpretation aligns with broader secular changes in the South Korean food environment. For example, dietary variety and food availability increased in relation to continued socioeconomic development over the study period. At each survey wave, the dietary patterns were derived independently using the same clustering approach; correspondingly, the consistent direction of this trend across 16 years and across both sexes further supports the interpretation that it represents not an artifact of cluster labeling but a genuine shift in children's dietary behavior.

Age differed significantly across dietary pattern groups, with children in the flour-based pattern being the oldest. This finding may reflect developmental changes during late childhood, when children gradually become more independent in food selection

**Table 4.** Least-square means and 95% confidence intervals for nutrient intake and energy distribution according to dietary patterns among South Korean primary school–aged boys

| Nutrient | Rice-based pattern (n=2,535) | Flour-based pattern (n=969) | Diversified type (n=1,782) | P-value |
|---|---|---|---|---|
| Energy (kcal) | 1,828.52[a] (1,799.66–1,857.38) | 1,985.29[b] (1,933.99–2,036.59) | 2,098.61[c] (2,059.81–2,137.42) | <0.001 |
| Protein (g) | 64.84[a] (63.60–66.89) | 69.20[b] (66.91–71.48) | 77.21[c] (75.30–79.12) | <0.001 |
| Fat (g) | 40.64[a] (39.66–41.63) | 56.44[b] (54.36–58.52) | 64.81[c] (63.03–66.59) | <0.001 |
| Carbohydrate (g) | 297.53[a] (292.75–302.30) | 298.51[a] (290.86–306.16) | 300.29[a] (294.24–306.33) | 0.761 |
| Calcium (mg) | 477.71[a] (464.74–490.68) | 456.69[b] (437.53–475.86) | 599.97[c] (580.93–619.01) | <0.001 |
| Phosphorus (mg) | 1,052.18[b] (1,032.25–1,071.11) | 883.24[b] (854.03–912.45) | 1,169.13[a] (1,145.73–1,192.53) | <0.001 |
| Iron (mg) | 11.20[a] (10.12–12.29) | 11.19[a] (10.50–11.88) | 12.01[a] (11.53–12.50) | 0.070 |
| Potassium (mg) | 2,281.59[b] (2,237.39–2,327.39) | 2,301.61[b] (2,214.13–2,389.09) | 2,552.74[a] (2,495.25–2,610.23) | <0.001 |
| Vitamin A (RAE) | 603.99[a] (564.77–643.71) | 559.74[a] (501.13–618.36) | 687.90[a] (625.03–750.77) | 0.587 |
| Carotene (µg) | 2,644.22[a] (2,420.44–2,868.00) | 2,322.10[a] (1,980.06–2,664.13) | 2,697.49[a] (2,325.60–3,069.39) | 0.211 |
| Thiamin (mg) | 1.286[a] (1.253–1.319) | 1.40[b] (1.34–1.45) | 1.49[c] (1.45–1.54) | <0.001 |
| Riboflavin (mg) | 1.272[a] (1.242–1.301) | 1.61[b] (1.54–1.67) | 1.63[b] (1.59–1.67) | <0.001 |
| Niacin (mg) | 12.69[b] (12.38–12.99) | 12.52[b] (12.02–13.01) | 14.50[a] (14.10–14.88) | <0.001 |
| Vitamin C (mg) | 70.46[a] (67.46–73.45) | 70.74[ab] (64.69–76.79) | 76.34[b] (72.32–80.35) | 0.050 |
| Carbohydrate (%EN) | 65.51[a] (65.13–65.89) | 60.64[b] (60.04–61.24) | 57.78[c] (57.22–58.33) | <0.001 |
| Fat (%EN) | 19.37[a] (18.93–19.81) | 24.85[b] (24.25–25.45) | 27.01[c] (26.47–27.54) | <0.001 |
| Protein (%EN) | 14.17[a] (14.01–14.32) | 13.84[b] (13.59–14.10) | 14.72[c] (14.48–14.95) | <0.001 |

Values are presented as least-squares means (95% confidence intervals). Models were adjusted for age (years, continuous), energy intake (kcal/day, continuous), household income status (low, lower-middle, upper-middle, and high), and pediatric body mass index percentile category (underweight, normal weight, and obesity). The P-values were derived from the survey-weighted linear regression models described above. Values with different superscript letters (a, b, c) within a row differ significantly (P<0.05) according to post hoc pairwise comparisons between dietary patterns; conversely, values sharing a letter do not differ significantly.
RAE, retinol activity equivalents; %EN, percentage of total daily energy intake.

**Table 5.** Least-square means and 95% confidence intervals for nutrient intake and energy distribution according to dietary patterns among South Korean primary school–aged girls

| Nutrient | Rice-based pattern (n=2,272) | Flour-based pattern (n=831) | Diversified type (n=1,784) | P-value |
|---|---|---|---|---|
| Energy (kcal) | 1,567.25[a] (1,541.41–1,593.09) | 1,731.29[b] (1,685.28–1,777.31) | 1,813.09[c] (1,776.65–1,849.53) | <0.001 |
| Protein (g) | 54.83[a] (53.77–55.88) | 58.83[b] (56.83–60.83) | 65.14[c] (63.26–67.01) | 0.003 |
| Fat (g) | 34.30[a] (33.41–35.20) | 47.77[b] (45.91–49.63) | 54.36[c] (52.81–55.91) | <0.001 |
| Carbohydrate (g) | 258.11[a] (253.78–262.45) | 265.81[ab] (258.46–273.17) | 265.60[b] (260.15–271.06) | <0.001 |
| Calcium (mg) | 414.78[a] (401.59–427.97) | 456.69[b] (437.53–475.86) | 520.30[c] (505.34–535.26) | <0.001 |
| Phosphorus (mg) | 896.53[b] (880.11–912.95) | 883.24[b] (854.03–912.45) | 1,001.15[a] (979.39–1,022.92) | <0.001 |
| Iron (mg) | 9.31[b] (8.99–9.63) | 9.59[b] (8.97–10.21) | 10.38[a] (10.00–10.77) | <0.001 |
| Potassium (mg) | 2,032.27[b] (1,986.93–2,077.62) | 2,093.05[b] (2,018.58–2,167.53) | 2,272.22[a] (2,214.39–2,330.06) | <0.001 |
| Vitamin A (RAE) | 508.26[a] (484.15–532.38) | 471.89[a] (438.66–505.12) | 610.21[a] (558.87–661.55) | 0.993 |
| Carotene (µg) | 2,251.76[b] (2,108.77–2,394.74) | 1,928.22[a] (1,749.81–2,106.62) | 2,417.85[b] (2,116.51–2,719.20) | <0.001 |
| Thiamin (mg) | 1.09[a] (1.06–1.11) | 1.19[b] (1.14–1.24) | 1.29[c] (1.25–1.33) | 0.269 |
| Riboflavin (mg) | 1.08[a] (1.05–1.11) | 1.39[b] (1.33–1.45) | 1.41[b] (1.37–1.45) | <0.001 |
| Niacin (mg) | 10.66[b] (10.42–10.90) | 10.67[b] (10.26–11.08) | 12.42[a] (12.03–12.82) | <0.001 |
| Vitamin C (mg) | 69.30[b] (66.04–72.57) | 69.24[b] (62.09–76.40) | 79.54[a] (74.72–84.35) | 0.004 |
| Carbohydrate (%EN) | 66.22[a] (65.82–66.63) | 61.85[b] (61.13–62.56) | 59.05[c] (58.53–59.58) | <0.001 |
| Fat (%EN) | 19.61[a] (19.29–19.93) | 24.39[b] (23.80–24.99) | 26.29[c] (25.88–26.70) | <0.001 |
| Protein (%EN) | 14.01[a] (13.85–14.17) | 13.56[b] (13.29–13.82) | 14.36[c] (14.14–14.58) | <0.001 |

Values are presented as least-square means (95% confidence intervals). Models were adjusted for age (years, continuous), energy intake (kcal/day, continuous), household income status (low, lower-middle, upper-middle, and high), and pediatric body mass index percentile category (underweight, normal weight, and obesity). The P-values were derived from the survey-weighted linear regression models described above. Values with different superscript letters (a, b, c) within a row differ significantly (P<0.05) according to post hoc pairwise comparisons between dietary patterns; conversely, values sharing a letter do not differ significantly.
RAE, retinol activity equivalents; %EN, percentage of total daily energy intake.

and increasingly exposed to food environments outside the home [2]. Given that independent eating behaviors increase with age, older school-aged children and adolescents are more likely to consume convenience foods and commercially prepared meals than the younger ones [3,11].

Household income level was also significantly associated with dietary patterns. Children belonging to higher-income households were more frequently found in the diversified-type group, whereas those belonging to low-income households were more often noted in the rice-based pattern group. Consistent with our findings, previous studies demonstrated that socioeconomic status influences dietary quality and meal environments among children [10,11]. In addition, children from higher-income households are more likely to consume breakfast regularly and maintain healthier dietary habits than those from lower-income households [12,13].

Likewise, meal-skipping behaviors differed significantly across the dietary patterns. Breakfast skipping was most prevalent in both sexes in the flour-based pattern group. Among school-aged children and adolescents, breakfast skipping has been consistently associated with poorer dietary quality, irregular eating patterns, and inadequate micronutrient intake [14,15]. Regular breakfast consumption has also been linked to improved cognitive performance and academic achievement among children [15,16]. Therefore, the risk of unfavorable nutritional and behavioral outcomes during childhood may increase in the flour-based pattern group, who skipped breakfast the most.

Eating-out frequency also varied across dietary patterns. The flour-based pattern and diversified-type groups reported higher frequencies of daily eating out than the rice-based pattern group. Frequent eating out among children is associated with increased consumption of energy-dense and commercially prepared foods [3,5]. In South Korea, eating-out behaviors among children may also reflect broader family lifestyle patterns and food environment changes.

Dietary supplement use differed substantially across dietary patterns, with lower use observed mostly in the flour-based pattern group. In children, dietary supplement use has been associated with parental health awareness, socioeconomic status, and overall dietary quality [17]. Therefore, children without taking dietary supplements in the flour-based pattern group may have parents who paid less attention to balanced nutritional intake or who prioritized protein-rich food intake rather than overall dietary quality.

In addition, significant differences in vigorous physical activity were observed only among boys. Participation in vigorous physical activity was highest among boys in the rice-based pattern group and lowest among those in the flour-based pattern group. Physical activity levels among children have been associated with dietary behaviors, energy intake, and body weight status [18]. Given that regular physical activity during childhood is important for healthy growth and obesity prevention, these findings suggest that dietary interventions should consider not only food intake but also lifestyle behaviors.

Regarding weight status, pediatric BMI percentile differed significantly according to dietary patterns among boys only. Meanwhile, girls in the flour-based pattern group demonstrated relatively higher levels of perceived overweight status than their actual obesity prevalence. These findings suggest that body weight awareness increased during late childhood and that body image concerns began to emerge before adolescence [19,20]. Distorted body image perception during childhood may contribute to unhealthy eating behaviors and inappropriate weight-control practices [20].

Nutrient intake also significantly differed across dietary patterns. The diversified-type group showed relatively higher intakes of protein, calcium, potassium, riboflavin, niacin, and vitamin C than the other dietary pattern groups. Conversely, the rice-based pattern exhibited a higher proportion of energy intake derived from carbohydrates. Similar to our findings, previous studies showed that Westernized dietary patterns are associated with poorer dietary quality and imbalanced nutrient intake among children and adolescents [3,5]. Although the diversified type demonstrated relatively favorable nutrient profiles, calcium intake remained below the recommended levels, consistent with previous reports indicating insufficient calcium intake among South Korean youth [21].

Regarding the overall characteristics of each dietary pattern in this study, the diversified type represented the most nutritionally balanced dietary behavior, whereas the flour-based pattern represented a nutritionally vulnerable group characterized by frequent meal-skipping, lower micronutrient intake, and less favorable lifestyle behaviors. Dietary habits established during childhood have been associated with future obesity risk and long-term health outcomes; therefore, early nutritional interventions targeting school-aged children are essential [1,2].

### Limitations

This study has several limitations. First, the KNHANES exhibits a cross-sectional design; consequently, causal relationships between dietary patterns and health-related factors could not be established. Second, dietary intake was assessed using a single 24-hour dietary recall, which may not accurately reflect participants' usual dietary intake, thereby subjected to recall bias. This limitation may be particularly relevant in children because their day-to-day dietary intake tends to fluctuate more than that of adults; thus, estimates of individual dietary patterns may be less stable. Third, dietary pattern analysis using cluster analysis involves subjective decisions regarding food grouping and the number of clusters selected; both may influence the resulting patterns. Additionally, dietary patterns were derived from the percentage of energy contributed by each food group; this approach may disproportionately reflect high-energy food groups and underrepresent low-energy but nutritionally important food groups such as vegetables and seaweed. This limitation should be considered when interpreting the nutritional adequacy of the identified patterns. Furthermore, residual confounding factors that were not fully controlled may have affected the observed associations. Nevertheless, this study also has several strengths. For example, we utilized nationally representative KNHANES data that were collected over a long-term period. We also comprehensively evaluated dietary patterns alongside sociodemographic and lifestyle characteristics among South Korean primary school–aged children.

### Conclusion

Three distinct dietary patterns were identified among South Korean primary school–aged children, each showing unique sociodemographic, lifestyle, and nutritional characteristics. The diversified type demonstrated relatively balanced nutritional profiles, closely aligning with KDRI recommendations. Meanwhile, the rice-based pattern exhibited a higher proportion of energy intake derived from carbohydrates, as well as relatively inadequate energy intake among older girls. In contrast, the flour-based pattern may represent a nutritionally vulnerable group characterized by older age, frequent meal-skipping, lower dietary supplement use, relatively lower micronutrient intake, and greater body weight awareness. Furthermore, the rice-based pattern showed a marked secular decline, while the diversified type demonstrated an increase between 2007 and 2022, suggesting that South Korean primary school–aged children have gradually shifted toward more diversified dietary habits. Accordingly, age- and time-sensitive nutrition policies are needed.

When developing nutritional recommendations and intervention programs for school-aged children, healthcare providers should consider not only dietary patterns but also the socioeconomic status, lifestyle behaviors, sex, age, and nutritional needs of this population. By receiving early nutritional interventions and establishing healthy eating habits during childhood, these children may experience better long-term health outcomes.

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### Conflict of interest

None.

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### Data availability

The data that support the findings of this study are publicly available and can be accessed from the Korea Disease Control and Prevention Agency (http://www.kdca.go.kr).

## SUPPLEMENTARY MATERIALS

Supplementary materials are available from https://doi.org/10.7762/cnr.2026.0018.

## REFERENCES

1. World Health Organization. Diet, nutrition and the prevention of chronic diseases. World Health Organization; 2003.
2. Craigie AM, Lake AA, Kelly SA, Adamson AJ, Mathers JC. Tracking of obesity-related behaviours from childhood to adulthood: a systematic review. Maturitas 2011;70:266-84.
3. Liberali R, Kupek E, Assis MA. Dietary patterns and childhood obesity risk: a systematic review. Child Obes 2020;16:70-85.

4. Hu FB. Dietary pattern analysis: a new direction in nutritional epidemiology. Curr Opin Lipidol 2002;13:3-9.
5. Newby PK, Tucker KL. Empirically derived eating patterns using factor or cluster analysis: a review. Nutr Rev 2004;62:177-203.
6. Kweon S, Kim Y, Jang MJ, et al. Data resource profile: the Korea National Health and Nutrition Examination Survey (KNHANES). Int J Epidemiol 2014;43:69-77.
7. Jeon JH, Seo MY, Kim SH, Park MJ. Dietary supplement use in Korean children and adolescents, KNHANES 2015-2017. Public Health Nutr 2021;24:957-64.
8. Tak E, Kim J, Lee H, Kang M. Secular trends in dietary patterns among Korean adults: using data from the 2007-2022 Korea National health and nutrition examination survey. Nutr J 2025;24:163.
9. Lee JS, Kim H, Shin S. Socioeconomic disparities in dietary patterns among Korean children and adolescents. Public Health Nutr 2021; 24:3721-30.
10. Darmon N, Drewnowski A. Does social class predict diet quality? Am J Clin Nutr 2008;87:1107-17.
11. Eicher-Miller HA, Boushey CJ, Bailey RL, Yang YJ. A scoping review of household factors contributing to dietary quality and food security in low-income households with school-age children. Adv Nutr 2023; 14:1135-53.
12. Rampersaud GC, Pereira MA, Girard BL, Adams J, Metzl JD. Breakfast habits, nutritional status, body weight, and academic performance in children and adolescents. J Am Diet Assoc 2005;105:743-60.
13. Hartline-Grafton H, Levin M. Breakfast and school-related outcomes in children and adolescents in the US: a literature review and its implications for school nutrition policy. Curr Nutr Rep 2022;11:653-64.
14. Deshmukh-Taskar PR, Nicklas TA, O'Neil CE, Keast DR, Radcliffe JD, Cho S. The relationship of breakfast skipping and type of breakfast consumption with nutrient intake and weight status in children and adolescents: the National Health and Nutrition Examination Survey 1999-2006. J Am Diet Assoc 2010;110:869-78.
15. Seura T, Nagai R, Yamazaki S, Bando K, Sogawa M. The impact of skipping breakfast on academic performance in youths: a meta-analysis of observational studies. J Nutr Sci Vitaminol (Tokyo) 2025;71: 339-48.
16. World Health Organization. Global recommendations on physical activity for health. World Health Organization; 2010.
17. Revranche M, Biscond M, Husky MM. Investigating the relationship between social media use and body image among adolescents: a systematic review. Encephale 2022;48:206-18.
18. Lunde C, Gattario KH. Performance or appearance?: young female sport participants' body negotiations. Body Image 2017;21:81-9.
19. Ministry of Health and Welfare; The Korean Nutrition Society. 2020 Dietary Reference Intakes for Koreans. Ministry of Health and Welfare; 2020.
20. Ambrosini GL. Childhood dietary patterns and later obesity: a review of the evidence. Proc Nutr Soc 2014;73:137-46.
21. Boushey C, Ard J, Bazzano L, et al. Dietary patterns and growth, size, body composition, and/or risk of overweight or obesity: a systematic review. USDA Nutrition Evidence Systematic Review; 2020.

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CLINICAL NUTRITION RESEARCH

# Gender differences in beverage consumption patterns, dietary behaviors, and beverage-derived nutrient intake among South Korean university students: a cross-sectional study

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**Objective:** College students exhibit high beverage consumption and various diet-related problems. Therefore, this study investigated gender-specific beverage consumption patterns and evaluated beverage-related behaviors and beverage-derived nutrient intake among college students.

**Methods:** This study included 366 college students (171 men and 195 women) from Chungnam, South Korea. Beverage categories included carbonated and sugar-sweetened beverages, caffeinated beverages, energy drinks, alcoholic beverages, and milk and liquid yogurt products. Beverage preference, consumption frequency, beverage-related dietary behaviors, and dietary intake were assessed using 3-day 24-hour dietary recalls to evaluate beverage-derived nutrient intake.

**Results:** The mean total beverage intake was 433.9 g/day. Carbonated and sugar-sweetened beverages accounted for the highest intake (144.9 g/day), followed by caffeinated beverages (125.6 g/day), alcoholic beverages (124.3 g/day), and milk and liquid yogurt products (39.2 g/day). Beverages contributed 10.1% of total energy intake and 35.5% of total sugar intake. Carbonated and sugar-sweetened beverages were the largest contributors to carbohydrate and sugar intake, whereas alcoholic beverages contributed the most energy. Milk and liquid yogurt products were the largest contributors to beverage-derived fat and protein intake. Male students had significantly higher intakes of carbonated and sugar-sweetened beverages, alcoholic beverages, total beverages, and beverage-derived energy and sugar than female students.

**Conclusion:** These findings highlight the need for nutrition education to promote healthier beverage choices among college students and support the development of gender-specific beverage-related interventions.

**Keywords:** Beverages; Feeding behaviors; Nutrient intake; University students

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## INTRODUCTION

In South Korea, rising incomes and changing lifestyles have increased beverage demand and supply in the food industry. National health statistics show that daily beverage intake among adults aged ≥ 19 years increased significantly from 210.9 g in 2015 to 316.5 g in 2024. This represents an increase of over 100 g over 9 years, reflecting a consistent upward trend [1].

Beverage intake varied significantly by age, with adults aged 19 to 29 years consuming 426.3 g/day of beverages and milk, surpassing all other age groups [2]. College students in this demographic showed even higher consumption (442.9 mL/day) than the general 19 to 29 age group (426.3 mL/day) [3]. Studies show that college students consume the highest amounts of carbonated, sweetened, caffeinated, and alcoholic beverages [3,4]. In contrast, milk and liquid yogurt products show lower intake levels than other beverage categories [3,5]. To date, most research has examined individual high-consumption categories, such as sweetened, caffeinated, and alcoholic drinks, separately [6,7]. Consequently, comprehensive studies examining overall beverage consumption patterns, related dietary behaviors, nutrient contributions, and gender differences remain limited.

University students, previously dependent on school meals or parental support, must suddenly manage their own diets upon entering university [8]. The autonomy of university life, including social gatherings, dormitory living, or off-campus housing, has been associated with dietary issues such as skipping meals, frequent eating out, irregular eating habits, and excessive alcohol consumption [9,10]. Beverage consumption among university students is negatively associated with solid food intake, raising concerns about potential nutritional and dietary imbalances [11-14]. Sugar-sweetened carbonated beverages, which are high in sugar, significantly contribute to energy intake. Liquid foods with empty calories lack essential nutrients, provide little satiety, and empty rapidly from the stomach, often increasing subsequent energy intake and potential nutritional risk [15]. Similarly, caffeinated beverages are often consumed with foods high in simple sugars, such as cakes, cookies, and bread, further increasing caloric intake [16]. Excessive alcohol consumption also contributes to nutritional imbalances by reducing food intake and impairing nutrient absorption [17].

Beverage choices and related dietary behaviors differ by gender, with male students more likely to consume excessive energy intake from sugary drinks or alcohol consumption. In contrast, female students may show different beverage-related dietary behaviors associated with caffeine intake, dessert consumption, or dieting practices [18]. Therefore, examining gender-specific beverage consumption patterns and nutrient intake among college students is essential for developing targeted nutrition education guidelines.

In this study, beverages were categorized as carbonated and sugar-sweetened beverages, caffeinated beverages, alcoholic beverages, and milk and liquid yogurt. We examined gender differences in beverage consumption patterns among college students and compared dietary behaviors and nutrient intake across beverage consumption groups. This study aimed to provide foundational evidence to inform the development of tailored nutritional interventions and dietary education strategies based on gender-specific characteristics.

## METHODS

### Ethics statement

This study was approved by the Institutional Review Board of Kongju National University (No. KNU_IRB_2022_103). All participants received a detailed explanation of the study procedures before participation and provided written informed consent. The study was conducted in accordance with the principles of the Declaration of Helsinki.

### Participants

This study was conducted among college students residing in the Chungnam region who understood the study purpose and procedures and voluntarily agreed to participate. To ensure an accurate assessment of dietary intake, participants were eligible if they had no history of memory-related disorders, self-reported eating disorders (such as anorexia nervosa or bulimia nervosa), dietary restrictions, or were not taking medications affecting appetite. Of the 395 participants who initially consented, data from 366 participants (171 men and 195 women) were included in the final analysis, with 29 participants excluded due to incomplete survey responses (response rate, 92.7%).

### Study procedure

A self-administered questionnaire was used to collect data on participants' general characteristics and beverage consumption patterns. It was developed based on previous studies and finalized after a pilot survey involving 10 participants and subsequent revisions [7,19]. The questionnaire on general characteristics included age, housing type, allowance, exercise frequency, and smoking status and frequency. The beverage consumption section addressed beverage preferences, consumption frequency, and beverage-purchasing behaviors.

Beverages were categorized into four groups: carbonated and sugar-sweetened beverages (carbonated beverages and other sugar-sweetened beverages), caffeinated beverages (coffee, energy drinks, and tea), alcoholic beverages, and milk and liquid yogurt. Preference was assessed using a 5-point Likert scale: "strongly dislike" (1), "dislike" (2), "neutral" (3), "like" (4), and "strongly like" (5), with higher scores indicating greater preference. Consumption frequency was assessed as the number of times a beverage was consumed per week. The response categories were converted into weekly frequencies as follows: "rarely" was scored as 0, "once a month" as 0.25, "2–3 times a month" as 0.625, "once a week" as 1, "2–4 times a week" as 3, "5–6 times a week" as 5.5, "daily" as 7, and "2–3 times a day" as 17.5, and used to estimate weekly consumption frequency.

Beverage-purchasing behavior and beverage-related health knowledge were assessed by examining whether participants considered nutrition labels when selecting beverages, which label components they reviewed most closely, reasons for not checking nutrition labels, occasions of frequent beverage consumption, locations where beverages were purchased, factors influencing beverage selection, and average monthly expenditure on beverages.

Dietary intake was assessed over 3 days using the 24-hour dietary recall method. On the first day, dietary intake data were collected through an interviewer-administered recall. After training, participants were instructed to independently complete dietary records for two additional days, including weekdays and weekends, to capture their usual dietary intake patterns. The completed records were subsequently collected and reviewed. The survey included all foods and beverages consumed in a single day, along with information on the types and amounts of ingredients used in each dish, whether the recorded intake reflected usual dietary patterns, and water consumption.

Dietary data were converted from estimated food volumes to actual weights and analyzed using the nutritional analysis program CAN-Pro 5.0 (The Korean Nutrition Society) to estimate daily intake by food group as well as total energy and nutrient intake. To assess sugar intake, the US Department of Agriculture's sugar database [20] and the Ministry of Food and Drug Safety's Food Composition Database [21] were used. For caffeine and alcohol intake, a database was developed using the Food Composition Database [21], supplemented with data from manufacturer websites and commercial product beverage manufacturer information, and used for intake analysis. Alcohol intake was calculated by converting alcohol by volume to grams using the formula specified in the Guidelines for Voluntary Nutrition Labeling of Alcoholic Beverages [22].

### Statistical analysis

All data were analyzed using SAS ver. 9.4 (SAS Institute Inc.) to calculate means, standard deviations, frequencies, and percentages. Differences by gender were evaluated using Student t-test for continuous variables and the chi-square test for categorical variables. Statistical significance was defined as $P < 0.05$.

## RESULTS

### General characteristics

Among the 366 participants, 171 were men, and 195 were women. The mean age was 21.7 years, without a significant difference between gender (Table 1). There were no significant gender differences in grade level, living arrangements, or allowance. Regarding exercise frequency, the most common categories among men were 1 to 2 times per week (38.6%) and 3 to 4 times per week (23.4%). Conversely, in women, the most common responses were "almost never" (58.0%) and 1 to 2 times per week (32.3%), indicating a significant gender difference ($P < 0.001$). Regarding smoking status, 60 men (35.1%) and 22 women (11.3%) were smokers, showing a significant gender difference ($P < 0.001$). Smoking frequency, the most prevalent category among men was ≥ 10 cigarettes per day (56.7%), but 1 to 4 cigarettes per day (54.6%) in women, also showing a significant gender difference ($P < 0.001$).

### Beverage-purchasing behavior

Among all participants, 136 (37.2%) reported checking nutrition facts labels when purchasing beverages, without a significant gender difference (Table 2). For label components, both gender prioritized calories, sugars, and protein; however, women were more likely than men for calories (62.8% vs. 43.1%), indicating a significant gender difference ($P < 0.05$). The most common reasons for not checking nutrition labels were "no perceived need" (51.3%) and "out of habit" (40.9%), with no significant gender differences. Regarding beverage consumption occasions, men most commonly reported drinking beverages when thirsty (42.1%), after meals (21.1%), during snacks (11.1%), frequently (11.1%), and after exercise (8.2%). Conversely, women most consumed beverages during snacks (34.4%), when thirsty (24.1%), after meals (23.6%), frequently (9.2%), and during meals (8.7%),

**Table 1.** General characteristics of the study participants

| Characteristic | Total (n=366) | Men (n=171) | Women (n=195) | $t/\chi^2$ (P) |
|---|---|---|---|---|
| Age (yr) | 21.68±7.61 | 21.56±2.67 | 21.80±10.14 | −0.32 (0.752) |
| Grade | | | | 9.17 (0.057) |
| 1st | 123 (33.61) | 59 (34.50) | 64 (32.82) | |
| 2nd | 62 (16.94) | 33 (19.30) | 29 (14.87) | |
| 3rd | 64 (17.49) | 36 (21.05) | 28 (14.36) | |
| 4th | 83 (22.68) | 33 (19.30) | 50 (25.64) | |
| Graduate school | 34 (9.29) | 10 (5.85) | 24 (12.31) | |
| Type of residence | | | | 1.91 (0.385) |
| Alone | 164 (44.81) | 82 (47.95) | 82 (42.05) | |
| With parents or spouse | 60 (16.39) | 29 (16.96) | 31 (15.90) | |
| With siblings or friends | 142 (38.80) | 60 (35.09) | 82 (42.05) | |
| Monthly allowance (KRW) | | | | 3.86 (0.145) |
| <300,000 | 142 (38.80) | 63 (36.84) | 79 (40.51) | |
| ≥300,000 and <600,000 | 162 (44.26) | 72 (42.11) | 90 (46.15) | |
| ≥600,000 | 62 (16.94) | 36 (21.05) | 26 (13.33) | |
| Exercise frequency | | | | 71.93 (<0.001) |
| Almost never | 147 (40.16) | 34 (19.88) | 113 (57.95) | |
| 1–2 times a week | 129 (35.25) | 66 (38.60) | 63 (32.31) | |
| 3–4 times a week | 53 (14.48) | 40 (23.39) | 13 (6.67) | |
| 5–6 times a week | 20 (5.46) | 17 (9.94) | 3 (1.54) | |
| Every day | 17 (4.64) | 14 (8.19) | 3 (1.54) | |
| Smoking | | | | 29.70 (<0.001) |
| Yes | 82 (22.40) | 60 (35.09) | 22 (11.28) | |
| No | 284 (77.60) | 111 (64.91) | 173 (88.72) | |
| Daily cigarette consumption | | | | 14.98 (<0.001) |
| 1–4 | 21 (25.61) | 9 (15.00) | 12 (54.55) | |
| 5–9 | 23 (28.05) | 17 (28.33) | 6 (27.27) | |
| ≥10 | 38 (46.34) | 34 (56.67) | 4 (18.18) | |

Values are presented as mean±standard deviation or number (%).
KRW, South Korean won.

showing a significant gender difference (P < 0.001). The most common place to purchase beverages (multiple responses allowed) was convenience stores, reported by 312 participants (85.3%). Beverage specialty stores were used significantly more often by women (28.7%) than by men (9.4%) (P < 0.001). The primary factors influencing beverage selection were taste (75.1%), price (10.7%), calories (6.6%), and health effects (5.7%), without significant gender differences. The most common average monthly beverage expenditure was 20,000–40,000 South Korean won (KRW) (31.2%), followed by ≥ 40,000 KRW (23.2%) and 10,000–20,000 KRW (23.2%), without significant differences between men and women.

## Beverage preference

Among all participants, the most preferred beverage category was carbonated and sugar-sweetened drinks (3.8 points), whereas the least preferred beverage was energy drinks (2.7 points). When comparing preferences by gender, men showed a significantly higher preference for carbonated beverages (4.0 vs. 3.6, P < 0.001) and energy drinks (3.1 vs. 2.3, P < 0.001). In contrast, women showed a significantly higher preference for tea (3.4 vs. 3.2, P < 0.05) (Table 3).

## Beverage consumption frequency

The weekly frequency of beverage consumption in all participants was highest for coffee (2.8 times), followed by carbonated beverages (2.3 times), alcoholic beverages (1.6 times), and milk and liquid yogurt (1.6 times). In contrast, energy drinks were consumed least frequently (0.6 times). Regarding gender differences, significant differences were observed in consuming carbonated beverages (2.9 vs. 1.8, P < 0.001), energy drinks (1.0 vs. 0.2, P < 0.001), and alcoholic beverages (2.0 vs. 1.3, P = 0.001), with higher consumption rates among men than women (Table 4).

## Daily beverage intake

The total daily beverage intake was 433.9 g/day, accounting for

**Table 2.** Beverage-purchasing behavior of university students by gender

| Variable | Total (n=366) | Men (n=171) | Women (n=195) | $\chi^2$ (P) |
|---|---|---|---|---|
| Use of nutrition label when purchasing beverages | | | | 1.44 (0.230) |
| Yes | 136 (37.16) | 58 (33.92) | 78 (40.00) | |
| No | 230 (62.84) | 113 (66.08) | 117 (60.00) | |
| Nutrition label component of interest among users[a)] | | | | 11.21 (0.021)[b)] |
| Calorie | 74 (54.41) | 25 (43.10) | 49 (62.82) | |
| Carbohydrate | 2 (1.47) | 1 (1.72) | 1 (1.28) | |
| Sugars | 46 (33.82) | 21 (36.21) | 25 (32.05) | |
| Protein | 9 (6.62) | 7 (12.07) | 2 (2.56) | |
| Caffeine | 2 (1.47) | 1 (1.72) | 1 (1.28) | |
| Alcohol content for alcoholic beverages | 3 (2.21) | 3 (5.17) | 0 (0.00) | |
| Reason for not using nutrition labels among non-users[a)] | | | | 3.60 (0.327)[b)] |
| No perceived need | 118 (51.30) | 60 (53.10) | 58 (49.57) | |
| Out of habit | 94 (40.87) | 41 (36.28) | 53 (45.30) | |
| Difficulty understanding | 8 (3.48) | 5 (4.42) | 3 (2.56) | |
| Small font size | 10 (4.35) | 7 (6.19) | 3 (2.56) | |
| Occasions for beverage consumption | | | | 47.20 (<0.001) |
| When thirsty | 119 (32.51) | 72 (42.11) | 47 (24.10) | |
| Snack time | 86 (23.50) | 19 (11.11) | 67 (34.36) | |
| During meals | 28 (7.65) | 11 (6.43) | 17 (8.72) | |
| After meals | 82 (22.40) | 36 (21.05) | 46 (23.59) | |
| After exercise | 14 (3.83) | 14 (8.19) | 0 (0.00) | |
| Often | 37 (10.11) | 19 (11.11) | 18 (9.23) | |
| Beverage purchase location[c)] | | | | |
| Convenience store | 312 (85.25) | 152 (88.89) | 160 (82.05) | 3.22 (0.073) |
| Supermarket | 99 (27.05) | 47 (27.49) | 52 (26.67) | 0.00 (0.960) |
| Beverage store | 72 (19.67) | 16 (9.36) | 56 (28.72) | 20.70 (<0.001) |
| Vending machine | 37 (10.11) | 14 (8.19) | 23 (11.79) | 1.31 (0.253) |
| Online shopping malls | 8 (2.19) | 3 (1.75) | 5 (2.56) | 0.28 (0.728)[b)] |
| Key factors in beverage selection | | | | 8.27 (0.142) |
| Taste | 275 (75.14) | 126 (73.68) | 149 (76.41) | |
| Health effects | 21 (5.74) | 13 (7.60) | 8 (4.10) | |
| Price | 39 (10.66) | 18 (10.53) | 21 (10.77) | |
| Calorie | 24 (6.56) | 8 (4.68) | 16 (8.21) | |
| Satiety | 5 (1.37) | 4 (2.34) | 1 (0.51) | |
| Volume | 2 (0.55) | 2 (1.17) | 0 (0.00) | |
| Average monthly expenditure on beverage (KRW) | | | | 3.96 (0.412) |
| <5,000 | 23 (6.28) | 8 (4.68) | 15 (7.69) | |
| ≥5,000 and <10,000 | 59 (16.12) | 26 (15.20) | 33 (16.92) | |
| ≥10,000 and <20,000 | 85 (23.22) | 43 (25.15) | 42 (21.54) | |
| ≥20,000 and <40,000 | 114 (31.15) | 49 (28.65) | 65 (33.33) | |
| ≥40,000 | 85 (23.22) | 45 (26.32) | 40 (20.51) | |

Values are presented as number (%).
KRW, South Korean won.
[a)]Percentages for nutrition label components were calculated among nutrition label users, and percentages for reasons for nonuse were calculated among nutrition label nonusers. [b)]Fisher exact test. [c)]Multiple responses.

32.1% of total food intake (Table 5). Carbonated and sugar-sweetened beverages had the highest intake (144.9 g/day, 36.7% of total beverage intake), followed by caffeinated beverages (125.6 g, 31.0%), alcoholic beverages (124.3 g, 19.4%), and milk and liquid yogurt products (39.2 g, 12.4%). Compared with women, men had significantly higher total beverage intake (485.4 vs. 388.7, $P < 0.05$), carbonated and sugar-sweetened beverage intake (171.9 vs. 121.1, $P < 0.01$), and alcoholic beverage intake (156.2 vs. 96.3, $P < 0.05$).

**Table 3.** Beverage type-specific preferences of university students by gender

| Beverage category | Total (n=366) | Men (n=171) | Women (n=195) | t (P) |
|---|---|---|---|---|
| Carbonated and sugar-sweetened beverages | | | | |
| Carbonated beverages | 3.82±1.08 | 4.03±0.92 | 3.63±1.17 | 3.65 (<0.001) |
| Other beverages | 3.72±0.92 | 3.80±0.87 | 3.66±0.96 | 1.39 (0.166) |
| Caffeinated beverages | | | | |
| Coffee | 3.55±1.30 | 3.61±1.29 | 3.50±1.30 | 0.82 (0.414) |
| Energy drinks | 2.67±1.18 | 3.13±1.24 | 2.28±0.97 | 7.24 (<0.001) |
| Tea | 3.32±1.15 | 3.18±1.18 | 3.44±1.12 | −2.21 (0.028) |
| Alcoholic beverages | 3.25±1.22 | 3.27±1.28 | 3.23±1.17 | 0.38 (0.701) |
| Milk and liquid yogurt | 3.75±1.00 | 3.74±0.99 | 3.76±1.02 | −0.38 (0.704) |

Values are presented as mean±standard deviation. Preference score: strongly dislike, 1; dislike, 2; neutral, 3; like, 4; and strongly like, 5.

**Table 4.** Weekly beverage consumption frequency of university students by gender

| Beverage category | Total (n=366) | Men (n=171) | Women (n=195) | t (P) |
|---|---|---|---|---|
| Carbonated and sugar-sweetened beverages | | | | |
| Carbonated beverages | 2.30±2.51 | 2.89±2.78 | 1.79±2.12 | 4.19 (<0.001) |
| Other beverages | 1.17±1.87 | 1.27±2.08 | 1.09±1.67 | 0.89 (0.375) |
| Caffeinated beverages | | | | |
| Coffee | 2.83±3.34 | 3.07±3.59 | 2.62±3.10 | 1.28 (0.200) |
| Energy drinks | 0.57±1.45 | 1.00±1.96 | 0.19±0.54 | 5.24 (<0.001) |
| Tea | 0.92±1.74 | 0.74±1.33 | 1.08±2.03 | −1.92 (0.056) |
| Alcoholic beverages | 1.62±1.93 | 1.97±1.99 | 1.32±1.83 | 3.27 (0.001) |
| Milk and liquid yogurt | 1.61±1.92 | 1.59±1.61 | 1.63±2.16 | −0.21 (0.837) |

Values are presented as mean±standard deviation. Frequency score: rarely, 0; once a month, 0.25; 2–3 times a month, 0.625; once a week, 1; 2–4 times a week, 3; 5–6 times a week, 5.5; daily, 7; and 2–3 times a day, 17.5.

**Table 5.** Daily beverage intake of university students by gender

| Beverage category | Total (n=366) | Men (n=171) | Women (n=195) | t (P) |
|---|---|---|---|---|
| Total food intake (g/day) | 1,203.59±418.83 | 1,303.39±468.96 | 1,116.07±347.63 | 4.29 (<0.001) |
| Total beverages | | | | |
| Daily intake (g/day) | 433.86±360.82 | 485.41±408.30 | 388.65±307.36 | 2.53 (0.012) |
| Proportion of total food intake (%)[a)] | 32.09±18.48 | 32.78±19.46 | 31.48±17.60 | 0.67 (0.503) |
| Carbonated and sugar-sweetened beverages | | | | |
| Daily intake (g/day) | 144.85±173.97 | 171.92±202.78 | 121.11±140.34 | 2.75 (0.006) |
| Proportion of total beverage intake (%)[b)] | 36.67±34.84 | 39.22±35.79 | 34.50±33.94 | 1.23 (0.219) |
| Caffeinated beverages | | | | |
| Daily intake (g/day) | 125.57±166.27 | 125.71±175.82 | 125.45±157.87 | 0.02 (0.988) |
| Proportion of total beverage intake (%)[b)] | 31.02±35.10 | 27.17±34.04 | 34.31±35.75 | −1.85 (0.065) |
| Alcoholic beverages | | | | |
| Daily intake (g/day) | 124.25±233.41 | 156.16±261.30 | 96.27±202.46 | 2.43 (0.016) |
| Proportion of total beverage intake (%)[b)] | 19.40±28.61 | 23.39±31.21 | 15.99±25.78 | 2.33 (0.020) |
| Milk and liquid yogurt | | | | |
| Daily intake (g/day) | 39.19±73.31 | 31.62±65.71 | 45.82±78.96 | −1.88 (0.061) |
| Proportion of total beverage intake (%)[b)] | 12.37±24.06 | 10.22±22.23 | 15.21±25.35 | −1.89 (0.060) |

Values are presented as mean±standard deviation.
[a)]Percentage of total beverages to total food intake. [b)]Percentage of specific beverages to total beverage intake.

## Daily energy and nutrient intake from beverages

Energy and nutrient intake from beverages are shown in Table 6. The total energy intake was 1,790.2 kcal/day for all participants, with beverages accounting for 10.1% of total energy intake; alcoholic beverages contributed the highest proportion (4.5%). Carbohydrate intake was 219.5 g/day, with beverages contributing

**Table 6.** Daily energy and nutrient intake from beverages of university students by gender

| Beverage category | Total (n=366) | Men (n=171) | Women (n=195) | t (P) |
|---|---|---|---|---|
| Energy (kcal/day) | 1,790.16±493.46 | 1,942.02±546.50 | 1,656.99±397.88 | 5.64 (<0.001) |
| Carbonated and sugar-sweetened beverages | 49.42±64.41 (2.67) | 56.20±72.85 (2.79) | 43.48±55.49 (2.56) | 1.86 (0.064) |
| Caffeinated beverages | 22.25±40.79 (1.27) | 25.00±45.52 (1.33) | 19.83±36.08 (1.22) | 1.19 (0.234) |
| Alcoholic beverages | 92.85±176.16 (4.54) | 115.05±193.93 (5.09) | 73.37±156.89 (4.06) | 2.24 (0.026) |
| Milk and liquid yogurt | 28.60±55.12 (1.59) | 22.62±46.31 (1.09) | 33.84±61.47 (2.02) | −1.99 (0.048) |
| Total beverages | 193.11±207.45 (10.06) | 218.87±230.58 (10.30) | 170.52±182.44 (9.86) | 2.20 (0.028) |
| Carbohydrate (g/day) | 219.45±60.59 | 234.08±64.03 | 206.62±54.41 | 4.51 (<0.001) |
| Carbonated and sugar-sweetened beverages | 11.26±14.99 (4.97) | 13.30±17.20 (5.58) | 9.47±12.52 (4.43) | 2.41 (0.017) |
| Caffeinated beverages | 4.30±9.28 (1.90) | 5.04±10.07 (2.13) | 3.65±8.50 (1.70) | 1.41 (0.160) |
| Alcoholic beverages | 1.66±4.35 (0.79) | 2.19±4.99 (0.95) | 1.20±3.65 (0.65) | 2.15 (0.033) |
| Milk and liquid yogurt | 3.94±9.81 (1.67) | 2.66±5.75 (1.00) | 5.07±12.23 (2.25) | −2.46 (0.015) |
| Total beverages | 21.17±20.60 (9.33) | 23.19±21.74 (9.66) | 19.40±19.42 (9.04) | 1.76 (0.079) |
| Fat (g/day) | 58.86±21.13 | 62.64±23.37 | 55.54±18.37 | 3.20 (0.002) |
| Carbonated and sugar-sweetened beverages | 0.25±0.89 (0.41) | 0.12±0.52 (0.19) | 0.36±1.11 (0.60) | −2.76 (0.006) |
| Caffeinated beverages | 0.10±0.38 (0.19) | 0.11±0.42 (0.20) | 0.09±0.35 (0.18) | 0.54 (0.590) |
| Alcoholic beverages | 0.00±0.03 (0.00) | 0.00±0.04 (0.00) | 0.00±0.00 (0.00) | 1.00 (0.319) |
| Milk and liquid yogurt | 1.03±2.42 (1.76) | 0.87±2.13 (1.37) | 1.17±2.64 (2.11) | −1.23 (0.221) |
| Total beverages | 1.38±2.59 (2.36) | 1.09±2.22 (1.76) | 1.62±2.86 (2.89) | −1.98 (0.049) |
| Protein (g/day) | 64.61±21.84 | 71.52±23.55 | 58.55±18.23 | 5.83 (<0.001) |
| Carbonated and sugar-sweetened beverages | 0.27±1.03 (0.43) | 0.15±0.63 (0.20) | 0.38±1.28 (0.63) | −2.25 (0.025) |
| Caffeinated beverages | 0.38±0.88 (0.66) | 0.34±0.77 (0.53) | 0.42±0.96 (0.77) | −0.91 (0.365) |
| Alcoholic beverages | 0.25±1.01 (0.35) | 0.36±1.36 (0.44) | 0.15±0.52 (0.27) | 1.92 (0.056) |
| Milk and liquid yogurt | 1.07±2.86 (1.66) | 0.80±1.79 (1.10) | 1.31±3.53 (2.16) | −1.77 (0.077) |
| Total beverages | 1.98±3.30 (3.09) | 1.65±2.34 (2.26) | 2.26±3.94 (3.82) | −1.83 (0.068) |
| Sugars (g/day) | 46.93±26.02 | 47.15±27.33 | 46.71±24.89 | 0.15 (0.877) |
| Carbonated and sugar-sweetened beverages | 10.83±14.50 (19.68) | 13.06±16.85 (22.40) | 8.87±11.78 (17.30) | 2.72 (0.007) |
| Caffeinated beverages | 4.10±8.65 (7.53) | 4.89±9.72 (8.62) | 3.41±7.54 (6.59) | 1.61 (0.108) |
| Alcoholic beverages | 1.13±5.00 (2.03) | 1.67±6.71 (2.46) | 0.66±2.67 (1.65) | 1.85 (0.066) |
| Milk and liquid yogurt | 3.33±6.56 (6.26) | 2.40±5.26 (4.46) | 4.15±7.43 (7.83) | −2.62 (0.009) |
| Total beverages | 19.39±19.07 (35.50) | 22.02±22.11 (37.94) | 17.09±15.63 (33.36) | 2.43 (0.016) |

Values are presented as mean±standard deviation (%). Percentages indicate the contributions of beverages to total nutrient intake.

9.3% of total intake; carbonated and sugar-sweetened beverages accounted for the largest proportion (5.0%). Fat intake was 58.9 g/day, with beverages contributing 2.4% of total intake, mainly from milk and liquid yogurt products (1.8%). Protein intake was 64.6 g/day, with beverages contributing 3.1% of total intake, with milk and liquid yogurt products contributing the highest proportion (1.7%). Sugar intake was 46.9 g/day, with beverages contributing 35.5% of total intake, of which carbonated and sugar-sweetened beverages contributed the highest proportion (19.7%). When comparing men and women, total energy, carbohydrate, fat, and protein intakes were significantly higher in men than in women. Energy intake from beverages (218.9 kcal vs. 170.5 kcal, $P < 0.05$) and sugar intake (22.0 g vs. 17.1 g, $P < 0.05$) were also significantly higher in men, whereas beverage-derived fat intake was significantly higher in women (1.6 g vs. 1.1 g, $P < 0.05$).

## DISCUSSION

College students entering early adulthood often exhibit high beverage consumption and experience various diet-related challenges. Therefore, this study aimed to investigate beverage-related dietary behaviors, beverage consumption patterns by type (carbonated and sugar-sweetened beverages, caffeinated beverages, alcoholic beverages, and milk and liquid yogurt products), beverage-related nutrient intake, and gender differences among college students in Chungnam, South Korea.

In this study, 62.8% of participants did not check nutrition labels when purchasing beverages. The most common reason for not checking labels was the perception that it was unnecessary (51.3%), with no significant gender differences observed. Among participants who checked nutrition labels, calories were the most frequently considered component (54.4%). Similarly, Kim and Han [3], who investigated beverage consumption patterns among college students, reported that more than half of the participants did not check nutrition labels, primarily because they perceived no need to do so, and that calories were the most frequently checked nutritional information among those who used nutrition labels. These findings reveal that nutrition education for college students should emphasize the importance of nutrition labeling and enhance practical skills related to using nutrition information when selecting beverages.

When beverage consumption patterns were compared by gender, male students showed greater preferences for carbonated beverages and energy drinks. Consequently, they exhibited significantly higher consumption frequency of these beverages, alcoholic beverages, and total beverage intake than female students. These gender differences in beverage consumption patterns may also reflect differences in lifestyle characteristics, as male students in this study reported higher frequencies of exercise and smoking than female students. Such lifestyle factors may influence beverage choices and nutrient intake and should be considered when interpreting gender differences in beverage consumption. The mean total beverage intake among participants was 433.9 g/day, which was somewhat lower than the combined intake of beverages (316.5 g), alcoholic beverages (109.7 g), and milk (92.6 g) reported among adults aged ≥ 19 years in the 2024 Korea National Health and Nutrition Examination Survey [1]. Nevertheless, similar beverage consumption patterns were observed between this study and national survey data. In this study, beverage intake among college students was highest for carbonated and sugar-sweetened beverages (144.9 g/day), followed by caffeinated beverages (125.6 g/day), alcoholic beverages (124.3g/day), and milk and liquid yogurt products (39.2 g/day). Similarly, Han [2] used data from the 2019 Korea National Health and Nutrition Examination Survey and reported that beverage consumption among adults aged 19 to 29 years was highest for carbonated and sugar-sweetened beverages (390.9 g), followed by alcoholic beverages (176.9 g), caffeinated beverages (164.5 g), and milk and liquid yogurt products (58.2 g). Collectively, these findings reveal that carbonated and sugar-sweetened beverages remain the predominant beverage types consumed among college students. In addition, the average intakes of milk and liquid yogurt, which contributed the largest proportions of protein and fat from beverages, were only 39.2 g/day, corresponding to approximately one-fifth of the recommended daily milk intake of 200 g according to the Dietary Reference Intakes for Koreans [23].

Compared with findings from Bae and Yeon [24], based on data from the 2008 Korea National Health and Nutrition Examination Survey, carbonated and sugar-sweetened beverage intake in this study (144.9 g/day) was higher than that reported among elementary (72.1 g), middle (55.4 g), and high school students (105.3 g). Conversely, milk intake reported among elementary school students (147.8 g), middle school students (143.9 g), and high school students (120.2 g) was substantially higher than the intake of milk and liquid yogurt products in this study (39.2 g/day). College students represent a transitional population between adolescence, when school meals and nutrition education are commonly provided, and adulthood, when independent dietary behaviors become increasingly important. Compared with previous studies among children and adolescents, college students in this study had a relatively higher intake of carbonated and sugar-sweetened beverages and a lower intake of milk products. Although direct comparisons should be interpreted cautiously due to differences in study populations and methodologies, these findings suggest that beverage consumption patterns may shift toward increased consumption of carbonated and sugar-sweetened beverages and decreased consumption of milk products during the transition from adolescence to early adulthood. Given the importance of establishing healthy dietary behaviors during early adulthood, nutrition education promoting increased consumption of milk and liquid yogurt products while reducing excessive intake of carbonated and sugar-sweetened, alcoholic, and caffeinated beverages may be beneficial, particularly among male students.

The mean energy intake in this study was 1,942.0 kcal/day among men and 1,657.0 kcal/day among women. These findings were similar to those of Lee and Kwak [25], who reported nutrient intake among college students in Daejeon and reported energy intakes of 1,942.0 kcal/day for men and 1,605.4 kcal/day for women, and were also generally consistent with a previous study [26]. Protein intake was 71.5 g/day among men and 58.6 g/day among women, which was lower than that reported for adults aged 19 to 29 years in the Korea National Health and Nutrition Examination Survey [27] but exceeded the recommended intake levels suggested by the Dietary Reference Intakes for Koreans [23]. Compared with the Korean recommendation for total sugar intake ( < 20% of total energy intake), the proportion of energy from sugar intake was within the recommended range for both men (9.7%) and women (11.3%).

Analysis of beverage contribution to energy and macronutrient intake showed that beverages contributed most substantially to sugar intake (35.5%), followed by energy (10.1%), carbohydrate (9.3%), protein (3.1%), and fat (2.4%). Carbonated and sugar-sweetened beverages contributed the highest proportions of carbohydrate and sugar intake (5.0% and 19.7%, respectively), whereas alcoholic beverages contributed the largest proportion of energy intake (4.5%). Milk and liquid yogurt products contributed the highest proportions of fat and protein intake from beverages (1.8% and 1.7%, respectively). Notably, beverage-derived energy and sugar intakes were significantly higher among male than female students.

Carbonated and sugar-sweetened beverages are energy-dense beverages that contain high amounts of sugar while providing relatively limited nutritional value and have been associated with poorer diet quality [28]. Excessive intake of carbonated and sugar-sweetened beverages may increase energy intake due to their high sugar content. It may potentially be associated with poorer dietary quality when consumed excessively. Therefore, appropriate nutrition education aimed at reducing excessive consumption of carbonated and sugar-sweetened beverages among college students is necessary.

In this study, alcoholic beverages accounted for the largest share of beverage-derived energy intake. This finding is consistent with that of Park et al. [29], who assessed dietary intake according to alcohol consumption status using data from the 2005 Korea National Health and Nutrition Examination Survey. Excessive alcohol consumption may increase energy intake through accompanying food consumption [11], whereas chronic alcohol intake has been associated with reduced dietary intake and nutritional deficiencies [17]. Therefore, educational efforts are needed to raise awareness of the nutritional consequences of excessive alcohol consumption among college students. In addition, prospective studies are needed further to investigate the relationship between alcohol consumption and nutrient intake.

Milk contains high-quality protein, calcium, and various vitamins and minerals, and the Korean Nutrition Society recommends consuming at least 200 mL/day [23]. Bae and Yeon [24] reported that dairy consumers among children and adolescents showed higher protein and micronutrient intake than nonconsumers. Although the intake of milk and liquid yogurt products was below the recommended level, these beverages contributed the highest proportions of protein and fat intake among all beverage categories. Kim and Kim [30] reported that individuals with health- and safety-oriented dietary lifestyles had greater beverage-related knowledge and higher consumption of milk and dairy products. Therefore, milk and liquid yogurt products may serve as potential alternatives to frequently consumed beverages, such as carbonated and sugar-sweetened, or alcoholic beverages, among college students. However, additional research is needed to evaluate this possibility further. In this study, milk and liquid yogurt products were combined into a single beverage category due to their relatively low overall consumption. However, many commercially available liquid yogurt products contain added sugars, which may affect their nutritional quality. Therefore, future studies should distinguish between milk and liquid yogurt products to better assess their individual nutritional contributions and health implications.

## Limitations

This study has several limitations. First, because the participants were limited to college students residing in Chungnam, South Korea, the generalizability of findings to the broader population of Korean college students may be limited. Second, dietary intake was assessed using 3-day, 24-hour dietary recalls, including weekdays and weekends, to reflect usual dietary intake better. However, this method may not fully capture long-term dietary behaviors and beverage consumption patterns. Third, the cross-sectional design of this study limited the ability to establish causal relationships between beverage consumption patterns and nutrient intake. Another limitation is that anthropometric measures, such as body mass index and other obesity-related indicators, were not included, as this study primarily focused on beverage consumption patterns, beverage-related dietary behaviors, and beverage-derived nutrient intake. Future studies incorporating obesity-related indicators may provide further insights into the associations between beverage consumption patterns, nutrient intake, and obesity-related health outcomes, thereby enhancing the clinical significance of these findings.

Despite these limitations, this study has several strengths. It quantitatively assessed beverage consumption patterns, beverage-related dietary behaviors, and nutrient intake from beverages among male and female college students and identified gender differences in beverage consumption characteristics. These findings also provide foundational evidence for developing gender-specific nutrition education strategies and dietary interventions targeting beverage consumption among college students.

## Conclusion

This study found that college students had high beverage consumption, with carbonated and sugar-sweetened beverages accounting for the largest proportion of beverage intake and contributing substantially to total sugar intake. Significant gender differences were observed in beverage preferences, consumption patterns, and beverage-derived nutrient intake, with male students consuming more carbonated and sugar-sweetened beverages, alcoholic beverages, and beverage-derived energy and sugars than female students. These findings highlight the need for nutrition education to promote healthier beverage choices among college students and support gender-specific beverage-related nutrition education and intervention.

## ARTICLE INFORMATION

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Conceptualization: MKC. Formal analysis: SYK, MKC. Investigation: SYK. Methodology: SYK, MKC. Supervision: MKC. Writing - original draft: all authors. Writing - review & editing: MHK, MKC. All authors read and approved the final manuscript.

### Conflict of interest

Mi-Kyeong Choi is an editorial board member of this journal, but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflict of interest relevant to this article was reported.

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### Data availability

Data of this research is available from the corresponding author upon reasonable request.

## REFERENCES

1. Ministry of Health and Welfare; Korea Disease Control and Prevention Agency. Korea health statistics 2024: Korea National Health and Nutrition Examination Survey (KNHANES IX-3). Korea Disease Control and Prevention Agency; 2025.
2. Han G. Status of beverage and water intake among adults in Korea: data from Korea National Health and Nutrition Examination Survey 2019. Korean J Food Nutr 2021;34:430-40.
3. Kim W, Han Y. Consumption and purchasing behavior of beverages among college students in urban areas. Korean J Hum Ecol 2020;29:241-53.
4. Ju YJ, Oh SS, Park SI, Lee HJ, Yoo MG, Park EC. College alcohol study for alcohol-related behaviors and problems. Health Policy Manag 2019;29:58-67.
5. Kim SH. A survey on dietary behaviors and liquid consumptions of university students in Kongju of Chungnam Province in Korea. Korean J Nutr 2009;42:327-37.
6. Lee JJ, Lee SH. A study on selection of beers consumption and beers in convenience store of university students. Korean J Tour Leis Res 2018;30:5-19.
7. Kim TY, Kim SM, Kim JY, et al. Awareness and consumption of energy drinks and associated factors among college students in Cheongju. Korean J Community Nutr 2018;23:60-72.
8. Chang YJ. Food preferences of college students. Korean J Nutr 1984;17:10-9.
9. Lee YN, Choi HM. A study on the relationship between body mass index and the food habits of college students. J Korean Soc Food Cult 1994;9:1-10.
10. Hong H, Lee JS. Survey on Korean food preference of college students in Seoul: focused on the staple food and snack. Korean J Nutr 2006;39:699-706.
11. Jun YS, Choi MK, Kim MH. The effects of alcohol intake on nutritional intake status of college students in Chungnam. J Korean Diet Assoc 2002;8:240-9.
12. Bae YJ, Kim MH. A study evaluating nutrient intake and diet quality in female college students according to coffee consumption. J Korean Diet Assoc 2009;15:128-38.
13. Kim SH. Coffee consumption behaviors, dietary habits, and dietary nutrient intakes according to coffee intake amount among university students. J Nutr Health 2017;50:270-83.
14. Kim K, Lee YK. Association between sugar-sweetened beverage intake and dietary quality using nutritional quotient among adults in Daegu, Korea. Korean J Community Nutr 2021;26:350-62.
15. Cassady BA, Considine RV, Mattes RD. Beverage consumption, appetite, and energy intake: what did you expect? Am J Clin Nutr 2012;95:587-93.
16. Mosdol A, Christensen B, Retterstol L, Thelle DS. Induced changes in the consumption of coffee alter ad libitum dietary intake and physical activity level. Br J Nutr 2002;87:261-6.
17. Lieber CS. Relationships between nutrition, alcohol use, and liver disease. Alcohol Res Health 2003;27:220-31.
18. Davy SR, Benes BA, Driskell JA. Sex differences in dieting trends, eating habits, and nutrition beliefs of a group of midwestern college

students. J Am Diet Assoc 2006;106:1673-7.
19. Yoo HS, Sim KH. Survey on the high-caffeine energy drink consumption status of university students in Seoul. J East Asian Soc Diet Life 2014;24:407-20.
20. United States Department of Agriculture. USDA National Nutrient Database for Standard Reference: sugars content [Internet]. United States Department of Agriculture; 2015 [cited 2022 Aug 26]. Available from: https://fdc.nal.usda.gov/
21. Ministry of Food and Drug Safety. Food nutrition component database [Internet]. Ministry of Food and Drug Safety; 2022 [cited 2022 Sep 5]. Available from: https://various.foodsafetykorea.go.kr/nutrient/
22. Ministry of Food and Drug Safety. Guidelines for voluntary nutrition labeling of alcoholic beverages. Ministry of Food and Drug Safety; 2017. p. 6-7.
23. Ministry of Health and Welfare; The Korean Nutrition Society. 2020 Dietary reference intakes for Koreans: application. Ministry of Health and Welfare; 2021. p. 58-72.
24. Bae YJ, Yeon JY. Evaluation of nutrient intake and diet quality according to beverage consumption status of elementary school, middle school, and high school students: from the Korean National Health and Nutrition Examination Surveys, 2007-2008. Korean J Nutr 2013;46:34-49.
25. Lee MS, Kwak CS. The comparison in daily intake of nutrients, quality of diets and dietary habits between male and female college students in Daejeon. Korean J Community Nutr 2006;11:39-51.
26. Kim JY, Han SH, Yang BM. Implication of high-body-fat percentage on cardiometabolic risk in middle-aged, healthy, normal-weight adults. Obesity (Silver Spring) 2013;21:1571-7.
27. Ministry of Health and Welfare; Korea Disease Control and Prevention Agency. Korea health statistics 2022: Korea National Health and Nutrition Examination Survey (KNHANES IX-1). Korea Disease Control and Prevention Agency; 2023.
28. Kleiser C, Schaffrath Rosario A, Mensink GB, Prinz-Langenohl R, Kurth BM. Potential determinants of obesity among children and adolescents in Germany: results from the cross-sectional KiGGS study. BMC Public Health 2009;9:46.
29. Park SH, Kang YH, Park HY. Alcohol consumption and the coronary heart disease-related risk factors in Korean adults: The Third Korea National Health and Nutrition Examination Survey (KNHANES III), 2005. Korean J Nutr 2008;41:232-41.
30. Kim YS, Kim BR. Nutrient intake status of male and female university students in Chuncheon area. J Korean Soc Food Sci Nutr 2015;44:1856-64.

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CLINICAL NUTRITION RESEARCH

# Assessment of nutrient intake, nutrition knowledge, and dietary habits by sports type among adolescent athletes at a physical education high school: a cross-sectional study

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**Objective:** This study aimed to compare the nutrient intake, nutrition knowledge, and dietary habits of track-and-field (TF) and weight-class (WC) adolescent varsity athletes.

**Methods:** This cross-sectional study included 144 adolescent athletes (TF group, 76; WC group, 68) aged 15 to 18 years at a physical education high school in Seoul, South Korea. Their nutrient intake, dietary quality, nutrition knowledge, dietary habits, and weight control behaviors were assessed using food records and questionnaires.

**Results:** Regarding nutrient intake, the consumption of carbohydrates, including energy, was substantially lower than the sports nutrition recommendations in both groups. However, the overall diet quality, including the mean adequacy ratio and nutrient adequacy ratio for key micronutrients, was significantly higher in the WC group than in the TF group, with female WC athletes consuming significantly more energy than female TF athletes ($P<0.05$). For nutrition knowledge, both groups lacked overall sports nutrition understanding; however, the WC group scored significantly higher in dietary fat knowledge ($P<0.05$). As for dietary habits, despite having better meal quality, harmful weight control behaviors, including skipping breakfast ($P<0.001$) and fasting ($P<0.05$), were significantly more common in the WC group than in the TF group.

**Conclusion:** The WC group, while showing better meal quality, practiced unhealthier dietary behaviors and weight control methods more often than the TF group. Additionally, both groups exhibited insufficient energy intake and lacked overall nutrition knowledge. Therefore, tailored sports nutrition education is urgently needed among South Korean adolescent athletes.

**Keywords:** Sports nutritional sciences; Adolescent; Athletes; Feeding behavior; Nutritional status

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## INTRODUCTION

### Background

Optimal nutrient intake among athletes improves their athletic abilities by reducing fatigue and the risk of illness and injury, thereby fostering enhanced athletic performance and rapid recovery from high-intensity training [1]. Sometimes, a "low weight" or "low fat/muscle ratio (leanness)" is a prerequisite for excellent sports performance [2]. Despite generally requiring a higher calorie intake than nonathletes, many athletes limit energy intake to lose weight [3]. In many sports, athletes need to change body shape and composition to improve athletic performance and qualify for a specific weight-class (WC); however, unhealthy weight loss on a diet that does not meet nutrition recommendations may be a problem for athletes [3]. Insufficient energy intake may lead to deficiencies in nutrients, including carbohydrates, iron, calcium, vitamin E, vitamin D, zinc, and magnesium [4]. According to several studies, the diets of adolescent athletes often do not meet the sports nutrition recommendation (SNR) and general nutrition recommendation [5-7].

Numerous adolescents have low levels of nutrition knowledge [8]. Good nutrition knowledge is one of the determinants of dietary behavior improvement and contributes to strengthening the skills and abilities necessary to resist the environmental impact of an unbalanced and unhealthy diet [8]. By improving the nutrition knowledge of adolescent athletes, they may learn good eating habits and rectify their erroneous beliefs about food [9]. A better understanding of nutrition during adolescence may affect one's lifelong relationship with diet in terms of eating habits, exercise, and body image relevance [4].

WC athletes in boxing, judo, taekwondo, wrestling, and weightlifting must reach a certain weight before a competition. This prerequisite may lead them to follow extreme diets, develop eating disorders, and have impaired health and performance [10]. Meanwhile, track-and-field (TF) athletes participating in long-distance running, walking, and jumping sports may pursue a slimmer, lighter body shape, potentially leading to improper energy intake and eating disorders [7].

Both WC and TF athletes require optimal nutrition for their health and athletic performance. While numerous studies have investigated and compared nutrient intake, nutrition knowledge, and dietary habits among athletes participating in team sports such as football, basketball, baseball, and volleyball, only a few focused on individual sports such as the TF and WC sports.

Therefore, this study aimed to compare and analyze the nutrient intake, nutrition knowledge, and dietary habits between TF and WC adolescent athletes. The findings of this study may guide them in properly managing their nutrition.

## METHODS

### Study design and ethics statement

This cross-sectional study was conducted between April and May 2018, with approval from the Institutional Review Board of Kyung Hee University (No. KHISIRB-18-006). All participants provided written informed consent prior to participation. In addition, this study conformed to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

### Participants

This study enrolled 401 adolescent athletes from a physical education high school in Seoul, South Korea. Eligible participants were then divided into TF and WC groups.

### General and anthropometric characteristics of the participants

Several factors potentially affecting participants' training (sex, age, grade level, athletic career, weekly exercise time and frequency, sleep time, and dietary supplement use) were investigated. Nutrition class participation, interest in nutrition topics, nutrition information sources, and practical application of nutrition knowledge were also assessed. Furthermore, data about the participants' body composition, including height, body weight, lean body mass (LBM), body mass index (BMI), fat weight, and percent body fat, were collected using an InBody 720 (Biospace Co.).

### Assessment of sports nutrition knowledge

Participants' nutrition knowledge was measured using the questionnaire Nutrition Knowledge Questionnaire for Athletes (NKQA) developed by Furber et al. [11] and classified into knowledge about carbohydrate, protein, fat, general nutrition, fluid, and sports nutrition. This questionnaire has 23 items about carbohydrate content in food, blood sugar index, and protein-saving effect specifically for carbohydrate knowledge assessment. Protein knowledge was assessed using 18 items about protein content in food, protein use by the body, and recommended protein intake. Regarding fat knowledge, 23 items about fat, saturated fat, and cholesterol were used. The general nutrition knowledge survey comprises 25 items, including macronutrient calories; food sources of vitamin C, iron, and calcium; and antioxidant nutrient function. For fluid knowledge, the questionnaire provides six items, including fluid intake before, during, and after exercise; dehydration; and sports drinks. Moreover, 14 questions, which include food intake before and after exercise and sports supplements, were used for sports nutrition knowledge. In total, the survey questionnaire has 109 questions, and each may be answered by "yes," "no," or "not sure." The score for each question is "1" for a correct response and "0" for an incorrect response or an "unsure" response. Thus, the total score ranges from 0 to 109.

### Assessment of dietary habits, body image self-perception, and weight control

To assess dietary habits, physical activity, body image self-perception, and weight control, we used the Korean Youth Risk Behavior Survey, which contains related questions distributed across 15 domains and 107 indices [12]. Regarding dietary habits, 16 questions are used to assess skipping breakfast, intake of fruit/vegetable/milk/carbonated beverages/high-caffeinated beverages/sweet drinks/instant noodles/unhealthy snacks, and use of convenience store/supermarket/store. Regarding health status, one item is used to assess self-perceived body image in terms of "very slim," "slim," "normal," "fat," and "very fat." Moreover, the weight control survey has four items: height, weight, effort, and weight control method. The question for weight control effort is "Have you ever tried to control your weight during the last 30 days?" Meanwhile, only those who responded to the questions related to weight loss, weight gain, and weight maintenance effort could answer the question "How did you try to control your weight for the last 30 days?"

### Assessment of nutrient intake

The school cafeteria provided group meals to all participants. A well-trained clinical dietitian instructed the participants on how to record their meals. After recording their food intake for 3 days, including the weekend, their answers were confirmed by a direct interview method. The participants' nutritional intake was analyzed using Computer Aided Nutritional Analysis Program, ver 5.0 (CAN-Pro, The Korean Nutrition Society).

To assess the appropriateness of nutrient intake, we calculated the nutrient adequacy ratio (NAR) and the mean adequacy ratio (MAR) of 12 nutrients (protein, vitamin A, vitamin C, thiamine, riboflavin, niacin, vitamin $B_6$, folic acid, calcium, phosphorus, iron, and zinc). An NAR value of 1.0 or more was assumed to be 1.0 [13]. NAR was calculated using the following equation: NAR = individual daily nutrient intake/recommended intake of each nutrient. For energy, NAR was calculated separately to evaluate overall energy adequacy. In the MAR calculation, energy was not included. MAR was calculated as follows: MAR = sum of NARs for each nutrient/number of different nutrients.

### Statistical analysis

All statistical data were analyzed using IBM SPSS ver. 23.0 (IBM Corp.). Continuous variables, expressed as mean ± standard deviation, were compared between TF and WC groups using Student t-test. To compare nutrient intakes between the two groups, we conducted analysis of covariance (ANCOVA) after adjusting for sex, age, BMI, athletic career, and weekly training duration. The significance of categorical variables was confirmed using a chi-squared test. Energy intake under-reporters were identified by estimating each participant's basal metabolic rate using the Schofield equation for adolescents and by deriving the estimated energy requirement (EER) using an activity factor reflecting the participants' physical activity level. Subsequently, we calculated the ratio of reported energy intake to EER and classified participants with a ratio below 0.70 as under-reporters. Additionally, a sensitivity analysis was conducted by excluding these under-reporters to evaluate whether potential energy under-reporting influenced the results [14]. A P-value less than 0.05 was considered statistically significant.

## RESULTS

### General and anthropometric characteristics

This study included 144 out of 401 adolescent athletes, aged 15 to 18 years. As shown in Table 1, 76 belonged to the TF group and 68 to the WC group. The TF group (64.5%) included slightly more males than the WC group (54.4%). The mean age was not significantly different between such groups. Body weight, BMI, and LBM were significantly higher in the WC group than in the TF group ($P < 0.05$), although no significant differences were noted in height and body fat percentage. Underweight was observed in 2.6% of athletes in the TF group and none in the WC group ($P < 0.01$). Conversely, overweight was significantly more common in the WC group than in the TF group (38.2% vs. 14.5%) ($P < 0.01$). While the length of athletic careers showed no significant difference, weekly training frequency and daily training volume were significantly higher in the WC group than in the TF group ($P < 0.05$). Meanwhile, no significant difference was noted in the mean daily sleeping time.

Table S1 presents the specific distribution of sports types

**Table 1.** General and anthropometric characteristics of the study participants

| Variable | All (n=144) | TF group (n=76) | WC group (n=68) |
|---|---|---|---|
| Age (yr) | 16.7±1.0 | 16.6±1.0 | 16.7±1.0 |
| Sex | | | |
| Male | 86 (59.7) | 49 (64.5) | 37 (54.4) |
| Female | 58 (40.3) | 27 (35.5) | 31 (45.6) |
| Anthropometric | | | |
| Height (cm) | 170.3±7.9 | 170.6±7.6 | 169.9±8.2 |
| Weight (kg) | 69.1±15.6 | 66.5±16.1 | 71.0±16.7* |
| BMI (kg/m$^2$) | 23.7±4.5 | 22.6±4.0 | 24.8±4.7** |
| Weight status[a)] | | | |
| Underweight | 2 (1.4) | 2 (2.6) | 0 (0.0)** |
| Normal weight | 105 (72.9) | 63 (82.9) | 42 (61.8)** |
| Overweight/obesity | 37 (25.7) | 11 (14.5) | 26 (38.2)** |
| LBM (kg) | 55.8±11.1 | 54.0±10.7 | 57.7±11.4* |
| Body fat (%) | 18.6±5.6 | 18.0±5.2 | 19.2±6.0 |
| Fat mass (kg) | 13.3±7.0 | 12.5±6.6 | 14.3±7.4 |
| Training-related | | | |
| Athletic career (yr) | 5.2±1.9 | 5.2±2.1 | 5.1±1.7 |
| Training frequency (days/wk) | 6.2±0.5 | 6.1±0.4 | 6.3±0.6* |
| Training volume (h/day) | 4.7±1.1 | 4.5±1.3 | 5.0±0.8* |
| Sleeping time (h/day) | 6.9±0.6 | 6.9±0.6 | 6.7±0.8 |

Values are presented as mean±standard deviation or number (%).
TF, track-and-field; WC, weight-class; BMI, body mass index; LBM, lean body mass.
[a)]Defined according to BMI: underweight (<18.5 kg/m$^2$), normal weight (18.5 to <25.0 kg/m$^2$), overweight/obesity (≥25.0 kg/m$^2$)
Significant differences between the TF and WC groups were evaluated using Student t-test (*P<0.05, **P<0.01).

among the TF and WC groups by sex. The TF group competed in five sports (track sprints, track distance, jump, throw, and pentathlon), whereas the WC group competed in four sports (weightlifting, taekwondo, judo, and wrestling).

## Dietary intakes of the participants

Table 2 presents the adolescent athletes' average daily diet intakes. The macronutrient intakes of the TF and WC groups were compared with the SNR [5] or the Korean Dietary Reference Intake 2015 (KDRI) [15]. The total daily energy intake of the TF group did not significantly differ from that of the WC group. Energy intake showed no significant difference between male participants in the TF and WC groups. As for females, energy intake was significantly higher in the WC group than in the TF group ($P<0.001$). However, the energy consumption of both sexes in the TF and WC groups was significantly less than the SNR. Moreover, the daily intake of carbohydrate, protein, and fat did not significantly differ between the two groups. The percentages of carbohydrate, protein, and fat intake were 54.6%, 15.8%, and 29.1% in the TF group and 54.8%, 15.4%, and 28.7% in the WC group, both of which were appropriate according to the KDRI criteria. The daily intake of dietary fiber was significantly higher in the WC group ($P<0.001$). Likewise, within the total daily energy intake, the proportion of saturated fat intake was significantly higher in the WC group than in the TF group ($P<0.001$).

Among vitamins, vitamin A intake was significantly higher in the TF group ($P<0.001$), whereas vitamin E and vitamin D intakes were significantly higher in the WC group ($P<0.001$). The WC group also demonstrated significantly higher intakes of niacin and folate ($P<0.05$). In contrast, thiamin, riboflavin, vitamin $B_{12}$, and vitamin C intakes exhibited no significant difference between such groups. Both groups consumed enough iron to meet the KDRI, demonstrating no significant between-group difference. Furthermore, calcium consumption in both groups was less than the KDRI. In the TF group, micronutrients such as calcium, vitamin D, vitamin C, vitamin A, potassium, magnesium, manganese, and copper were consumed at levels below the KDRI. In the WC group, the intake levels of calcium, vitamin C, vitamin A, potassium, magnesium, manganese, and copper were also below the KDRI level.

Regarding the influence of potential energy intake under-reporting, our sensitivity analysis excluded 64 participants identified as under-reporters. As presented in Table S2, this analysis revealed that macronutrient intakes showed patterns similar to the primary re-

**Table 2.** Dietary intakes of the TF and WC groups

| Variable | SNR[a] or KDRI[b] | | TF group (n=76) | WC group (n=68) |
|---|---|---|---|---|
| | Male | Female | | |
| Energy | | | | |
| Total (kcal/day) | 3,650–3,925[a] | 2,875[a] | 2,143.2±669.8 | 2,260.6±514.2 |
| Sex | | | | |
| Male | - | - | 2,486.6±495.2 | 2,291.6±569.1 |
| Female | - | - | 1,520.1±464.8 | 2,223.6±446.5*** |
| Per kg of body weight (g/kg/day) | - | - | 33.0±11.0 | 32.7±9.6 |
| Carbohydrate | | | | |
| Total (g/day) | - | - | 292.1±96.1 | 305.7±61.6 |
| Per kg of body weight (g/kg/day) | 5–10[a] | 5–10[a] | 4.5±1.6 | 4.4±1.3 |
| % of total energy intake | >50[a] | >50[a] | 54.6±4.6 | 54.8±4.9 |
| Fiber (g/day) | 25[a] | 20[b] | 20.3±7.7 | 25.7±8.3*** |
| Protein | | | | |
| Total (g/day) | 65[b] | 50[b] | 84.3±25.1 | 87.8±22.2 |
| Per kg of body weight (g/kg/day) | 1.2–1.8[a] | 1.2–1.8[a] | 1.3±0.4 | 1.3±0.4 |
| % of total energy intake | 15–20[a] | 15–20[a] | 15.8±1.8 | 15.4±1.3 |
| Fat | | | | |
| Total (g/day) | - | - | 69.3±23.9 | 73.4±23.7 |
| Per kg of body weight (g/kg/day) | - | - | 1.1±0.4 | 1.1±0.4 |
| % of total energy intake | 15–30[a] | 15–30[a] | 29.1±4.2 | 28.7±4.4 |
| Saturated fat (g/day) | - | - | 11.2±5.3 | 16.1±4.9*** |
| Saturated fat (% of total energy intake) | <8[b] | <8[b] | 4.7±1.6 | 6.4±1.3*** |
| Vitamins | | | | |
| Vitamin A (μg/day) | 850[b] | 600[b] | 672.8±313.2 | 477.1±118.1*** |
| Vitamin E (mg/day) | 11[b] | 11[b] | 17.8±6.3 | 22.6±7.1*** |
| Vitamin D (μg/day)[c] | 10[b] | 10[b] | 4.6±3.3 | 10.1±3.9*** |
| Thiamin (mg/day) | 1.3[b] | 1.2[b] | 2.0±0.8 | 2.2±0.6 |
| Riboflavin (mg/day) | 1.7[b] | 1.2[b] | 1.7±1.0 | 1.7±0.9 |
| Niacin (mg/day) | 17[b] | 14[b] | 14.6±4.9 | 16.2±4.6* |
| Folate (μg/day) | 400[b] | 400[b] | 410.0±140.6 | 454.0±120.1* |
| Vitamin $B_{12}$ (μg/day) | 2.7[b] | 2.4[b] | 7.1±3.1 | 7.5±3.5 |
| Vitamin C (mg/day) | 105[b] | 95[b] | 60.0±27.3 | 53.3±13.7 |
| Minerals | | | | |
| Calcium (mg/day) | 900[b] | 800[b] | 526.6±184.8 | 561.0±204.3 |
| Phosphorus (mg/day) | 1,200[b] | 1,200[b] | 1,226.8±334.6 | 1,337.3±321.6* |
| Sodium (mg/day)[c] | 1,500[b] | 1,500[b] | 3,768.1±1144.1 | 3,921.9±962.2 |
| Potassium (mg/day)[c] | 3,500[b] | 3,500[b] | 2,564.2±742.2 | 2,697.3±670.1 |
| Magnesium (mg/day) | 400[b] | 340[b] | 112.1±40.5 | 121.5±42.5 |
| Iron (mg/day) | 14[b] | 14[b] | 19.0±14.1 | 17.6±7.5 |
| Zinc (mg/day) | 10[b] | 9[b] | 12.0±4.1 | 14.3±4.9** |
| Copper (μg/day) | 840[b] | 840[b] | 744.6±426.1 | 729.1±254.0 |
| Selenium (μg/day) | 65[b] | 65[b] | 75.1±27.6 | 78.6±21.5 |
| Manganese (mg/day) | 4[b] | 3.5[b] | 1.7±0.6 | 2.0±0.7** |

Values are presented as mean±standard deviation or number (%).
TF, track-and-field; WC, weight-class.
[a]SNR (for adolescent athletes): sports nutrition recommendation [5]; [b]KDRI (Korean Dietary Reference Intake, 2015) [15]; [c]Adequate intake.
Significant differences between the TF and WC groups were evaluated using Student t-test (*P<0.05, **P<0.01, ***P<0.001).

sults. While the statistical significance observed in niacin, calcium, and phosphorus intake was not maintained, likely resulting from the reduced sample size, vitamin C intake significantly differed between the groups. Tables S3 and S4 enumerate the sex-stratified results of nutrient intake between the two groups.

## Dietary quality of the participants

Table 3 shows the MAR and NAR of each nutrient consumed by the TF and WC groups. The TF group had a significantly lower MAR than the WC group ($P<0.01$). Among the nutrient intakes investigated, protein had a NAR closest to the recommended intake, with no significant difference between the two groups. The NARs of energy, vitamin C, riboflavin, niacin, vitamin $B_6$, folic acid, phosphorus, iron, and zinc were significantly higher in the WC group than in the TF group ($P<0.05$). The NARs for vitamin A, vitamin C, and calcium for both groups were too low ($<73\%$, $<61\%$, and $<66\%$, respectively). This discrepancy, the WC group showing a higher vitamin C NAR despite having a lower absolute vitamin C intake than the TF group (Table 2), may be attributed to the higher proportion of males in the TF group, who have a higher recommended nutrient intake.

## Nutrition knowledge of the participants

Table 4 lists the number (0–109 points) and percentage (0%–100%) of participants' correct answers on the NKQA. The mean score of total nutrition knowledge was 27.9 ± 14.0 points for the TF group and 29.4 ± 15.7 points for the WC group, showing no significant between-group difference. Among the six subsections (carbohydrate, protein, fat, general nutrition, fluid, and sports nutrition) of the nutritional knowledge assessment, knowledge about fat was significantly higher in the WC group than in the TF group ($P<0.05$). Regarding carbohydrate knowledge, the two groups obtained similar percentages of participants achieving correct answers. While the percentage of participants with correct answers for protein knowledge was slightly higher in the TF group than in the WC group, the between-group difference remained nonsignificant. The scores for general nutrition, fluid, and sports nutrition were similar, with no significant differences noted between the groups. The TF group had the highest rate of correct answers regarding protein, followed by fluid, general nutrition, carbohydrate, sports nutrition, and fat. Meanwhile, the WC group had the highest rate of correct answers in the order of protein, fluid, fat, general nutrition, carbohydrate, and sports nutrition.

## Dietary habits of the participants

Table 5 presents the adolescent athletes' healthy and unhealthy dietary habits. In the healthy dietary habit assessment, the WC group had a significantly lower proportion of participants who ate breakfast daily than the TF group ($P<0.001$). The proportion of athletes consuming fruits daily was low in both groups, with only 22.4% in the TF group and 19.1% in the WC group. The TF group had a higher proportion of participants who consumed vegetables more than thrice a day than the WC group (23.7% vs. 13.2%). Both fruit and vegetables intakes did not show significant differences between such groups. In addition, only 15.8% of the TF group and 11.8% of the WC group responded that they drank milk more than twice a day.

With regard to unhealthy dietary habits, the WC group had significantly more participants drinking carbonated drinks beyond thrice a week than the TF group ($P<0.001$). Only 2.6% of the TF group and 5.9% of the WC group drank high-caffeine beverages more than thrice per week, demonstrating no significant between-group difference. The proportion of participants consuming sugar-sweetened beverages at least thrice a week was higher in

**Table 3.** Dietary quality of the TF and WC groups

| Variable | All (n=144) | TF group (n=76) | WC group (n=68) |
|---|---|---|---|
| NAR | | | |
| Energy | 0.85±0.16 | 0.81±0.17 | 0.90±0.13** |
| Protein | 0.98±0.08 | 0.97±0.09 | 0.99±0.06 |
| Vitamin A | 0.72±0.21 | 0.73±0.23 | 0.70±0.17 |
| Vitamin C | 0.56±0.20 | 0.51±0.21 | 0.61±0.19** |
| Thiamin | 0.98±0.07 | 0.97±0.09 | 0.98±0.05 |
| Riboflavin | 0.92±0.13 | 0.89±0.15 | 0.96±0.18** |
| Niacin | 0.87±0.17 | 0.82±0.19 | 0.92±0.14*** |
| Vitamin $B_6$ | 0.94±0.17 | 0.92±0.16 | 0.97±0.11* |
| Folate | 0.94±0.14 | 0.86±0.18 | 0.95±0.11** |
| Calcium | 0.63±0.22 | 0.60±0.22 | 0.66±0.21 |
| Phosphorus | 0.92±0.14 | 0.89±0.16 | 0.95±0.11* |
| Iron | 0.92±0.12 | 0.90±0.16 | 0.95±0.11* |
| Zinc | 0.95±0.12 | 0.92±0.14 | 0.97±0.19* |
| MAR[a] | 0.86±0.11 | 0.83±0.13 | 0.89±0.08** |

Values are presented as mean±standard deviation.
TF, track-and-field; WC, weight-class; NAR, nutrient adequacy ratio; MAR, mean adequacy ratio.
[a]Calculated according to 12 nutrients excluding energy
Significant differences between the TF and WC groups were evaluated using Student t-test (*P<0.05, **P<0.01, ***P<0.001).

**Table 4.** Subsection and total scores achieved on the nutritional knowledge questionnaire for athletes by the TF and WC groups

| Nutrition knowledge subsection | TF group (n=76) | WC group (n=68) |
|---|---|---|
| Carbohydrate (n=23) | 5.8±3.6 (25.1) | 5.8±3.5 (25.2) |
| Protein (n=18) | 6.2±3.5 (34.4) | 5.9±3.3 (32.5) |
| Fat (n=23) | 4.4±3.9 (19.2) | 6.2±5.1 (26.8)* |
| General nutrition (n=25) | 6.5±4.4 (26.1) | 6.6±4.4 (26.6) |
| Fluid (n=6) | 1.7±1.3 (28.9) | 1.7±1.3 (28.4) |
| Sports nutrition (n=14) | 3.3±2.8 (23.7) | 3.3±2.5 (23.2) |
| Total (n=109) | 27.9±14.0 (25.6) | 29.4±15.7 (27.0) |

The number of correct answers in each subsection is presented as mean±standard deviation (%).
TF, track-and-field; WC, weight-class.
Significant differences between the TF and WC groups were evaluated using Student t-test (*P<0.05).

**Table 5.** Dietary habits of the study participants[a)]

| Variable | All (n=144) | TF group (n=76) | WC group (n=68) |
|---|---|---|---|
| Healthy dietary habits[b)] | | | |
| Breakfast, ≥7 times/wk | 50 (34.7) | 37 (48.7) | 13 (19.1)*** |
| Fruit, ≥1 times/day | 30 (20.8) | 17 (22.4) | 13 (19.1) |
| Vegetable, ≥3 times/day | 27 (18.8) | 18 (23.7) | 9 (13.2) |
| Milk, ≥2 times/day | 20 (13.9) | 12 (15.8) | 8 (11.8) |
| Unhealthy dietary habits[b)] | | | |
| Carbonated beverage, ≥3 times/wk | 39 (27.1) | 12 (15.8) | 27 (39.7)** |
| High-caffeine beverage, ≥3 times/wk | 6 (4.2) | 2 (2.6) | 4 (5.9) |
| Sugar-sweetened beverage, ≥3 times/wk | 87 (60.4) | 49 (64.5) | 38 (55.9) |
| Fast food, ≥3 times/wk | 17 (11.8) | 9 (11.8) | 8 (11.8) |
| Instant noodle, ≥3 times/wk | 22 (15.3) | 9 (11.8) | 13 (19.1) |
| Unhealthy snack, ≥3 times/wk | 38 (26.4) | 17 (22.4) | 21 (30.9) |

Values are presented as number (%).
TF, track-and-field; WC, weight-class.
[a)]Participants' dietary habits over the past 7 days were assessed using the Korean Youth Risk Behavior Survey. [b)]Over the past 7 days.
Significant differences between the TF and WC groups were evaluated using the chi-squared test (**P<0.01, ***P<0.001).

**Table 6.** Weight control behavior in the study participants

| Variable | All | TF group | WC group |
|---|---|---|---|
| Effort to control weight during the last month | 144 (100) | 76 (100) | 68 (100) |
| No | 53 (36.8) | 30 (39.5) | 23 (33.8) |
| Weight loss | 63 (43.8) | 31 (40.8) | 32 (47.1) |
| Weight gain | 9 (6.3) | 7 (9.2) | 2 (2.9) |
| Weight maintenance | 19 (13.2) | 8 (10.5) | 11 (16.2) |
| Method to control weight[a)] | 91 (100) | 46 (100) | 45 (100) |
| Regular exercise | 85 (93.4) | 43 (93.5) | 42 (93.3) |
| Fasting | 18 (19.8) | 4 (8.7) | 14 (31.1)* |
| Reduce meal size | 73 (80.2) | 36 (78.3) | 37 (82.2) |
| Diet pill | 8 (8.8) | 3 (6.5) | 5 (11.1) |
| Diarrhea or diuretic medicine | 1 (1.1) | 0 (0.0) | 1 (2.2) |
| Vomiting after a meal | 3 (3.3) | 1 (2.2) | 2 (4.4) |
| One-food diet | 5 (5.5) | 3 (6.5) | 2 (4.4) |
| Oriental medicine | 8 (8.8) | 5 (10.9) | 3 (6.7) |
| Diet food | 5 (5.5) | 3 (6.5) | 2 (4.4) |

Values are presented as number (%).
TF, track-and-field; WC, weight-class.
[a)]Respondents who made an effort to lose, gain, or maintain weight during the last month. Multiple answers may be selected.
Significant differences between the TF and WC groups were evaluated using the chi-squared test (*P<0.05)

the TF group than in the WC group (64.5% vs. 55.9%), although the difference was not significant. Regarding the intake of fast food, instant noodles, and unhealthy snacks more than thrice per week, no significant differences were observed between the TF and WC groups.

### Weight control behavior and body image self-perception of the participants

Table 6 summarizes the results of the weight control behavior questionnaire. We found no significant differences between the TF and WC groups in terms of effort to control weight (no, weight loss, weight gain, and weight maintenance).

Participants controlled their weight through methods such as regular exercise, meal size reduction, fasting, oriental medicine intake, one-food diet, diet food consumption, and diet pill administration. The most commonly used method for weight control was regular exercise (TF, 93.5%; WC, 93.3%), but no significant difference was noted between the two groups. The next most common method was meal size reduction in both groups. The proportion of participants who applied fasting was significantly higher in the

WC group than in the TF group (31.1% vs. 8.7%).

Table S5 compares the measured weight status with body image self-perception. The percentage of agreement of body image with weight status did not significantly differ between the TF and WC groups (61.8% vs. 60.3%). In the TF group, 25.0% perceived their weight to be lower than the BMI standard, whereas 13.1% perceived it to be higher. In the WC group, 27.9% perceived their weight to be lower than the BMI standard, whereas 11.8% perceived it to be higher. Female participants had a lower agreement on weight status than male participants. Cohen's kappa indicated a moderate agreement in males and a slight agreement in females. Compared with the BMI standard, 30.2% of males perceived their weight to be lower, while 2.3% perceived it to be higher. Conversely, 27.6% of females perceived their weight to be higher than the BMI standard, while 20.7% perceived it to be lower.

### Interesting topics and information sources about nutrition among participants

Table S6 lists the results of the participants' interest in nutrition and the sources of nutrition information. Only 26.3% of the TF group and 38.2% of the WC group had received nutrition education, showing no significant between-group difference. Regarding the topics of interest in nutrition, the TF group was most interested in quick recovery after training (63.2%) as compared with the WC group (44.1%), showing a significant difference ($P < 0.05$). The WC group was most interested in body fat reduction. The percentage of respondents who expressed interest in increasing muscle mass was higher in the WC group than in the TF group. Conversely, the degree of interest in nutrition supplements was higher in the TF group. Nonetheless, the degrees of interest in body fat reduction, muscle mass increase, and nutrition supplementation were not significantly different between the two groups. The degree of interest in good food habits was relatively low in both groups compared with body fat loss, quick recovery, and muscle buildup. Overall, the TF group was most interested in quick recovery, followed by fat loss, muscle buildup, and nutrition supplements, while the WC group was most interested in fat loss, followed by muscle buildup, quick recovery, and nutrition supplements. The least interesting topic for both groups was glycogen loading.

The most common nutrition information sources were coaches/trainers, followed by friends and mass media. In addition, the participants obtained nutrition information from their family, dietitian/physician, and magazines. None of these information sources significantly differed between the TF and WC groups.

Moreover, the practical application of nutrition knowledge showed no significant difference between the two groups. Only 25.0% of the TF group and 14.7% of the WC group responded that they applied nutrition to training. Those who did not apply nutrition to training chose the "Just so" or "Not at all" response.

## DISCUSSION

This study revealed inadequate nutrition intake and the need for nutrition education among South Korean adolescent athletes involved in TF and WC sports. This study may be the first to compare and analyze the nutrient intake, nutrition knowledge, and dietary habits of TF and WC adolescent athletes. According to self-reported food records, the TF and WC groups consumed energy and carbohydrates below the SNR. While the WC group had a significantly higher diet quality of micronutrients than the TF group, calcium, vitamin C, and magnesium intake was less than the KDRI in both groups. Both groups also had low scores in all items of the nutrition knowledge questionnaire, likely resulting from the lack of opportunities for nutrition education.

TF sports involve athletic performance based on physical skills such as running, jumping, and throwing. They require speed, strength, power, and endurance; thus, a healthy nutrition strategy is essential to overcome the stresses of high-intensity training [16]. For WC sports, such as taekwondo, judo, wrestling, boxing, weightlifting, and bodybuilding, athletes must reach a certain weight to qualify for a competition. As a result, many of the WC athletes resort to extreme weight control methods, including fasting, eating disorders, and unhealthy diets; therefore, establishing healthy eating habits is crucial among these athletes [10].

Nutrition promotes optimal growth and development, making it an integral part of sporting competition for adolescent athletes [4]. Nutrition knowledge is essential for adolescent athletes because they need to know what, when, and how much to eat before, during, and after an exercise to achieve optimal performance [17]; however, no significant differences were identified by sex in this study. Most of the participants lacked sports nutrition knowledge, as well as basic nutrition knowledge, including nutrient sources and macronutrient and micronutrient functions. Their lack of nutrition knowledge may be explained by the findings that they did not receive proper nutrition education and opportunities to meet nutrition experts. Athletes tend to seek nutrition information from coaches, colleagues, the Internet, and family members rather than nutrition experts. With high nutrition knowledge, athletes can increase their quality of meals [18]. Therefore, providing effective nutrition education programs for adolescents may help improve the quality of their food intake [18].

This study was conducted within the "in season" period, during which adequate nutrient intake of athletes is crucial for energy supplementation and recovery before, during, and after competition and training. However, the daily energy intake of both participant groups was significantly lower than the SNR. The lack of energy intake may be explained by the fact that half of the TF group and only 1/5 of the WC group ate breakfast each day. Although athletes may skip breakfast to lose weight, weight reduction can become more difficult because they eat most of their calories at dinner [19]. Erdman et al. [20] found that 98% of elite Canadian athletes consumed breakfast, whereas only 23% of nonelite athletes did so. Breakfast is crucial for athletes because it replenishes the glycogen depleted overnight and the carbohydrates needed for exercise [20]. Thus, athletes skipping breakfast may not meet their total required daily energy intake, as well as the carbohydrate intake, required to compete [21]. Moreover, approximately 40% of the TF group and 50% of the WC group are currently losing weight, likely causing their energy shortages. Energy intake below the recommended level should be avoided because it negatively affects not only the healthy growth and development of adolescent athletes but also their athletic performance and health [22]. For example, a persistent energy deficit lowers athletes' muscle strength, glycogen storage, concentration, coordination, and training response, thereby negatively affecting their athletic performance [1]. It may also lead to adverse health consequences, including eating disorders, dehydration, anorexia, and bulimia, as a result of hunger, fatigue, and stress [22]. Consuming fruit, bread, milk, and cheese between meals may be helpful for adolescent athletes to optimize their daily energy intake and nutrient timing.

According to the SNR for adolescent athletes, the recommended carbohydrate intake is 50% of the daily intake or 3–8 g per kg body weight, depending on the intensity of exercise [5]. A previous study suggested that the carbohydrate intake of adolescent TF athletes should be more than 55% of the total energy intake or equal to 6–10 g of carbohydrates per kg body weight [23]. In our study, the mean carbohydrate intake per body weight was similar between groups but lower than the SNR. Considering the long daily exercise time of both groups, they need to increase their intake of carbohydrates, the primary energy source of exercise; guidelines for carbohydrate intake are generally 5–7 g/kg for moderate-intensity training (< 1 hour, low-intensity exercise) and 7–10 g/kg for increased high-intensity training (2–5 hours, endurance training) [24]. With carbohydrate deficiency, athletes may experience glycogen depletion, fatigue accumulation, slow recovery from training, and poor athletic performance [24]. Adolescents having difficulty obtaining sufficient carbohydrates from their meals may additionally drink juice or sports drinks to help increase their carbohydrate intake.

The protein intake of adolescent athletes is often reported to be 1.2–1.6 g/kg/day [25]. The mean protein intake per body weight (1.3 ± 0.4 g/kg/day) was comparable between the TF and WC groups and is similar to a previous report, indicating that the protein intake of our participants is appropriate. In general, nonvegetarian athletes easily exceed protein recommendations [6]. Our participants consumed protein that is approximately 1.5 times the KDRI. In the US, UK, and Australia, adolescent athletes consumed protein that is 2 to 3 times the recommendation of each country [26]. Among elite adolescent athletes, the protein intake is 1.5–2.0 g per body weight, particularly for WC sports requiring body weight control and energy intake restriction in preparation for a competition [6]. Nonetheless, coaches should always be concerned because vegetarian adolescent athletes who strictly limit their energy intake may have a low protein intake [6].

The dietary fat consumption of the TF and WC groups was approximately 30% of their total energy intake, in line with the recommended range of 15% to 30% [15]. For athletes, dietary fat intake above 30% is not recommended because it may contribute to excessive weight gain [27]. If athletes are trying to meet their energy needs, healthy fats may be the most energy-dense option [27].

The busy daily schedule of elite adolescent athletes may lead to an imbalanced diet, increasing the risk of micronutrient deficiency [5]. The WC group met the recommended nutrient intake of vitamin D, whereas the TF group did not. In a cross-sectional study of South Korean adolescents, vitamin D deficiency was very common, with 73.3% of them reporting such deficiency [28]. WC athletes trying to lose body weight are at increased risk of deficiency in micronutrients, including vitamin D, calcium, and iron [10]. Calcium and vitamin D are essential for maintaining muscle contraction, bone health, and other physical performance, but most adolescent athletes do not consume adequate amounts [1]. In this study, low calcium intake of the TF and WC groups may be associated with low dairy intake. Calcium deficiency has been reported in WC and TF sports [2], and athletes trying to lose weight might experience decreased bone mineral density and impaired exercise performance [29]. A common nutritional goal among athletes is the moderate and well-timed consumption of nutritionally balanced meals; this goal improves their health and exercise performance and promotes recovery [30]. Despite the importance of diversity in food choice, both the TF and WC groups had an insufficient vitamin C intake, which is often associated with inadequate consumption of fruit and vegetables.

Many sports require low body weight and a low fat–muscle ratio for excellent performance. Therefore, adolescent athletes may try to lose weight to increase their physical strength, reach a certain WC, and develop a slim and lean body for sporting performance [3]. Although nutritional optimization leads to increased self-confidence and peak performance among athletes [31], approximately 40% of the TF group and nearly half of the WC group were currently losing weight, making their daily energy intake significantly below the SNR. The WC group showed a significantly higher rate of fasting than the TF group. Various studies have reported high fasting rates among high school and college wrestlers [32]. Fasting in athletes not only can impair mood and concentration but can also have adverse effects on cardiovascular function, heat regulation, kidney function, and electrolyte balance [33]. For adolescent athletes, primarily females, chronic energy deficiencies may delay puberty and lead to irregular menstrual periods, poor bone health, and increased injury risk, which, in turn, negatively affect exercise performance [4]. When trying to lose weight or diet, adolescent athletes lacking nutrition knowledge need to consult a dietitian or physician. However, only 14.5% of the TF group and 23.5% of the WC group received nutritional information from a dietitian or physician. Of note, the TF (39.5%) and WC (32.4%) groups were acquiring nutritional information from colleagues who also lack nutrition knowledge. Rather than nutrition experts, nutrition information sources for athletes are often coaches, who may not be qualified to provide such information [34].

In interesting topics in nutrition, the TF group was most interested in quick recovery, followed by body fat loss, muscle buildup, and nutrition supplements. Similarly, the WC group was most interested in body fat loss, followed by muscle buildup, quick recovery, and nutrition supplements. Regarding nutrition for quick recovery from training, athletes should focus primarily on carbohydrates, protein, and fluids [35]. Despite high-intensity training for more than 4.5 hours a day, the TF group had a lower-than-recommended carbohydrate intake, which could have delayed their recovery from training. The WC group spent a longer time in training ( > 5.0 hours daily compared with 4.5 hours daily) than the TF group, likely because of a weight loss exercise in addition to power, strength, endurance, and technical training. As shown by interest in muscle buildup and nutrition supplements in both groups, adolescent athletes consider taking nutritional supplements for various reasons, including increased muscle mass, power and endurance, and optimized body composition [4]. However, the potential long-term effects of nutrition supplements have not been investigated among younger ones because of ethical considerations [5]. With regard to sports nutrition knowledge, both the TF and WC groups lacked such knowledge, showing an average of three correct answers out of 14 questions. Sports nutrition education is important among adolescent athletes to understand nutrition supplements accurately. Nutrition experts must also continue to provide nutrition guidelines for quick recovery, body fat loss, and muscle buildup, which are of primary interest to adolescent athletes.

This study has several strengths. It is a relatively large study compared with other studies involving South Korean adolescent athletes. Other studies have only fewer than 50 participants. To our knowledge, the present study may be the first to compare the nutrient intake, nutrition knowledge, and dietary habits between South Korean adolescent athletes involved in TF and WC sports. Although this study did not evaluate the biochemical factors of adolescent athletes, the results may help improve adolescent athletes' nutrition knowledge, nutrient intake, dietary habits, health status, and athletic performance in future studies. Concerning the results, further research on the nutrition-related factors for athletes in different sports types is warranted.

## Limitations

This study also has several limitations that need to be considered. For example, it relied on participants' self-reported data on food intake, dietary habits, and nutrition knowledge, which are subject to potential recall and social desirability bias. Additionally, given that data were collected in 2018, the findings may not fully reflect the current nutritional status and dietary behaviors of South Korean adolescent athletes. However, considering the limited availability of data on nutrient intake, nutrition knowledge, and dietary habits in this population, this study provides valuable baseline information for future research. Furthermore, this study only recruited athletes from a single high school; thus, the results may not be generalizable to a broader population of South Korean adolescent athletes in TF and WC sports. Finally, nutrient adequacy was evaluated using the 2015 KDRIs despite the recent release of the 2025 KDRIs. The dietary data used in this study were collected in 2018. By utilizing the guidelines that were tailored to adolescents at that specific time, the interpretation of our results remains valid and contextually appropriate. Furthermore, the reference values for energy and major nutrients remain largely consistent between the two guidelines; thus, applying the updated KDRIs would not alter our fundamental conclusion regarding widespread nutrient inadequacy.

### Conclusion

The TF group had better dietary habits than the WC group but had lower energy and micronutrient intake, diet quality, and fat nutrition knowledge. Despite having more training than the TF group, the WC group more often reported that they attempted to lose weight through unhealthy ways, including fasting and reducing meal size to less than the SNR. Nutrient intake, nutrition knowledge, and dietary habits differed between these two groups; however, both groups demonstrated nutrient intake that was considerably lower than the SNR, had no nutritional education experience and nutrition knowledge, and showed similar interests in nutrition. Considering the nutrition-related problems observed in this study, individualized nutrition intervention with continuous sports nutrition education is necessary for the health and athletic performance of adolescents.

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Conceptualization: ISL, SL. Formal analysis: SL. Investigation: SL. Methodology: SL. Supervision: ISL. Writing - original draft: SL, PK. Writing - review & editing: all authors. All authors read and approved the final manuscript.

### Conflict of interest

None.

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### Data availability

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

## SUPPLEMENTARY MATERIALS

Supplementary materials are available from https://doi.org/10.7762/cnr.2026.0024.

## REFERENCES

1. Hoch AZ, Goossen K, Kretschmer T. Nutritional requirements of the child and teenage athlete. Phys Med Rehabil Clin N Am 2008;19:373-98.
2. Werner A, Thiel A, Schneider S, Mayer J, Giel KE, Zipfel S. Weight-control behaviour and weight-concerns in young elite athletes: a systematic review. J Eat Disord 2013;1:18.
3. Carl RL, Johnson MD, Martin TJ; Council on Sports Medicine and Fitness. Promotion of healthy weight-control practices in young athletes. Pediatrics 2017;140:e20171871.
4. Desbrow B, McCormack J, Burke LM, et al. Sports Dietitians Australia position statement: sports nutrition for the adolescent athlete. Int J Sport Nutr Exerc Metab 2014;24:570-84.
5. Smith JW, Holmes ME, McAllister MJ. Nutritional considerations for performance in young athletes. J Sports Med (Hindawi Publ Corp) 2015;2015:734649.
6. Jeukendrup A, Cronin L. Nutrition and elite young athletes. Med Sport Sci 2011;56:47-58.
7. Meyer F, O'Connor H, Shirreffs SM; International Association of Athletics Federations. Nutrition for the young athlete. J Sports Sci 2007;25 Suppl 1:S73-82.
8. Birkenhead KL, Slater G. A review of factors influencing athletes' food choices. Sports Med 2015;45:1511-22.
9. Calella P, Iacullo VM, Valerio G. Validation of a general and sport nutrition knowledge questionnaire in adolescents and young adults: GeSNK. Nutrients 2017;9:439.
10. Sundgot-Borgen J, Garthe I. Elite athletes in aesthetic and Olympic weight-class sports and the challenge of body weight and body compositions. J Sports Sci 2011;29 Suppl 1:S101-14.
11. Furber MJ, Roberts JD, Roberts MG. A valid and reliable nutrition knowledge questionnaire for track and field athletes. BMC Nutr 2017;3:36.
12. Kim A, Kim J, Kye S. Sugar-sweetened beverage consumption and influencing factors in Korean adolescents: based on the 2017 Korea Youth Risk Behavior Web-based Survey. J Nutr Health 2018;51:465-79.
13. Heaney S, O'Connor H, Gifford J, Naughton G. Comparison of strat-

egies for assessing nutritional adequacy in elite female athletes' dietary intake. Int J Sport Nutr Exerc Metab 2010;20:245-56.
14. Black AE. Critical evaluation of energy intake using the Goldberg cut-off for energy intake:basal metabolic rate: a practical guide to its calculation, use and limitations. Int J Obes Relat Metab Disord 2000;24:1119-30.
15. Ministry of Health and Welfare; The Korean Nutrition Society. Dietary reference intakes for Koreans 2015. Ministry of Health and Welfare; 2015.
16. Burke LM. The IAAF consensus on nutrition for athletics: updated guidelines. Int J Sport Nutr Exerc Metab 2007;17:411-5.
17. Jessri M, Jessri M, RashidKhani B, Zinn C. Evaluation of Iranian college athletes' sport nutrition knowledge. Int J Sport Nutr Exerc Metab 2010;20:257-63.
18. Diehl K, Yarmoliuk T, Mayer J, et al. Eating patterns of elite adolescent athletes: results of a cross-sectional study of 51 Olympic sports. Dtsch Z Sportmed 2013;64:126-31.
19. Shriver LH, Betts NM, Wollenberg G. Dietary intakes and eating habits of college athletes: are female college athletes following the current sports nutrition standards? J Am Coll Health 2013;61:10-6.
20. Erdman KA, Tunnicliffe J, Lun VM, Reimer RA. Eating patterns and composition of meals and snacks in elite Canadian athletes. Int J Sport Nutr Exerc Metab 2013;23:210-9.
21. Manore MM. Weight management for athletes and active individuals: a brief review. Sports Med 2015;45 Suppl 1:S83-92.
22. Mountjoy M, Sundgot-Borgen J, Burke L, et al. The IOC consensus statement: beyond the female athlete triad: relative energy deficiency in sport (RED-S). Br J Sports Med 2014;48:491-7.
23. Aerenhouts D, Deriemaeker P, Hebbelinck M, Clarys P. Energy and macronutrient intake in adolescent sprint athletes: a follow-up study. J Sports Sci 2011;29:73-82.
24. Burke LM, Cox GR, Cummings NK, Desbrow B. Guidelines for daily carbohydrate intake: do athletes achieve them? Sports Med 2001; 31:267-99.
25. Petrie HJ, Stover EA, Horswill CA. Nutritional concerns for the child and adolescent competitor. Nutrition 2004;20:620-31.
26. Bass S, Inge K. Nutrition for special populations: children and young athletes. In: Burke L, Deakin V, editors. Clinical sports nutrition. 3rd ed. McGraw-Hill; 2006. p. 589-632.
27. Parnell JA, Wiens KP, Erdman KA. Dietary intakes and supplement use in pre-adolescent and adolescent Canadian athletes. Nutrients 2016;8:526.
28. Byun EJ, Heo J, Cho SH, Lee JD, Kim HS. Suboptimal vitamin D status in Korean adolescents: a nationwide study on its prevalence, risk factors including cotinine-verified smoking status and association with atopic dermatitis and asthma. BMJ Open 2017;7:e016409.
29. Khodaee M, Olewinski L, Shadgan B, Kiningham RR. Rapid weight loss in sports with weight classes. Curr Sports Med Rep 2015;14:435-41.
30. Bingham ME, Borkan ME, Quatromoni PA. Sports nutrition advice for adolescent athletes: a time to focus on food. Am J Lifestyle Med 2015;9:398-402.
31. Cockburn E, Fortune A, Briggs M, Rumbold P. Nutritional knowledge of UK coaches. Nutrients 2014;6:1442-53.
32. Oppliger RA, Landry GL, Foster SW, Lambrecht AC. Bulimic behaviors among interscholastic wrestlers: a statewide survey. Pediatrics 1993;91:826-31.
33. Choma CW, Sforzo GA, Keller BA. Impact of rapid weight loss on cognitive function in collegiate wrestlers. Med Sci Sports Exerc 1998;30:746-9.
34. Trakman GL, Forsyth A, Devlin BL, Belski R. A systematic review of athletes' and coaches' nutrition knowledge and reflections on the quality of current nutrition knowledge measures. Nutrients 2016;8:570.
35. Heaton LE, Davis JK, Rawson ES, et al. Selected in-season nutritional strategies to enhance recovery for team sport athletes: a practical overview. Sports Med 2017;47:2201-18.

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CLINICAL NUTRITION RESEARCH

# Discrepancies between preschoolers' self-perceived healthy eating practices and parental assessments: a cross-sectional study in South Korea

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**Objective:** Although healthy dietary habits established in early childhood are critical for lifelong health, most previous studies have relied predominantly on parental proxy reports rather than children's self-perceptions. This study compared preschoolers' self-perceived healthy dietary practices with their parents' evaluations and examined discrepancies between them.
**Methods:** This study included 243 preschoolers aged 2 to 7 years and their parents, recruited from daycare centers in Cheonan, South Korea. Data were collected using the validated, structured, self-administered Healthy Eating Practice Questionnaire, which assessed nutrition and hygiene. Mean Healthy Eating Practice Scores were compared between preschoolers and their parents using paired t-tests, and stratified analyses were conducted by sex and age.
**Results:** Preschoolers rated their healthy dietary practices significantly higher than their parents did (P<0.001). The discrepancy was greater for nutrition than for hygiene, with hygiene ratings more consistent. This domain-specific pattern was consistent across sexes and age groups. When stratified by sex and age, preschooler-parent Healthy Eating Practice Score differences were significantly higher in boys than in girls (25.0±21.0 vs. 20.0±14.9, respectively; P=0.035).
**Conclusion:** Discrepancies between preschoolers' self-perceptions and their parents' evaluations suggest that incorporating both perspectives is essential for accurately assessing children's dietary practices. These findings support the development of dual-perspective dietary assessment and education strategies in early childhood.

**Keywords:** Preschool; Parents; Eating behavior; Perception

## INTRODUCTION

The prevalence of obesity and picky eating habits among children and adolescents in South Korea has steadily increased [1]. Selective eating and consumption of high-calorie, low-nutrient foods in early childhood increase the risk of nutritional deficiencies during growth and chronic diseases in adulthood, including obesity, diabetes, and cardiovascular diseases [2,3]. Early childhood is a critical period for establishing dietary habits [4], which directly influence future food choices, nutritional balance, and self-regulatory skills [5]. Therefore, establishing proper dietary habits in early childhood is essential for lifelong health, highlighting the need for early nutritional education and guidance.

However, rising dual-income families and dining-out culture

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have reduced home mealtimes, making preschoolers' dietary management increasing challenging. Particularly, children's dietary habits are not merely personal preference but are directly influenced by parental eating attitudes and guidance behaviors [6-8]. As key role models, parents' nutritional knowledge, eating habits, and attitudes are closely associated with their children's healthy dietary practices [7-10].

To promote healthy dietary habits in preschoolers, it is essential to understand the process of changes in their dietary behaviors. However, most previous studies, both domestic and international, have relied on parent or teacher reports rather than children's self-perceptions [11-13]. Previous studies have demonstrated meaningful parent-child differences in reports of identical health-related behaviors [14], with studies on dietary habits showing that parents tend to overestimate the quality of their children's actual behaviors [15].

These findings highlight the limitation of relying solely on parental perceptions, which may not fully capture preschoolers' perspectives on dietary behavior changes or accurately identify their health behaviors or dietary problems. Furthermore, analyzing parent-child perceptual gaps is significant for identifying their determinants and understanding children's perceptions of healthy eating behaviors. However, studies directly comparing infants' self-awareness with parents' perceptions remain limited [16]. To better understand behaviors related to the development of healthy dietary habits in preschoolers, research that incorporates both children's direct responses and parental assessments is essential. Therefore, this study aimed to examine discrepancies between preschoolers' self-perceived healthy dietary attitudes and practices and their parents' evaluations.

## METHODS

### Ethics statement

This study was approved by the Institutional Review Board of Dankook University (No. 2024-05-050-007) and adhered to the Declaration of Helsinki principles. The study procedures were explained in detail to all participants before the study began, and informed consent was obtained.

### Study design

This cross-sectional survey compared preschoolers' self-perceived levels of healthy eating practices with their parents' evaluations of the children's practices. In addition, the study examined whether discrepancies between children's and parents' perceptions varied by child's sex and age.

### Study participants

The study participants were preschoolers aged 2 to 7 years and their parents, recruited from daycare centers and kindergartens supported by the Center for Children's Foodservice Management (CCFSM) in Cheonan, South Korea. The survey was conducted in two phases: the first phase from August to November 2024, and the second phase from April to May 2025.

In the first phase, 136 pairs of preschoolers and parents participated; however, six pairs were excluded for incomplete responses, resulting in a final sample of 130 pairs (n = 260) included in the analysis. In the second phase, 118 pairs participated, and after excluding five pairs with insufficient data, 113 pairs (n = 226) were included. Finally, a total of 243 pairs (n = 486) from both phases were pooled for the final analysis.

### General characteristics and growth status assessment of preschoolers

General characteristics of the preschoolers, including sex, age, height, weight, and body mass index (BMI), were obtained through self-reported questionnaires completed by their parents at the time of the survey. To assess growth status, we used the 2017 Korean National Growth Charts for Children and Adolescents developed by the Korea Disease Control and Prevention Agency and the Korean Pediatric Society. Short stature was defined as height-for-age below the 3rd percentile, and underweight as weight-for-age below the 5th percentile. Based on BMI-for-age percentiles, children were classified as underweight (< 5th percentile), normal weight (5th to < 85th percentile), overweight (85th to < 95th percentile), or obese (≥ 95th percentile) [17].

### Healthy Eating Practices Questionnaire (HEPQ)

This study used the HEPQ developed to target infants and young children aged ≥ 24 months and validated through a stepwise process from 2020 to 2022 to objectively assess the level of healthy dietary practices in preschoolers, including the effectiveness of early childhood education programs at the CCFSM [16,18]. The HEPQ was designed using child-friendly facial expressions and illustrations so that children can independently choose response options to questions and consisted of versions for both preschoolers and parents, with established reliability and validity. Core dietary items were derived and subjected to rigorous validation during initial development [16,18]. Subsequently, the scoring system and domain-specific criteria were established, with evaluation objectivity strengthened through correlation analysis with the Nutrition Quotient for Preschoolers [18].

The HEPQ assesses dietary behaviors, including food preferences, intake levels, and hygiene practices (hand washing and tooth brushing), categorized into two domains: nutrition and hygiene. The questionnaire responses from both preschoolers and parents were evaluated across four subdomains: food preference, food intake level, hand washing, and tooth brushing. Based on questionnaire responses, the Healthy Eating Practice Score (HEPS) was calculated. Each subdomain comprises three to five items, and the responses, measured on 3- to 5-point Likert scales, were converted to a 100-point scale for standardized scoring.

### Statistical analysis

Categorical variables describing the general characteristics of preschoolers were summarized as frequencies and percentages (%). Continuous variables, such as age, height, and weight, were expressed as mean ± standard deviation. The HEPS scores for preschoolers and parents were calculated as mean ± standard deviation. Differences between child- and parent-reported HEPS scores were analyzed using paired t-tests. Independent t-tests were used to examine whether discrepancy scores differed by child's sex or age group. All statistical analyses were performed using IBM SPSS ver. 28.0 (IBM Corp.), and statistical significance was defined at $P < 0.05$.

## RESULTS

### General characteristics of preschoolers

General characteristics of the participants are presented in Table 1. Among the 243 children, 117 (48.1%) were boys and 126 (51.9%) were girls. Three-year-olds comprised the largest age group (n = 64, 26.3%), followed by 4-year-olds (n = 61, 25.1%) and 5-year-olds (n = 51, 21.0%). Most children were within the normal range for height (n = 229, 94.2%) and weight (n = 225, 92.6%). For BMI, 184 children (75.7%) fell within the normal range, followed by the overweight or obese group (n = 44, 18.1%) (Table 1).

### HEPS difference scores between preschoolers' self-perceptions and parental perceptions

The difference between preschoolers' self-reported HEPS scores and parental HEPS scores is shown in Table 2. The total scores reported by preschoolers were significantly higher by 22.4 points than the scores evaluated by parents ($P < 0.001$). Regarding the subdomains, preschoolers' self-reported scores for food preference (mean = 78.2) and food intake level (mean = 85.3) were significantly higher than parental evaluations (73.4 and 66.9, respectively; $P < 0.001$). Conversely, for the hygiene subdomains (hand washing and tooth brushing), parental evaluation scores were slightly higher than those of the children; particularly, in tooth brushing, parents (mean = 42.2) scored significantly higher than preschoolers (mean = 41.6) ($P = 0.033$).

### Comparison of the HEPS scores between preschoolers' self-perceptions and parental perceptions stratified by sex and age

When stratified analyses to compare the HEPS total scores reported by preschoolers and their parents were conducted by sex and age, preschoolers' self-reported scores were significantly higher than those reported by parents, regardless of sex and age ($P < 0.001$). However, results varied across subdomains. In both boys and girls, and in both age groups (≤ 4 and > 4 years), pre-

**Table 1.** General characteristics of study participants

| Variable | Total |
|---|---|
| Sex | |
| Boy | 117 (48.1) |
| Girl | 126 (51.9) |
| Total | 243 (100) |
| Age (yr) | 4.19±1.23 |
| 2 | 46 (18.9) |
| 3 | 64 (26.3) |
| 4 | 61 (25.1) |
| 5 | 51 (21.0) |
| 6 | 19 (7.8) |
| ≥7 | 2 (0.9) |
| Total | 243 (100) |
| Height (cm) | 102.88±9.62 |
| Normal | 229 (94.2) |
| Short stature[a] | 14 (5.8) |
| Total | 243 (100) |
| Weight (kg) | 17.65±8.06 |
| Normal | 225 (92.6) |
| Underweight[b] | 18 (7.4) |
| Total | 243 (100) |
| Body mass index[c] | |
| Normal | 184 (75.7) |
| Underweight | 15 (6.2) |
| Overweight or obese | 44 (18.1) |
| Total | 243 (100) |

Values are presented as number (%) or mean±standard deviation.
[a]Short stature was defined as height-for-age below the 3rd percentile; [b]Underweight was defined as weight-for-age below the 5th percentile; [c]Body mass index was defined based on the BMI-for-age percentiles: underweight (<5th percentile), normal weight (5th to <85th percentile), overweight (85th to <95th percentile), or obese (≥95th percentile).

schoolers' self-reported scores were significantly higher than parents' scores in the food preference and intake levels subdomain (P < 0.001). Conversely, in the hand washing or tooth brushing subdomain, parents' scores tended to be higher than preschoolers' self-reported scores, although this difference was not statistically significant (Table 3).

## Preschooler-parent score differences compared by sex and age

Analysis of preschooler-parent score differences by sex and age showed significant differences by sex only. The mean difference in total HEPS scores was significantly higher for boys (25.0 points) than for girls (20.0 points, P = 0.035). In terms of the subdomains, boys showed a significantly larger discrepancy in the food prefer-

**Table 2.** HEPS difference scores between preschoolers' self-perceptions and parental perceptions

| HEPS | Preschooler | Parent | Difference | P-value[a)] | P-value[b)] |
|---|---|---|---|---|---|
| Total | 248.5±22.9 | 226.1±24.7 | 22.4±18.2 | <0.001 | <0.001 |
| Food preference | 78.2±9.9 | 73.4±10.1 | 4.8±7.6 | <0.001 | <0.001 |
| Food intake level | 85.3±12.4 | 66.9±13.2 | 18.4±12.4 | <0.001 | <0.001 |
| Hand washing | 43.5±5.4 | 43.7±4.5 | −0.2±4.0 | 0.673 | 0.465 |
| Tooth brushing | 41.6±6.3 | 42.2±5.8 | −0.7±4.7 | 0.238 | 0.033 |

Values are presented as mean±standard deviation.
HEPS, Healthy Eating Practice Score.
a)Independent sample t-test for comparing mean scores between preschoolers and parents; b)Paired t-test comparing preschoolers' and parents' scores for each child.

**Table 3.** Comparison of HEPS scores between preschoolers' self-perceptions and parental perceptions stratified by sex and age

| Variable | Preschooler | Parent | Difference | P-value[a)] | P-value[b)] |
|---|---|---|---|---|---|
| Sex | | | | | |
| Boy | | | | | |
| HEPS | 248.8±21.3 | 223.3±24.6 | 25.0±21.0 | <0.001 | <0.001 |
| Food preference | 78.9±9.0 | 72.9±8.9 | 6.0±7.8 | <0.001 | <0.001 |
| Food intake level | 85.8±12.2 | 65.9±12.9 | 19.7±13.9 | <0.001 | <0.001 |
| Hand washing | 43.2±5.9 | 43.1±4.8 | 0.1±4.7 | 0.797 | 0.846 |
| Tooth brushing | 40.9±6.5 | 41.5±6.1 | −0.8±5.3 | 0.421 | 0.089 |
| Girl | | | | | |
| HEPS | 248.2±24.4 | 228.2±25.0 | 20.0±14.9 | <0.001 | <0.001 |
| Food preference | 77.5±10.7 | 73.8±11.0 | 3.7±7.2 | 0.008 | <0.001 |
| Food intake level | 84.7±12.7 | 67.8±13.4 | 17.2±10.8 | <0.001 | <0.001 |
| Hand washing | 43.7±4.9 | 44.3±4.1 | −0.4±3.2 | 0.339 | 0.126 |
| Tooth brushing | 42.2±6.0 | 42.9±5.5 | −0.5±4.2 | 0.375 | 0.202 |
| Age | | | | | |
| ≤4 yr | | | | | |
| HEPS | 247.5±23.3 | 226.0±22.8 | 21.4±18.3 | <0.001 | <0.001 |
| Food preference | 77.4±10.0 | 73.1±9.7 | 4.3±7.6 | <0.001 | <0.001 |
| Food intake level | 84.4±12.7 | 66.5±12.6 | 17.8±12.3 | <0.001 | <0.001 |
| Hand washing | 44.0±5.1 | 44.1±4.1 | −0.1±4.0 | 0.799 | 0.691 |
| Tooth brushing | 41.9±6.3 | 42.4±6.0 | −0.6±4.8 | 0.434 | 0.124 |
| >4 yr | | | | | |
| HEPS | 250.5±22.2 | 226.3±28.8 | 24.6±18.0 | <0.001 | <0.001 |
| Food preference | 80.0±9.5 | 74.1±10.9 | 6.1±7.3 | <0.001 | <0.001 |
| Food intake level | 87.5±11.4 | 67.8±14.5 | 19.7±12.8 | <0.001 | <0.001 |
| Hand washing | 42.3±5.7 | 42.6±5.1 | −0.3±4.0 | 0.694 | 0.467 |
| Tooth brushing | 40.8±6.2 | 41.8±5.5 | −0.8±4.6 | 0.322 | 0.121 |

Values are presented as mean±standard deviation.
HEPS, Healthy Eating Practice Score.
a)Independent sample t-test for comparing mean scores between preschoolers and parents; b)Paired t-test comparing preschoolers' and parents' scores for each child.

ence domain (6.0 points) compared to girls (3.7 points, P=0.017). Conversely, no significant sex differences were observed in food intake level, hand washing, or tooth brushing (P>0.05) (Table 4).

## DISCUSSION

Although parental reports have traditionally been the primary method for assessing children's dietary behaviors, relying solely on them may overlook the significant perceptual differences between parents and children. This study addressed this gap by directly comparing preschoolers' self-perceptions with parental evaluations, thereby providing a more comprehensive basis for pediatric dietary guidance. Overall, preschoolers rated their own dietary practices significantly more positively than their parents, with the largest discrepancy observed in food preferences.

These findings are consistent with previous studies reporting parent-child discrepancies in health behavior perceptions. For example, Lago-Ballesteros et al. [19] found significant differences between adolescents' actual physical activity levels and those perceived by adolescents and their parents, highlighting perceptual gaps in health-related behaviors within families. Although their study focused on physical activity among adolescents rather than dietary habits in preschoolers, it supports the consistency of parent-child perceptual discrepancies across health domains.

These perceptual discrepancies may reflect developmental characteristics of early childhood. Egocentric thinking and positive illusions often lead preschoolers to overestimate their own abilities, contributing to differences between parental and child responses. Supporting this, Venkatesh and DeJesus [20] reported that preschoolers' self-reports on eating behaviors more positively than those of their parents. Similarly, Warren et al. [21] suggested that such overestimation may result from inherent cognitive and reporting limitations in young children. In this study, parent-child discrepancies in HEPS remained highly significant among older preschoolers (>4 years; paired t-test, P<0.001), in whom self-reporting is developmentally more reliable, with a magnitude comparable to that in younger children (≤4 years). This indicates that the observed discrepancy is robust across cognitive developmental phases and is not an artifact of the youngest children's self-reports.

The analysis of perceptual discrepancies by sex showed that parent-child score discrepancies were significantly larger for boys than for girls. This result aligns with the findings of Wrottesley et al. [22], who reported that perceptual differences between children and parents are structurally distinct by sex. This finding may reflect boys' higher activity levels and impulsive tendencies, which may lead to more positive perceptions of their eating habits. Alternatively, it may reflect that parents monitor boys' dietary behaviors more strictly than girls'.

Parents' tendency to evaluate their children's behaviors more negatively than children themselves may reflect higher parental expectations, as Liu et al. [23] and Berge et al. [24] reported that parents with higher health expectations and normative standards tend to assess behaviors more strictly than they are in reality. This aligns with studies by Kwon et al. [25] and Marwaha et al. [26], which frequently observed instances in which parental evaluations did not align with children's actual behaviors or self-perceptions. Specifically, parents may apply more conservative criteria due to concerns about picky eating and inadequate intake, whereas preschoolers interpret their behaviors positively, thereby contributing to significant perceptual gaps.

These findings reveal that close cooperation between families and educational institutions is essential for improving healthy eating practices among preschoolers. Although positive self-perception may motivate children, discrepancies between perception and actual behavior may hinder the development of healthy eating habits. Therefore, parents and educators should understand preschoolers' developmental characteristics and provide age-ap-

**Table 4.** Preschooler-parent score differences compared by sex and age

| HEPS | Sex | | P-value[a)] | Age | | P-value[b)] |
|---|---|---|---|---|---|---|
| | Boy | Girl | | ≤4 yr | >4 yr | |
| Total | 25.0±21.0 | 20.0±14.9 | 0.035 | 21.4±18.3 | 24.6±18.0 | 0.221 |
| Food preference | 6.0±7.8 | 3.7±7.2 | 0.017 | 4.3±7.6 | 6.1±7.3 | 0.096 |
| Food intake level | 19.7±13.9 | 17.2±10.8 | 0.120 | 17.8±12.3 | 19.7±12.8 | 0.283 |
| Hand washing | 0.1±4.7 | −0.4±3.2 | 0.313 | −0.1±4.0 | −0.3±4.0 | 0.693 |
| Tooth brushing | −0.8±5.3 | −0.5±4.2 | 0.553 | −0.6±4.8 | −0.8±4.6 | 0.674 |

Values are presented as mean±standard deviation.
HEPS, Healthy Eating Practice Score.
[a)]Independent sample t-test for comparing mean scores between preschoolers and parents; [b)]Paired t-test comparing preschoolers' and parents' scores for each child.

propriate guidance. Parent education programs that promote objective assessment of their children's dietary development may help reduce the perceptual gap between children and parents through dietary education linked with home-based activities.

### Limitations

This study has several limitations. First, the regional sample of preschoolers and parents may limit the generalizability of the findings to the broader population. Second, self-administered questionnaires may have introduced social desirability bias and recall error. Third, the food intake level subdomain was assessed based on perceptions rather than actual dietary intake, thereby limiting quantitative dietary assessment. The largest parent-child discrepancy was observed in this domain, with children rating their intake substantially higher than their parents did. On the parental side, picky or fussy eating is common among preschoolers and a frequent source of parental concern [24,25]. Parents worried about their child's eating may focus on food refusal and inadequate intake, leading to conservative proxy ratings that reflect feeding concern rather than actual consumption. On the child's side, preschoolers may overestimate their dietary behaviors due to self-presentation and developmental optimism bias, with a tendency to report eating foods and recall preferred or recent meals more readily. These findings indicate that perception-based food intake ratings are subject to systematic biases among reporters, highlighting the need to complement them with objective dietary assessments and to address parental feeding concerns in preschool nutritional interventions. Fourth, this descriptive study did not examine factors potentially associated with the magnitude of parent-child perception discrepancies. These discrepancies may be influenced by a child's weight status (e.g., overweight or obesity), parental feeding attitudes, and the dietary environment. Future studies investigating the relationship between perception discrepancies and clinical growth indicators are warranted. Despite these limitations, this study is among the first to directly compare preschoolers' self-reported dietary perceptions with parental evaluations in a Korean population, providing foundational evidence for dual-perspective approaches in early childhood nutrition assessment. Future studies should include diverse regions and socioeconomic backgrounds to improve the generalizability of the findings. Additionally, future research incorporating observation-based behavioral assessments and objective dietary measures, such as the 24-hour recall method, is needed to determine how parent-child perceptual discrepancies relate to actual nutritional status.

### Conclusion

This study found that preschoolers consistently rated their dietary practices more positively than their parents did, regardless of sex and age, with the largest discrepancies observed in food preferences and intake rather than hygiene-related behaviors. Notably, the perceptual gap was significantly larger in boys than in girls, suggesting sex-specific influences on parent-child discrepancies. These findings highlight the need to incorporate both child and parental perspectives in early childhood dietary assessment. Tailored dietary education programs that address these perceptual gaps may provide practical and policy-relevant evidence for promoting healthy eating habits.

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Conceptualization: KK. Methodology: JA, SL. Validation: KK. Formal analysis: JA. Investigation: all authors. Data curation: all authors. Supervision: KK. Writing - original draft: JA, SL. Writing - review & editing: SL, KK. All authors read and approved the final manuscript.

### Conflict of interest

None.

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None.

### Data availability

The data in this study are available from the corresponding author upon reasonable request.

## REFERENCES

1. Korea Disease Control and Prevention Agency. Current status of obesity prevalence in children and adolescents in Korea [Internet]. Korea Disease Control and Prevention Agency; 2015 [cited 2026 Jan 16]. Available from: https://chs.kdca.go.kr/cdhs/biz/pblcVis/details.do?ctgrSn=31
2. Ministry of Health and Welfare; Korea Centers for Disease Control

and Prevention; Ministry of Education. Increase in chronic diseases such as obesity and hypertension, need to improve health behavior: results of the 2016 Korea National Health and Nutrition Examination Survey and the 2017 Youth Health Behavior Online Survey [Internet]. Ministry of Health and Welfare; 2017 [cited 2026 Jan 16]. Available from: https://www.mohw.go.kr/board.es?act=view&bid=0027&list_no=342756&mid=a10503010100
3. Korea Disease Control and Prevention Agency. Diet and nutrition [Internet]. Korea Disease Control and Prevention Agency; 2023 [cited 2026 Jan 16]. Available from: https://health.kdca.go.kr/healthinfo/biz/health/gnrlzHealthInfo/gnrlzHealthInfo/gnrlzHealthInfoView.do
4. Scudine KG, Castelo PM, Hoppe JP, Portella AK, Silveira PP. Early influences on development of sensory perception and eating habits. Adv Nutr 2024;15:100325.
5. Cheon IA, Han MA, Park J, Choi SW, Ryu SY. The association between parental characteristics and dietary habits of early childhood. J Korean Soc Matern Child Health 2013;17:150-61.
6. Lee E, Park H. The effects mother's nutritional knowledge, eating behavior and eating guidance on their children's picky eating behavior. J Humanit Soc Sci 21 2022;13:2095-110.
7. World Health Organization. Infant and young child feeding [Internet]. World Health Organization; 2023 [cited 2025 Jan 16]. Available from: https://www.who.int/news-room/fact-sheets/detail/infant-and-young-child-feeding
8. Ahn MY. The influence of parents' perceptions of eating habits and dietary practices on young children's eating behaviors. J Korea Inst Inf Electron Commun Technol 2025;18:183-95.
9. Ham J. Study of awareness about the management and guidance of eating habits during early childhood by parents and teachers. J Humanit Soc Sci 21 2019;10:1149-62.
10. Won SI. Assessment of dietary characteristics and eating behavior in children using a dietary screening test. J East Asian Soc Diet Life 2024;34:557-71.
11. Rendall S, Dodd H, Harvey K. Behavioural validation of a parent-report measure of child food fussiness. Appetite 2020;154:104796.
12. Wallace A, Kirkpatrick SI, Darlington G, Haines J. Accuracy of parental reporting of preschoolers' dietary intake using an online self-administered 24-h recall. Nutrients 2018;10:987.
13. Fisher JO, Hughes SO, Miller AL, et al. Characteristics of eating behavior profiles among preschoolers with low-income backgrounds: a person-centered analysis. Int J Behav Nutr Phys Act 2022;19:91.
14. Stage VC, Downing C, Hegde AV, Dev DA, Peterson AD, Goodell LS. Comparison of parent and child ratings of fruit and vegetable liking to assess parent accuracy as proxy reporters. Ecol Food Nutr 2019;58:166-86.
15. Koning M, de Jong A, de Jong E, Visscher TL, Seidell JC, Renders CM. Agreement between parent and child report of physical activity, sedentary and dietary behaviours in 9-12-year-old children and associations with children's weight status. BMC Psychol 2018;6:14.
16. Park D, Gong BJ, Kim D, et al. Development and validation of an illustrated questionnaire on healthy eating practices among Korean preschool children. Nutr Res Pract 2025;19:985-1001.
17. Korea Disease Control and Prevention Agency; The Korean Pediatric Society. 2017 Korean national growth charts for children and adolescents: development and user guide. Korea Disease Control and Prevention Agency; 2017.
18. Han YH, Park D, Kim D, et al. Development and usability evaluation of a web-based healthy eating practice questionnaire for Korean preschool children: a child-parent dyad approach. Nutr Res Pract 2026;20:132-44.
19. Lago-Ballesteros J, Garcia-Pascual M, Gonzalez-Valeiro MA, Fernandez-Villarino MA. Gender influences on physical activity awareness of adolescents and their parents. Int J Environ Res Public Health 2021;18:5707.
20. Venkatesh S, DeJesus JM. Can children report on their own picky eating? Similarities and differences with parent report. Appetite 2022;177:106155.
21. Warren J, Guelinckx I, Livingstone B, et al. Challenges in the assessment of total fluid intake in children and adolescents: a discussion paper. Eur J Nutr 2018;57:43-51.
22. Wrottesley SV, Bosire EN, Mukoma G, et al. Age and gender influence healthy eating and physical activity behaviours in South African adolescents and their caregivers: transforming adolescent lives through nutrition initiative (TALENT). Public Health Nutr 2021;24:5187-206.
23. Liu KS, Chen JY, Sun KS, et al. The knowledge, attitudes, and practices of healthy eating questionnaire: a pilot validation study in Chinese families. Front Public Health 2024;12:1355638.
24. Berge JM, MacLehose RF, Meyer C, Didericksen K, Loth KA, Neumark-Sztainer D. He said, she said: examining parental concordance on home environment factors and adolescent health behaviors and weight status. J Acad Nutr Diet 2016;116:46-60.
25. Kwon KM, Shim JE, Kang M, Paik HY. Association between picky eating behaviors and nutritional status in early childhood: performance of a picky eating behavior questionnaire. Nutrients 2017;9:463.
26. Marwaha S, Goswami M, Vashist B. Prevalence of principles of Piaget's theory among 4-7-year-old children and their correlation with IQ. J Clin Diagn Res 2017;11:ZC111-5.

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CLINICAL NUTRITION RESEARCH

# Prevalence and factors of concurrent wasting and stunting among children aged 6 to 59 months in Cambodia: a cross-sectional study using the Cambodia Demographic and Health Survey 2021–2022

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**Objective:** This study investigated the prevalence and factors of concurrent wasting and stunting (WaSt) in Cambodian children aged 6–59 months.
**Methods:** This cross-sectional analysis of the Cambodia Demographic and Health Survey from 2021 to 2022 included 3,420 children aged 6–59 months and a subsample of 1,237 aged 6–23 months for whom dietary indicators were available. WaSt was defined as height-for-age and weight-for-height z-scores below −2 standard deviations according to the World Health Organization (WHO) Growth Standards. Dietary indicators followed 2021 WHO/UNICEF infant and young child feeding definitions. Survey-weighted logistic regression was employed in Stata 18.0, with statistical significance set at $P<0.05$.
**Results:** The prevalence rates were 22.4% for stunting, 9.3% for wasting, and 2.1% for WaSt. The odds of WaSt were higher among children with low birth weight (adjusted odds ratio [AOR], 4.93; 95% confidence interval [CI], 1.92–12.63), those born to underweight mothers (AOR, 2.42; 95% CI, 1.06–5.56), and those from the poorest wealth tertile (AOR, 2.46; 95% CI, 1.14–5.31). Contrarily, the odds were lower among girls (AOR, 0.52; 95% CI, 0.28–0.97) and children of mothers who were overweight or obese (AOR, 0.25; 95% CI, 0.10–0.65). No dietary indicator was associated with WaSt, although power was limited by few cases (n=21).
**Conclusion:** WaSt was independently associated with low birth weight, maternal underweight, and household poverty, whereas no significant association with dietary indicators was observed. Integrated programs targeting maternal nutrition, birth outcomes, and poverty in vulnerable households are warranted.

**Keywords:** Wasting; Stunting; Cambodia Demographic and Health Survey; Child malnutrition

## INTRODUCTION

To date, child undernutrition remains a major global public health concern. Progress toward achieving international nutrition targets has been slow, with an estimated 150.2 million children aged <5 years affected by stunting and 42.8 million by wasting [1,2]. Beyond these two conditions individually, researchers have increasingly focused on concurrent wasting and stunting (WaSt), defined as the coexistence of wasting (weight-for-height z-score [WHZ], <−2) and stunting (height-for-age z-score [HAZ], <−2) [3,4]. As it combines acute and chronic growth failure, WaSt represents one of the most severe forms of undernutrition.

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Over the past two decades, Cambodia has achieved substantial reductions in stunting. The Cambodia Demographic and Health Survey (CDHS) 2021–2022 showed that the prevalence of stunting decreased from roughly 32% in 2014 to approximately 22% in 2021–2022. However, wasting has barely changed, remaining at around 10%, a level still considered high for the region [5,6]. Recent national and international reports present a similar picture, in which chronic undernutrition has improved over time while acute undernutrition continues to persist [7]. In other words, many Cambodian children continue to face several nutritional risks at once.

Child growth is influenced by factors operating at several levels. At the individual level, age (particularly between 6 and 23 months), sex, birth weight, recent illness, and feeding practices can directly affect nutritional status. Household circumstances, such as poverty, food insecurity, limited access to clean water, and poor sanitation, further increase the risk of impaired growth. Maternal characteristics, including a mother's nutritional status, education, and general health, also influence the child's development [8-10]. Although WaSt are frequently studied as separate problems, a growing body of evidence indicates that they share common underlying causes and often occur together, particularly in younger children and those exposed to repeated infections [8-10].

Children affected by WaSt face a significantly higher risk of poor health. Compared with children who have only one form of undernutrition, those with WaSt have greater morbidity and a markedly higher risk of death [3,11]. Although wasting alone can rapidly fluctuate, its coexistence with stunting signals more prolonged deprivation and vulnerability. However, most nutrition programs and surveillance systems still treat WaSt as distinct conditions, which means children with WaSt may go unrecognized and untreated.

This gap in identification and management has practical consequences for prevention and treatment. Earlier studies have associated WaSt with numerous factors, including low birth weight, male sex, frequent infections, poor complementary feeding, short birth intervals, and low maternal educational level and household wealth [8,12]. Nevertheless, the evidence base for WaSt remains limited, and few studies in Cambodia have used recent nationally representative data.

Against this background, a clearer understanding of the burden and determinants of WaSt in Cambodia is needed. Drawing on the CDHS 2021–2022 data, this study aimed to investigate the factors associated with WaSt among children aged 6–59 months. The findings are intended to inform more integrated nutrition policies and interventions that address WaSt, with particular attention to vulnerable groups, such as children aged 6–23 months [5,7]. This period is also a critical window for growth faltering: linear growth steeply deteriorates over the first 24 months of life, the same interval in which complementary foods are introduced and infant feeding practices exert their greatest influence on growth [13]. As WaSt incorporates a chronic (stunting) component, this is the window in which the association between diet and WaSt is most likely to be detectable.

### Objectives

This study aimed to examine the factors associated with WaSt among children aged 6–59 months in Cambodia using data from CDHS 2021–2022.

Specifically, this study aimed as follows: (1) to determine the prevalence of stunting, wasting, and WaSt among children aged 6–59 months in Cambodia; (2) to identify sociodemographic, maternal, child, and household environmental factors associated with WaSt among children aged 6–59 months in Cambodia; (3) to explore the association of dietary diversity and meal frequency with WaSt in children aged 6–23 months in Cambodia.

## METHODS

### Ethics statement

This study was approved by the Institutional Review Board of Sungshin Women's University (No. SSWUIRB-2026-003). The study was a secondary analysis of publicly available data from the CDHS. Permission to use the dataset was obtained from the Demographic and Health Surveys (DHS) program. Informed consent was obtained by the original survey organizers from the participants. However, the requirement for additional informed consent was waived. All data were anonymized before access, and no identifiable information was available to the researchers. All procedures were performed in accordance with the principles of the Declaration of Helsinki. This study was reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

### Study design and setting

This study was a cross-sectional secondary analysis of data obtained from CDHS 2021–2022 [5]. The CDHS is a nationally representative household survey conducted to obtain information on population health, nutrition, and demographic indicators. The survey was conducted across urban and rural areas in Cambodia using a stratified two-stage cluster sampling design. Data were collected between June 15, 2021, and January 30, 2022, by trained fieldworkers using standardized questionnaires. The present study used data on children aged < 5 years and their mothers to evaluate the factors associated with WaSt among children aged 6–59 months in Cambodia.

## Participants

The analytical sample was drawn from the Children's Recode file of the CDHS 2021–2022, which contains records of all living children aged < 5 years born to interviewed women. Anthropometric measurements in CDHS 2021–2022 were performed only among children aged 6–59 months. Younger infants were ineligible for anthropometric assessment and therefore excluded from the analysis. Children were eligible for inclusion if they (1) were aged 6–59 months at the time of the survey; (2) had valid anthropometric measurements; and (3) had HAZ and WHZ within the plausible range of −6 to +6 standard deviations (SDs) recommended by the World Health Organization (WHO). Children with missing or biologically implausible HAZ or WHZ were excluded. All children in the CDHS anthropometry subsample were living with their mothers; therefore, no further exclusion was required for linking maternal variables.

The CDHS 2021–2022 Children's Recode file included 3,544 children aged 6–59 months with measured anthropometry. After excluding 124 children (3.5%) with missing or biologically implausible HAZ or WHZ (outside ± 6 SD of the WHO median), 3,420 children remained in the main analytical sample for the prevalence and multivariable analyses (objectives 1 and 2). For the sub-analysis of dietary indicators (objective 3), the sample was further restricted to children aged 6–23 months within the analytical sample (n = 1,237), according to the WHO/United Nations Children's Fund (UNICEF) guidance [14] and DHS, phase 8 (DHS-8) protocol [5]. A flow diagram of participant selection is shown in Fig. 1.

## Data sources and measurement

All data were obtained from the publicly available CDHS 2021–2022 standard recode files, including the Children's Recode file, provided by the DHS program. Anthropometric measurements were obtained by trained CDHS field staff using standardized procedures consistent with WHO recommendations: recumbent length was measured for children aged < 24 months and standing height for children aged ≥ 24 months, and weight was measured to the nearest 0.1 kg using SECA digital scales. WHO-standardized HAZ and WHZ provided in the CDHS dataset (variables HW70 and HW72, divided by 100) were used to calculate stunting, wasting, and WaSt according to the WHO 2006 Child Growth Standards [15].

Birth weight was based on either a written record (e.g., health card) or maternal recall. Maternal anthropometry (height, weight, body mass index [BMI]) was measured during the survey by trained interviewers. Household wealth was assessed using the DHS-constructed wealth index, a composite indicator derived from principal component analysis of household assets, dwelling characteristics, and access to utilities. Water source and sanitation facility variables were classified as improved or unimproved according to the WHO/UNICEF Joint Monitoring Programme (JMP) ladder. Dietary indicators were derived from 24-hour dietary recall data following the 2021 WHO/UNICEF revised indi-

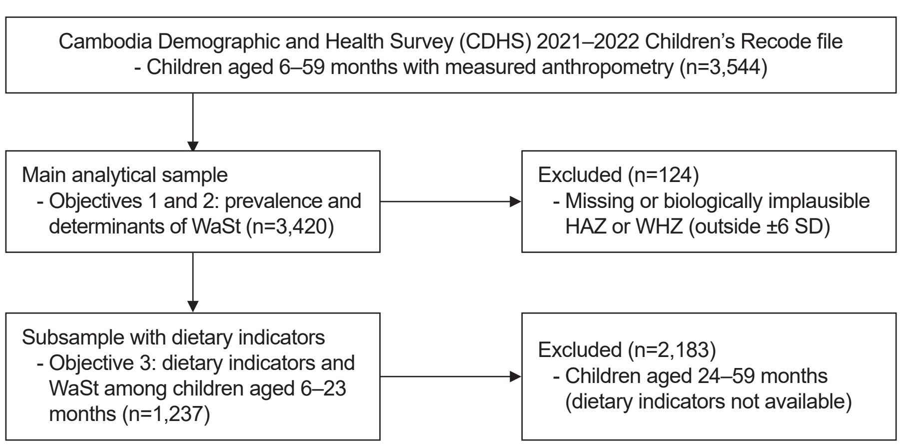


**Fig. 1.** Participant selection flowchart. WaSt, wasting and stunting; HAZ, height-for-age z-score; WHZ, weight-for-height z-score; SD, standard deviation.

cator definitions (DHS-8 methodology) [14].

## Variables

The primary outcome was WaSt, defined as a binary indicator with a value of 1 if a child had WHZ $< -2$ SD and HAZ $< -2$ SD according to the WHO Child Growth Standards (2006) and 0 otherwise. Stunting (HAZ $< -2$ SD) and wasting (WHZ $< -2$ SD) were also separately examined to establish prevalence.

Independent variables were selected based on the UNICEF conceptual framework for child undernutrition and previous evidence on the determinants of WaSt and were grouped into four domains:

(1) Child-level factors: age (6–11, 12–23, 24–35, 36–47, and 48–59 months), sex (male/female), birth weight (normal, $\geq 2{,}500$ g; low, $< 2{,}500$ g; missing/don't know retained as a category), and breastfeeding status (currently breastfeeding, ever breastfed but not current, never breastfed)—examined for the youngest children only (n = 1,902), per DHS design.

(2) Maternal factors: maternal age at child's birth (quartiles: 14–23, 24–27, 28–32, and 33–49 years), maternal education (no education, primary, secondary, or higher—secondary and higher were combined due to the small number of participants), maternal BMI (underweight, $< 18.5$ kg/m$^2$; normal, 18.5–24.9 kg/m$^2$; overweight/obese, $\geq 25.0$ kg/m$^2$—pregnant women excluded), and number of antenatal care visits ($\geq 4$, 1–3, missing retained as a category).

(3) Household factors: place of residence (urban/rural), wealth index (recategorized into three groups—poorest, poorer, and middle or above—to ensure adequate cell counts for the rare WaSt outcome), source of drinking water (improved/unimproved, per WHO/UNICEF JMP criteria), and sanitation facility (improved, unimproved, open defecation).

(4) Dietary indicators (available for children aged 6–23 months only): three diet indicators, based on the standard WHO/UNICEF infant and young child feeding indicator definitions (DHS-8 methodology), were derived from maternal 24-hour dietary recall data. These indicators were available only for children aged 6–23 months. First, each child's food intake during the previous 24 hours was classified into eight groups: (1) breast milk; (2) grains, white roots, and tubers (including bread, noodles, rice-based products, plantains, potatoes, and cassava); (3) legumes and nuts (combined into a single variable in the CDHS questionnaire); (4) dairy products (cow milk, infant formula, yogurt, and cheese); (5) flesh foods (meat, poultry, fish, organ meats, and processed meats, including sausages and ham); (6) eggs; (7) vitamin A–rich fruits and vegetables (pumpkin, carrots, squash, dark green leafy vegetables, sweet leaf bush, cassava leaves) and vitamin A–rich fruits such as mangoes and papayas; and (8) other fruits and vegetables. According to the WHO/DHS-8 guideline, a food group was considered consumed if the child had consumed any amount of food belonging to that group within the previous 24 hours; no minimum quantity threshold was applied. For each child, a food group score ranging from 0 to 8 was generated by summing the number of food groups consumed.

Subsequently, three binary dietary indicators were established using standard WHO/UNICEF cut-off points: (1) minimum dietary diversity (MDD) was defined as consumption of five or more of the eight food groups within the previous 24 hours; children who met this threshold were coded as 1 and all the other children as 0. (2) Minimum meal frequency (MMF) was defined according to age and breastfeeding status: $\geq 2$ solid, semi-solid, or soft feeds for breastfed children aged 6–8 months; $\geq 3$ such feeds for breastfed children aged 9–23 months; and $\geq 4$ feeds in total (combining solid meals and milk feeds) with at least two milk feeds for nonbreastfed children aged 6–23 months. Children who met the relevant age- and feeding status–specific threshold were coded as 1 and all the other children as 0. (3) Minimum acceptable diet (MAD), a composite summary indicator of overall diet adequacy that combines dietary diversity and feeding frequency into a single measure of whether a child received a minimally adequate diet, was defined as meeting the MDD and MMF simultaneously [14]. In addition, the food group score (0–8) was categorized into three levels (0–2, 3–4, and $\geq 5$ groups [MDD met]) to evaluate potential dose–response relationship with WaSt.

## Statistical analysis

All analyses were conducted using Stata ver. 18.0 (StataCorp LLC). To account for the complex multi-stage stratified cluster sampling design of the CDHS, survey weights were applied throughout the analyses. All the reported prevalence estimates, confidence intervals (CIs), and regression coefficients were survey-weighted.

Unweighted frequencies and weighted percentages were calculated for categorical variables. Children were classified into four mutually exclusive nutritional status groups (normal, stunting only, wasting only, and WaSt). Differences in participant characteristics across these groups were assessed using the Rao-Scott design-based F test, a survey-adjusted version of Pearson chi-squared test that accounts for the complex sampling design. The prevalence of stunting, wasting, and WaSt with 95% CIs were estimated using survey-weighted proportions. Associations between each independent variable and WaSt were first evaluated via survey-weighted simple (unadjusted) logistic regression to obtain crude odds ratios (CORs) with 95% CIs. Reference categories for categorical variables were selected according to conventions used in published WaSt research: the oldest age group (48–59 months) for child age; male for sex; normal birth weight (≥2,500 g) for birth weight; secondary or higher for maternal education; normal BMI (18.5–24.9 kg/m²) for maternal BMI; middle or above for household wealth; urban for residence; and improved for water source and sanitation. For ordinal categorical variables (age group, maternal age quartiles, maternal education, BMI, antenatal care visits, wealth index, and food group score categories), tests for linear trend (P-trend) were conducted by entering the variable in its ordinal form.

WaSt-associated variables at $P < 0.20$ in the bivariate analysis [16], alongside variables considered theoretically important based on the UNICEF conceptual framework [17], were entered into a multivariable survey-weighted logistic regression model to identify independent factors associated with WaSt. Adjusted odds ratios (AORs) with 95% CIs were reported, and statistical significance was set at $P < 0.05$ (two-sided). Breastfeeding was evaluated only in the bivariate analysis as data were available only for the youngest coresident children (n = 1,902).

For the subsample with dietary indicators of children aged 6–23 months (n = 1,237), the associations between MDD, MMF, MAD, and the food group score categories and WaSt were evaluated using survey-weighted logistic regression. Owing to the small number of WaSt cases in this age subgroup (n = 21), models were adjusted for a parsimonious set of covariates (child age in months as a continuous variable, child sex, and the three-category household wealth index) to avoid model overfitting.

Variables with substantial missingness (birth weight, 45.5%; antenatal care visits, 47.8%) were retained in the analysis, with "missing" coded as an explicit category, rather than excluding observations, to preserve statistical power and minimize selection bias caused by nonrandom missingness. No imputation was performed.

## RESULTS

### Descriptive data

The characteristics of the 3,420 children by nutritional status group are shown in Table 1. The four groups were mutually exclusive; thus, children with WaSt were counted only in the WaSt category. Therefore, the overall prevalence rates were 22.4% for stunting and 9.3% for wasting, consistent with Table 2. Overall, 70.5% of the children were normal, 20.3% stunted only, 7.2% wasted only, and 2.1% WaSt.

Nutritional status varied by child age and sex ($P = 0.030$ and $P = 0.002$, respectively). WaSt was uncommon during infancy and became more common after the age of 12 months. Furthermore, boys were more frequently affected than girls across all three abnormal categories, including WaSt (2.7% vs. 1.5%).

Birth weight and maternal nutritional status exhibited the steepest gradients. WaSt was observed in 7.2% of children with low birth weight, compared with 1.5% of those with normal birth weight ($P = 0.019$), and in 5.7% of children of underweight mothers but only 0.6% of those of overweight or obese mothers ($P < 0.001$).

Likewise, a socioeconomic gradient was evident. WaSt increased from 1.1% among children in households of middle wealth or above to 4.7% in the poorest households ($P < 0.001$). Moreover, undernutrition became more common as maternal educational level declined ($P < 0.001$). Children living in rural areas, using unimproved water sources, and lacking improved sanitation ($P = 0.002$, $P < 0.001$, and $P = 0.001$, respectively) were also more frequently affected, although some categories included few children. Nutritional status did not differ by maternal age or antenatal care visits ($P = 0.432$ and $P = 0.332$, respectively). Therefore, children with WaSt clustered among those with low birth weight, undernourished mothers, and the poorest, least-educated households.

The dietary characteristics of the 1,237 children aged 6–23 months are presented in Table 3. Just under half met the criteria for MDD (49.1%), whereas 80.3% and 43.7% met the MMF and MAD, respectively. Among the eight food groups, grains, roots, and tubers were the most commonly consumed (91.7%), followed by flesh foods (75.9%), vitamin A–rich fruits and vegetables (56.1%), and dairy products (54.4%). Legumes and nuts were the least-consumed food group (2.3%).

### Outcome data

Of the 3,420 children in the main analytical sample, 765 were stunted, 317 were wasted, and 72 had WaSt. In the subsample with dietary indicators of 1,237 children aged 6–23 months, 21 had WaSt.

**Table 1.** Characteristics of children aged 6–59 months by nutritional status, Cambodia Demographic and Health Survey 2021–2022 (n=3,420)

| Characteristic | Total sample | Normal (%) | Stunting only (%) | Wasting only (%) | WaSt (%) | P-value[a)] |
|---|---|---|---|---|---|---|
| All children | 3,420 (100) | 70.5 | 20.3 | 7.2 | 2.1 | - |
| Child age (mo) | | | | | | 0.030 |
| 6–11 | 399 (12.2) | 76.6 | 12.7 | 9.9 | 0.8 | |
| 12–23 | 838 (24.1) | 68.0 | 25.1 | 4.7 | 2.2 | |
| 24–35 | 665 (20.1) | 68.7 | 21.2 | 8.0 | 2.0 | |
| 36–47 | 762 (21.9) | 71.2 | 19.2 | 7.1 | 2.5 | |
| 48–59 | 756 (21.8) | 70.6 | 19.3 | 7.6 | 2.4 | |
| Child sex | | | | | | 0.002 |
| Male | 1,738 (50.4) | 66.9 | 22.1 | 8.3 | 2.7 | |
| Female | 1,682 (49.6) | 74.1 | 18.4 | 6.0 | 1.5 | |
| Birth weight (g) | | | | | | 0.019 |
| Normal (≥2,500) | 1,699 (51.2) | 70.7 | 20.6 | 7.2 | 1.5 | |
| Low (<2,500) | 125 (3.3) | 59.8 | 28.2 | 4.8 | 7.2 | |
| Missing/don't know | 1,596 (45.5) | 70.9 | 19.4 | 7.2 | 2.5 | |
| Maternal age at birth (yr)[b)] | | | | | | 0.432 |
| 14–23 | 842 (23.9) | 70.0 | 22.7 | 5.7 | 1.6 | |
| 24–27 | 661 (23.2) | 71.7 | 19.0 | 6.9 | 2.4 | |
| 28–32 | 713 (26.2) | 72.2 | 18.1 | 7.2 | 2.6 | |
| 33–49 | 716 (26.7) | 67.8 | 20.9 | 9.4 | 1.9 | |
| Maternal education | | | | | | <0.001 |
| No education | 453 (10.3) | 59.3 | 24.3 | 12.2 | 4.1 | |
| Primary | 1,466 (42.2) | 65.6 | 24.1 | 7.5 | 2.7 | |
| Secondary or higher | 1,501 (47.4) | 77.2 | 16.0 | 5.7 | 1.1 | |
| Maternal BMI (kg/m²)[c)] | | | | | | <0.001 |
| Underweight (<18.5) | 221 (7.1) | 52.8 | 26.7 | 14.8 | 5.7 | |
| Normal (18.5–24.9) | 2,148 (65.0) | 71.1 | 19.1 | 7.5 | 2.4 | |
| Overweight/obese (≥25.0) | 849 (28.0) | 74.0 | 20.7 | 4.7 | 0.6 | |
| Antenatal care visits | | | | | | 0.332 |
| ≥4 | 1,475 (45.8) | 70.8 | 20.8 | 6.6 | 1.8 | |
| 1–3 | 272 (6.4) | 63.6 | 22.3 | 11.8 | 2.4 | |
| None/missing | 1,673 (47.8) | 71.1 | 19.5 | 7.1 | 2.4 | |
| Place of residence | | | | | | 0.002 |
| Urban | 1,139 (38.5) | 76.4 | 15.8 | 6.7 | 1.2 | |
| Rural | 2,281 (61.5) | 66.8 | 23.1 | 7.4 | 2.7 | |
| Household wealth index | | | | | | <0.001 |
| Poorest | 1,076 (22.9) | 61.1 | 27.4 | 6.9 | 4.7 | |
| Poorer | 620 (19.1) | 68.2 | 21.5 | 8.2 | 2.0 | |
| Middle or above | 1,724 (58.0) | 74.9 | 17.1 | 6.9 | 1.1 | |
| Drinking water source | | | | | | <0.001 |
| Improved | 2,765 (85.8) | 71.9 | 19.2 | 7.2 | 1.8 | |
| Unimproved | 644 (14.2) | 60.8 | 27.5 | 7.5 | 4.3 | |
| Sanitation facility | | | | | | 0.001 |
| Improved | 2,758 (87.4) | 71.7 | 19.4 | 7.1 | 1.9 | |
| Unimproved | 32 (0.7) | 63.9 | 26.6 | 2.4 | 7.1 | |
| Open defecation | 616 (12.0) | 60.3 | 27.5 | 8.4 | 3.7 | |

Values in the total sample column are unweighted number (weighted %). Values in the normal, stunting only, wasting only, and WaSt columns are survey-weighted row percentages (the prevalence of each nutritional status within the characteristic category); rows sum to approximately 100% across the four groups. Percentages may not sum to 100% because of rounding, and denominators vary slightly across characteristics because of item missingness. Nutritional status groups are mutually exclusive: normal, neither stunted nor wasted; stunting only, HAZ <−2 without wasting; wasting only, WHZ <−2 without stunting; WaSt, concurrent WaSt (HAZ <−2 and WHZ <−2).

WaSt, wasting and stunting; BMI, body mass index; WHZ, weight-for-height z-score; HAZ, height-for-age z-score.

[a)]P-value from the Rao-Scott design-based F test (survey-adjusted Pearson chi-square) for the association between the characteristic and nutritional status group. [b)]Maternal age at the child's birth, categorized into quartiles. [c)]Maternal BMI; pregnant women were excluded.

**Table 2.** Survey-weighted prevalence of stunting, wasting, and WaSt among Cambodian children aged 6–59 months, CDHS 2021–2022 (n=3,420)

| Characteristic | Stunting | | Wasting | | WaSt | |
|---|---|---|---|---|---|---|
| | Weighted % (95% CI) | P-value | Weighted % (95% CI) | P-value | Weighted % (95% CI) | P-value |
| Overall | 22.4 (20.4–24.5) | - | 9.3 (7.9–10.8) | - | 2.1 (1.6–2.8) | - |
| Sex | | 0.003 | | 0.008 | | 0.042 |
| Male | 24.8 (22.1–27.6) | | 11.0 (9.0–13.4) | | 2.7 (1.9–3.8) | |
| Female | 19.9 (17.6–22.5) | | 7.5 (6.0–9.3) | | 1.5 (1.0–2.4) | |
| Age (mo) | | <0.001 | | 0.447 | | 0.555 |
| 6–11 | 13.5 (9.8–18.3) | | 10.7 (7.1–15.8) | | 0.8 (0.2–2.4) | |
| 12–23 | 27.3 (23.4–31.6) | | 6.9 (5.2–9.2) | | 2.2 (1.3–3.7) | |
| 24–35 | 23.3 (19.2–28.0) | | 10.0 (6.4–15.5) | | 2.0 (1.0–4.0) | |
| 36–47 | 21.7 (18.5–25.2) | | 9.6 (7.2–12.6) | | 2.5 (1.4–4.2) | |
| 48–59 | 21.8 (18.3–25.7) | | 10.1 (7.6–13.2) | | 2.4 (1.3–4.6) | |

Values are presented as survey-weighted percentage (95% CI). Stunting, HAZ <−2 SD; Wasting, WHZ <−2 SD; WaSt, HAZ <−2 SD and WHZ <−2 SD per WHO Child Growth Standards (2006) [15]. P-values were obtained from the design-based Rao-Scott $\chi^2$ test, which accounts for the complex multi-stage stratified cluster sampling design of the CDHS.
WaSt, concurrent wasting and stunting; CDHS, Cambodia Demographic and Health Survey; CI, confidence interval; HAZ, height-for-age z-score; WHZ, weight-for-height z-score.

**Table 3.** Dietary characteristics of children aged 6–23 months in the Cambodia Demographic and Health Survey 2021–2022 (n=1,237)

| Dietary characteristic | No. of participants | Weighted % (95% CI) |
|---|---|---|
| Dietary indicator | | |
| MDD[a)] | 565 | 49.1 (45.4–52.7) |
| MMF[b)] | 1,016 | 80.3 (77.1–83.2) |
| MAD[c)] | 500 | 43.7 (39.9–47.5) |
| Food group score category | | |
| 0–2 food groups | 187 | 14.5 (12.3–17.0) |
| 3–4 food groups | 485 | 36.5 (33.1–40.0) |
| ≥5 food groups (MDD met) | 565 | 49.1 (45.4–52.7) |
| Individual food groups consumed (DHS-8) | | |
| Breast milk | 711 | 51.4 (47.7–55.2) |
| Grains, roots, and tubers | 1,143 | 91.7 (89.6–93.5) |
| Legumes and nuts | 21 | 2.3 (1.3–4.3) |
| Dairy products | 584 | 54.4 (50.9–57.9) |
| Flesh foods | 926 | 75.9 (72.8–78.8) |
| Eggs | 512 | 43.3 (39.5–47.2) |
| Vitamin A–rich fruits/vegetables | 660 | 56.1 (52.2–60.0) |
| Other fruits and vegetables | 585 | 48.8 (45.5–52.1) |

Values are presented as unweighted number and survey-weighted percentage (95% CI). Food group consumption refers to the 24 hours preceding the survey.
CI, confidence interval; MDD, minimum dietary diversity; MMF, minimum meal frequency; MAD, minimum acceptable diet; DHS-8, Demographic and Health Surveys, phase 8.
[a)]MDD: consumption of ≥5 of 8 food groups in the previous 24 hours; [b)]MMF: ≥2 feeds (breastfed, 6–8 months), ≥3 feeds (breastfed, 9–23 months), ≥4 feeds with ≥2 milk feeds (nonbreastfed, 6–23 months); [c)]MAD: meeting both MDD and MMF.

## Main results

### *Prevalence of stunting, wasting, and WaSt*

The survey-weighted prevalence of stunting was 22.4% (95% CI, 20.4%–24.5%), wasting 9.3% (95% CI, 7.9%–10.8%), and WaSt 2.1% (95% CI, 1.6%–2.8%) (Table 2). All three forms of undernutrition were more prevalent in male than in female children: stunting (24.8% vs. 19.9%, P = 0.003), wasting (11.0% vs. 7.5%, P = 0.008), and WaSt (2.7% vs. 1.5%, P = 0.042). Stunting prevalence significantly varied by age (P < 0.001), being lowest at 6–11 months (13.5%) and highest at 12–23 months (27.3%). Contrarily, wasting and WaSt did not significantly differ across the age groups (P = 0.447 and P = 0.555, respectively).

*Factors associated with WaSt*

The crude and adjusted associations between child, maternal, and household characteristics and WaSt are shown in Table 4. In the unadjusted analysis, female sex (COR, 0.55; 95% CI, 0.31–0.99), low birth weight (COR, 5.21; 95% CI, 2.06–13.18), lack of maternal education (COR, 3.85; 95% CI, 1.61–9.20), maternal underweight (COR, 2.50; 95% CI, 1.06–5.92), rural residence (COR, 2.39; 95% CI, 1.03–5.51), belonging to the poorest wealth tertile (COR, 4.27; 95% CI, 2.14–8.54), unimproved drinking water (COR, 2.51; 95% CI, 1.31–4.82), and open defecation (COR, 2.02; 95% CI, 1.02–4.00) exhibited significant association with WaSt. Significant linear trends were observed across maternal education, maternal BMI, and household wealth (all $P < 0.001$).

In the multivariable model (n = 3,205), four factors remained independently associated with WaSt. Female children had lower odds than males (AOR, 0.52; 95% CI, 0.28–0.97; $P = 0.041$). Low birth weight was the strongest predictor (AOR, 4.93; 95% CI, 1.92–12.63; $P = 0.001$). Maternal underweight was associated with higher odds of WaSt (AOR, 2.42; 95% CI, 1.06–5.56; $P = 0.037$), whereas maternal overweight or obesity was associated with lower odds (AOR, 0.25; 95% CI, 0.10–0.65; $P = 0.004$), relative to normal maternal BMI. Children from the poorest households had more than two-fold higher odds of WaSt than those from middle-or-above households (AOR, 2.46; 95% CI, 1.14–5.31; $P = 0.022$). The associations of maternal education, rural residence, and open defecation were attenuated and lost statistical significance after adjustment, indicating that their crude effects were partially explained by household wealth and maternal nutritional status.

*Dietary indicators and WaSt among children aged 6–23 months*

The crude and adjusted associations between dietary indicators and WaSt are shown in Table 5. None of the dietary indicators exhibited significant association with WaSt in either the unadjusted or adjusted analyses. After adjustment for child age, sex, household wealth, maternal BMI, and maternal education, meeting the MDD (AOR, 0.58; 95% CI, 0.19–1.78; $P = 0.343$), MMF (AOR, 3.07; 95% CI, 0.75–12.63; $P = 0.119$), and MAD (AOR, 0.88; 95% CI, 0.28–2.80; $P = 0.835$) was not significantly associated with WaSt, and the food group score category showed no dose–response relationship (≥ 5 vs. 0–2 groups: AOR, 0.63; 95% CI, 0.12–3.22; $P = 0.581$). In these models, maternal underweight remained significantly associated with higher odds of WaSt and household wealth with markedly higher odds among the poorest children, although the wide CIs reflect the small number of WaSt cases (n = 21) in this subsample and should be cautiously interpreted.

## DISCUSSION

This study investigated the prevalence of WaSt and its associated factors among Cambodian children aged 6–59 months using nationally representative CDHS 2021–2022 data. The prevalence of WaSt was 2.1%, with stunting affecting 22.4% and wasting 9.3% of children. The multivariable analysis revealed that low birth weight, maternal underweight, and belonging to the poorest households were independently associated with higher odds of WaSt, whereas female sex and maternal overweight or obesity were associated with lower odds. Notably, none of the dietary indicators (MDD, MMF, and MAD) exhibited an association with WaSt among children aged 6–23 months.

The WaSt prevalence of 2.1% observed in this study is comparable to the 2.4% reported among Indonesian children aged 6–23 months using a similar national survey [18] and is consistent with the global pooled WaSt prevalence of approximately 3.5%, which tends to be higher in Asia (approximately 5%) than in other regions [19]. It is lower than estimates from several other settings, including Mozambique (3.5%) [4] and Ethiopia (4.7%–5.8%) [10,12]. The relatively lower prevalence in Cambodia may reflect the country's substantial progress in reducing stunting over the past decade. However, the persistently high wasting prevalence of around 10% indicates that acute undernutrition remains an unresolved problem. Collectively, these patterns indicate a continuing nutritional transition for Cambodia, with longer-term reductions in stunting outpacing those in wasting. Over the past two decades, Cambodia's rapid economic growth, urbanization, and gains in maternal education, sanitation, and access to clean water have resulted in a dramatic reduction in chronic undernutrition [5,20]. However, wasting has remained at approximately 10% over the same period [6], reflecting its closer dependence on more acute and episodic factors, such as recent illness, seasonal food insecurity, and complementary feeding practices, which have not improved at the same pace. National data also indicate that fewer than half of Cambodian children aged 6–23 months meet the MAD criteria, and these feeding patterns have demonstrated slight improvement in the past decade [21]. Similarly, a regional review of six Southeast Asian countries reported a pooled WaSt prevalence of 1.6% alongside a persistent wasting burden of 8.9%, noting that wasting has received less programmatic attention than stunting despite its greater risk of short-term mortality [15]. This pattern suggests that conventional nutrition programs centered

**Table 4.** Crude and adjusted associations between child, maternal, and household characteristics and concurrent wasting and stunting among Cambodian children aged 6–59 months, CDHS 2021–2022

| Variable | COR (95% CI) | P-value | AOR (95% CI) | P-value |
|---|---|---|---|---|
| Child age (mo) (P-trend=0.154) | | | | |
| 48–59 | 1.00 (Reference) | - | 1.00 (Reference) | - |
| 36–47 | 1.00 (0.41–2.45) | 0.991 | 0.79 (0.31–2.04) | 0.632 |
| 24–35 | 0.83 (0.32–2.17) | 0.708 | 0.66 (0.15–2.90) | 0.577 |
| 12–23 | 0.90 (0.40–2.01) | 0.798 | 0.76 (0.17–3.48) | 0.728 |
| 6–11 | 0.31 (0.08–1.18) | 0.086 | 0.24 (0.04–1.46) | 0.121 |
| Child sex | | | | |
| Male | 1.00 (Reference) | - | 1.00 (Reference) | - |
| Female | 0.55 (0.31–0.99) | 0.045 | 0.52 (0.28–0.97) | 0.041 |
| Birth weight | | | | |
| Normal (≥2,500 g) | 1.00 (Reference) | - | 1.00 (Reference) | - |
| Low (<2,500 g) | 5.21 (2.06–13.18) | 0.001 | 4.93 (1.92–12.63) | 0.001 |
| Missing/don’t know | 1.71 (0.92–3.20) | 0.091 | 1.21 (0.27–5.50) | 0.801 |
| Maternal age at birth (yr) (P-trend=0.724) | | | | |
| 24–27 | 1.00 (Reference) | - | - | - |
| 14–23 | 0.66 (0.29–1.50) | 0.322 | - | - |
| 28–32 | 1.08 (0.45–2.57) | 0.870 | - | - |
| 33–49 | 0.78 (0.33–1.82) | 0.566 | - | - |
| Maternal education (P-trend<0.001) | | | | |
| Secondary or higher | 1.00 (Reference) | - | 1.00 (Reference) | - |
| Primary | 2.54 (1.17–5.51) | 0.019 | 1.94 (0.89–4.26) | 0.098 |
| No education | 3.85 (1.61–9.20) | 0.003 | 2.62 (0.91–7.50) | 0.074 |
| Maternal BMI (kg/m²) (P-trend<0.001) | | | | |
| Normal (18.5–24.9) | 1.00 (Reference) | - | 1.00 (Reference) | - |
| Underweight (<18.5) | 2.50 (1.06–5.92) | 0.037 | 2.42 (1.06–5.56) | 0.037 |
| Overweight/obese (≥25.0) | 0.25 (0.10–0.64) | 0.004 | 0.25 (0.10–0.65) | 0.004 |
| Antenatal care visits (P-trend=0.303) | | | | |
| ≥4 | 1.00 (Reference) | - | - | - |
| 1–3 | 1.34 (0.46–3.93) | 0.591 | - | - |
| None/missing | 1.37 (0.75–2.48) | 0.302 | - | - |
| Place of residence | | | | |
| Urban | 1.00 (Reference) | - | 1.00 (Reference) | - |
| Rural | 2.39 (1.03–5.51) | 0.042 | 1.33 (0.59–3.00) | 0.494 |
| Household wealth index (P-trend<0.001) | | | | |
| Middle or above | 1.00 (Reference) | - | 1.00 (Reference) | - |
| Poorer | 1.77 (0.76–4.10) | 0.185 | 1.15 (0.50–2.68) | 0.741 |
| Poorest | 4.27 (2.14–8.54) | <0.001 | 2.46 (1.14–5.31) | 0.022 |
| Drinking water source | | | | |
| Improved | 1.00 (Reference) | - | - | - |
| Unimproved | 2.51 (1.31–4.82) | 0.006 | - | - |
| Sanitation facility | | | | |
| Improved | 1.00 (Reference) | - | 1.00 (Reference) | - |
| Unimproved | 4.00 (0.58–27.81) | 0.161 | 3.66 (0.68–19.73) | 0.131 |
| Open defecation | 2.02 (1.02–4.00) | 0.045 | 0.72 (0.33–1.58) | 0.415 |
| Breastfeeding status[a)] | | | | |
| Currently breastfeeding | 1.00 (Reference) | - | - | - |
| Ever breastfed, not current | 0.47 (0.20–1.11) | 0.086 | - | - |
| Never breastfed | 0.44 (0.11–1.85) | 0.264 | - | - |

Values are odds ratio (95% CI) from survey-weighted logistic regression accounting for the complex multi-stage stratified cluster sampling design of CDHS 2021–2022. Crude odds ratios (COR) are from simple (unadjusted) logistic regression. Adjusted odds ratios (AOR) are from a single multivariable model (n=3,205) mutually adjusting for child age, sex, birth weight, maternal education, maternal BMI, household wealth, place of residence, and sanitation facility. Model F(16, 630)=5.00, P<0.001. P-values were obtained from the Wald test associated with each survey-weighted logistic regression coefficient. P-trend was estimated by entering the variable as an ordinal predictor in the unadjusted analysis.

CDHS, Cambodia Demographic and Health Survey; CI, confidence interval; BMI, body mass index; -, variable was not retained in the multivariable model.

[a)]Breastfeeding status was available only for the youngest coresident children (n=1,902) and was assessed in the unadjusted analysis only.

**Table 5.** Crude and adjusted associations between dietary indicators and WaSt among Cambodian children aged 6–23 months, CDHS 2021–2022

| Dietary indicator | COR (95% CI) | P-value | AOR (95% CI)[a] | P-value |
|---|---|---|---|---|
| MDD met | 0.48 (0.17–1.33) | 0.158 | 0.58 (0.19–1.78) | 0.343 |
| MMF met | 1.77 (0.44–7.15) | 0.419 | 3.07 (0.75–12.63) | 0.119 |
| MAD met | 0.63 (0.22–1.81) | 0.387 | 0.88 (0.28–2.80) | 0.835 |
| Food group score | | - | | - |
| 0–2 groups | 1.00 (Reference) | - | 1.00 (Reference) | - |
| 3–4 groups | 1.75 (0.42–7.33) | 0.440 | 1.11 (0.24–5.11) | 0.894 |
| ≥5 groups (MDD met) | 0.74 (0.17–3.28) | 0.687 | 0.63 (0.12–3.22) | 0.581 |

Values are odds ratio (95% CI) from survey-weighted logistic regression accounting for the complex multi-stage stratified cluster sampling design of CDHS 2021–2022. P-values were obtained from the Wald test associated with each survey-weighted logistic regression coefficient. Because of the small number of WaSt cases in this subsample (n=21), the adjusted estimates have wide CIs and should be interpreted with caution.

WaSt, concurrent wasting and stunting; CDHS, Cambodia Demographic and Health Survey; COR, crude odds ratio; CI, confidence interval; AOR, adjusted odds ratio; MDD, minimum dietary diversity; MMF, minimum meal frequency; MAD, minimum acceptable diet.

[a]Adjusted for child age (in months), child sex, household wealth index, maternal body mass index, and maternal education.

on chronic undernutrition are insufficient to address the persistence of acute undernutrition.

Low birth weight emerged as the strongest independent predictor of WaSt, with affected children exhibiting nearly five times higher odds. This is consistent with evidence from Indonesia, where low birth weight was associated with roughly three times higher odds of WaSt [18]. Low birth weight reflects intrauterine growth restriction and prematurity, both of which impair linear growth and the accumulation of lean and fat mass, thereby increasing the risk of WaSt. The association with maternal nutritional status, with higher odds among underweight mothers and lower odds among overweight or obese mothers, further points to the intergenerational transmission of undernutrition, whereby maternal undernutrition contributes to impaired fetal growth, low birth weight, and subsequent child undernutrition. A similar protective effect of higher maternal BMI has been reported in Ethiopia, where children of mothers with a normal or higher BMI had significantly lower odds of WaSt than those of underweight mothers [10].

Children belonging to the poorest households had more than two-fold higher odds of WaSt, consistent with evidence from India, where children from wealthier families were considerably less likely to experience WaSt [19], and with the well-established socioeconomic gradient in child undernutrition. Interestingly, the crude associations of maternal education, rural residence, and inadequate sanitation weakened following adjustment, indicating that their associations are largely explained by household wealth and maternal nutritional status rather than representing independent effects. The lower odds of WaSt among girls are consistent with evidence showing that boys are more likely than girls to experience WaSt in early childhood [22], the two conditions that collectively define WaSt. The underlying mechanisms driving this difference remain poorly understood and are likely multifactorial [23]. Boys may be somewhat more physiologically vulnerable to early-life nutritional and infectious insults; however, the biological basis remains uncertain, particularly during infancy. Social factors are also likely to contribute, as the way sons and daughters are fed and cared for can differ. Notably, the same review reported a weaker male excess in South Asia, suggesting that social and environmental context influences the pattern rather than biology acting alone [23]. Separating the biological from the social contributions to this sex difference warrants further study.

The finding that household wealth predicted WaSt while current dietary indicators did not may seem paradoxical. However, household wealth is a marker of cumulative, structural conditions rather than a single day's diet. Poorer households experience sustained food insecurity; a higher burden of infection through inadequate water, sanitation, and hygiene; more limited access to health care; and greater maternal undernutrition. The pathways can influence child growth independently of complementary feeding diversity on any given day. As WaSt incorporates a chronic (stunting) component, it is more likely to reflect these accumulated deprivations than a contemporaneous measure of dietary diversity. Therefore, poverty may influence WaSt largely through infection-related, environmental, and intergenerational pathways rather than solely through current dietary intake.

Contrary to these established determinants, none of the dietary indicators were associated with WaSt, even after adjustment for maternal and household factors. This aligns with evidence that dietary diversity is more closely associated with chronic undernutrition than with acute wasting; in Tanzania, for example, low dietary diversity was significantly associated with stunting and underweight but not consistently with wasting [24]. Several explanations are plausible. As WaSt includes an acute (wasting) component, it is more likely driven by recent illness, infection, and food insecurity than by current dietary diversity, whereas dietary indicators capture only a single 24-hour recall that may not reflect a child's habitual intake. Furthermore, WaSt includes stunting, which slowly develops and reflects sustained nutritional deprivation over time. A single 24-hour recall records intake on 1 day only and cannot represent the repeated, day-after-day intake that influences linear growth. This mismatch between a short-term dietary measure and a partly chronic outcome may have attenuated the observed associations toward the null. The small number of WaSt cases in this subsample (n = 21) also limited the statistical power to detect modest associations. Collectively, these considerations indicate that improving dietary diversity alone may be insufficient to reduce WaSt without parallel attention to infection control, maternal nutrition, and household poverty.

## Limitations

The strengths of this study include the use of recent nationally representative data with standardized anthropometric measurements based on WHO growth standards and the application of survey weights to account for the complex sampling design, which improves the generalizability of the findings. This study has several limitations that need to be acknowledged. First, the cross-sectional design precludes any inference of causality, and as WaSt is an acute condition, a single cross-sectional survey may underestimate its true burden. Second, the number of WaSt cases was small (n = 72 overall and n = 21 in the subsample with dietary indicators), which widened CIs, particularly in the maternal-adjusted models for the dietary indicators. Therefore, these estimates should be cautiously interpreted. Third, birth weight and antenatal care data had substantial missingness (45.5% and 47.8%, respectively). Although missingness was retained as an explicit category to preserve sample size, residual bias from nonrandom missingness cannot be ruled out. Finally, the dietary indicators and birth weight data relied on maternal recall, which is subject to recall bias.

## Conclusion

In conclusion, WaSt affected approximately one in 50 Cambodian children aged 6–59 months and was independently associated with low birth weight, maternal underweight, and household poverty. The dietary information available in this study had three specific limitations: it was derived from a single 24-hour recall, which reflects only 1 day rather than habitual intake; the available indicators captured only meal frequency and whether a minimum number of food groups had been consumed, without information on portion sizes or dietary quality; and no detailed nutrient intake data were available, so energy, macronutrient, and micronutrient adequacy could not be evaluated. Within these limits, the dietary indicators exhibited no statistically significant association with WaSt; however, given the small number of WaSt cases (n = 21), this reflects an absence of detectable association under limited statistical power rather than demonstrated evidence of no effect. Within these limits, the findings indicate that WaSt may be driven more by biological vulnerability and socioeconomic disadvantage than by current feeding practices alone. Further studies using more detailed dietary assessments are warranted to better understand the contribution of diet to WaSt. Overall, these findings highlight the need for integrated nutrition programs that address maternal nutrition, low birth weight, and poverty together, rather than treating WaSt as separate concerns, with particular attention to the most vulnerable households.

# ARTICLE INFORMATION

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## Authors' contributions

Conceptualization: SL. Formal analysis: ML. Investigation: ML. Methodology: all authors. Supervision: SL. Writing - original draft: ML. Writing - review & editing: SL. All authors read and approved the final manuscript.

## Conflict of interest

Seungmin Lee is an editorial board member of this journal, but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflict of interest relevant to this article was reported.

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## Data availability

The data used in this study are not publicly available from the authors because they were obtained from a national statistical database. Access to the data is subject to the policies and procedures of the relevant data-providing agency.

## REFERENCES


1. World Health Organization. Joint child malnutrition estimates 2024 [Internet]. World Health Organization; 2024 [cited 2026 Jun 1]. Available from: https://www.who.int/data/gho/data/themes/topics/joint-child-malnutrition-estimates-unicef-who-wb
2. World Health Organization (WHO); United Nations Children's Fund (UNICEF); World Bank Group. Levels and trends in child malnutrition: UNICEF/WHO/World Bank Group joint child malnutrition estimates: key findings of the 2025 edition. World Health Organization; 2025.
3. Thurstans S, Sessions N, Dolan C, et al. The relationship between wasting and stunting in young children: a systematic review. Matern Child Nutr 2022;18:e13246.
4. Zaba T, Conkle J, Nyawo M, Foote D, Myatt M. Concurrent wasting and stunting among children 6-59 months: an analysis using district-level survey data in Mozambique. BMC Nutr 2022;8:15.
5. National Institute of Statistics (NIS); Ministry of Health. Cambodia: demographic and health survey 2021–2022. National Institute of Statistics; 2023.
6. United Nations Children's Fund (UNICEF). UNICEF and Cambodia renew commitments to improving nutrition for all [Internet]. UNICEF; 2025 [cited 2026 Jun 1]. Available from: https://www.unicef.org/cambodia/press-releases/unicef-and-cambodia-renew-commitments-improving-nutrition-all
7. UN Nutrition. Cambodia nutrition stakeholder and action mapping [Internet]. UN Nutrition; 2024 [cited 2026 Jun 1]. Available from: https://www.unnutrition.org/sites/default/files/2024-04/Cambodia%20Mapping-2024%20%28final%29.pdf
8. Dassie GA, Chala Fantaye T, Charkos TG, Sento Erba M, Balcha Tolosa F. Factors influencing concurrent wasting, stunting, and underweight among children under five who suffered from severe acute malnutrition in low- and middle-income countries: a systematic review. Front Nutr 2024;11:1452963.
9. Lai A, Velez I, Ambikapathi R, Seng K, Cumming O, Brown J. Risk factors for early childhood growth faltering in rural Cambodia: a cross-sectional study. BMJ Open 2022;12:e058092.
10. Roba AA, Assefa N, Dessie Y, et al. Prevalence and determinants of concurrent wasting and stunting and other indicators of malnutrition among children 6-59 months old in Kersa, Ethiopia. Matern Child Nutr 2021;17:e13172.
11. Mertens A, Benjamin-Chung J, Colford JM Jr, et al. Child wasting and concurrent stunting in low- and middle-income countries. Nature 2023;621:558-67.
12. Roba AA, Basdas O. Multilevel analysis of trends and predictors of concurrent wasting and stunting among children 6-59 months in Ethiopia from 2000 to 2019. Front Nutr 2023;10:1073200.
13. Victora CG, de Onis M, Hallal PC, Blossner M, Shrimpton R. Worldwide timing of growth faltering: revisiting implications for interventions. Pediatrics 2010;125:e473-80.
14. World Health Organization (WHO); United Nations Children's Fund (UNICEF). Indicators for assessing infant and young child feeding practices: definitions and measurement methods. World Health Organization; 2021.
15. World Health Organization (WHO); United Nations Children's Fund (UNICEF). WHO Child Growth Standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: methods and development. World Health Organization; 2006.
16. Hosmer DW, Lemeshow S. Applied logistic regression. 2nd ed. John Wiley & Sons; 2000.
17. United Nations Children's Fund (UNICEF). UNICEF conceptual framework on maternal and child nutrition. UNICEF; 2021.
18. Jokhu LA, Syauqy A. Determinants of concurrent wasting and stunting among children 6 to 23 mo in Indonesia. Nutrition 2024;122:112390.
19. Khura B, Mohanty P, Gandhi AP, et al. Mapping concurrent wasting and stunting among children under five in India: a multilevel analysis. Int J Public Health 2023;68:1605654.
20. Nakphong MK, Beltran-Sanchez H. Socio-economic status and the double burden of malnutrition in Cambodia between 2000 and 2014: overweight mothers and stunted children. Public Health Nutr 2021;24:1806-17.
21. United Nations Children's Fund (UNICEF). Young children's diets show no improvement in last decade, 'could get much worse' under COVID-19 - UNICEF [Internet]. UNICEF; 2021 [cited 2026 Jun 1]. Available from: https://www.unicef.org/press-releases/young-childrens-diets-show-no-improvement-last-decade-could-get-much-worse-under
22. Thurstans S, Opondo C, Seal A, et al. Boys are more likely to be undernourished than girls: a systematic review and meta-analysis of sex differences in undernutrition. BMJ Glob Health 2020;5:e004030.
23. Thurstans S, Opondo C, Seal A, et al. Understanding sex differences in childhood undernutrition: a narrative review. Nutrients 2022;14:948.
24. Khamis AG, Mwanri AW, Ntwenya JE, Kreppel K. The influence of dietary diversity on the nutritional status of children between 6 and 23 months of age in Tanzania. BMC Pediatr 2019;19:518.

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CLINICAL NUTRITION RESEARCH

# Factors associated with achieving adequate caloric delivery immediately after percutaneous endoscopic gastrostomy: a retrospective observational study

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**Objective:** Failure to achieve adequate caloric intake is common after percutaneous endoscopic gastrostomy (PEG) and may contribute to progressive malnutrition in older adults. This study aimed to identify factors associated with achieving adequate caloric delivery early after PEG placement.
**Methods:** This single-center retrospective observational study included patients aged ≥65 years who underwent PEG between January 2022 and December 2024. Target caloric intake was determined based on basal energy expenditure (BEE). The target nutritional intake achievement rate (TaNIAR) was defined as the ratio of final delivered calories to BEE. Patients were classified into an underfeeding group (TaNIAR <100%) and an appropriate-feeding group (TaNIAR ≥100%). Multivariable logistic regression analysis was performed to identify factors independently associated with achieving TaNIAR ≥100%.
**Results:** Fifty-nine patients were analyzed; 15 were classified as underfeeding and 44 as appropriate-feeding. The median final caloric intake, calculated in increments of 300 kcal corresponding to the packet size of the enteral formula, was 1,200 kcal (range, 600–1,200 kcal) in the underfeeding group and 1,200 kcal (range, 900–1,400 kcal) in the appropriate-feeding group. Multivariable analysis identified the use of a pectin-containing oligomeric formula (POF) (odds ratio [OR], 32.8; 95% confidence interval [CI], 3.7–292.9) and BEE ≤990 kcal/day (OR, 29.5; 95% CI, 3.1–277.7) as factors independently associated with achieving TaNIAR ≥100%. The final caloric intake clustered within a relatively narrow range in both groups.
**Conclusion:** Lower BEE and the use of POF were independently associated with achieving adequate caloric delivery after PEG placement. Optimization of enteral formula selection may represent a practical strategy to improve early nutritional adequacy in older patients. Further prospective studies are required to validate these findings.

**Keywords:** Gastrostomy; Enteral nutrition; Basal metabolism; Nutritional support; Aged

## INTRODUCTION

For patients who rely on long-term enteral nutrition, persistent failure to achieve adequate caloric intake leads to progressive malnutrition with multisystem consequences. Inadequate delivery of calories and protein results in muscle wasting, weakness, impaired immune function, and deterioration of overall prognosis [1].

One of the major reasons for insufficient caloric delivery in enteral nutrition–dependent patients is feeding intolerance, including vomiting, high gastric residual volume (GRV), diarrhea, and abdominal distension, which often leads clinicians to slow, inter-

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rupt, or discontinue feeding [2-4]. Although enteral nutrition via a nasogastric tube is commonly used during the initial phase, transition to a gastrostomy becomes necessary when long-term nutritional support is required. Percutaneous endoscopic gastrostomy (PEG) is widely used for this purpose and is superior to prolonged nasogastric feeding in terms of patient comfort and feasibility [5-7].

Even in older adults with low physical activity, resting and total energy expenditures remain substantial when adjusted for body weight [8]. In Japan, basal energy expenditure (BEE) is commonly estimated using a population-specific predictive equation proposed by the National Institute of Health and Nutrition [9]. However, despite standardized estimation of energy requirements, achieving adequate caloric intake immediately after PEG placement remains challenging in daily clinical practice.

Importantly, factors that facilitate or hinder the achievement of adequate nutritional intake during the early post-PEG period have not been sufficiently investigated. Therefore, this study aimed to identify factors associated with achieving adequate caloric delivery immediately after PEG placement in older adults.

## METHODS

### Ethics statement

The present study was approved by the Ethics Committee of Sonodakai and Sonoda Daiichi Hospital (approved March 22, 2023; No. 172). Due to the retrospective observational design of the study, the requirement for written informed consent was waived. Conversely, an opt-out approach was implemented, thereby affording eligible patients the opportunity to decline participation.

### Study design and participants

This single-center retrospective observational study included patients aged 65 years or older who underwent PEG at Sonoda Daiichi Hospital between January 2022 and December 2024. Patients younger than 65 years of age and those who underwent PEG for indications unrelated to nutritional management were excluded from the study.

A total of 111 patients who underwent PEG during the study period were screened using the electronic medical record system. Following the application of the eligibility criteria, 59 patients were included in the final analysis. The target nutritional intake achievement rate (TaNIAR) was defined as the ratio of final delivered calories to BEE. According to this definition, patients were classified into two groups: an underfeeding group (TaNIAR $<100\%$) and an appropriate-feeding group (TaNIAR $\geq 100\%$). All patients included in the study had received enteral nutrition via a nasogastric tube prior to PEG placement (Fig. 1). This study has been reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

### Nutritional management after PEG

Target daily caloric intake was determined for each patient using BEE, which was calculated with the predictive equation proposed by the National Institute of Health and Nutrition in Japan [9]. The prescribed daily dose of enteral nutrition was calculated by dividing the target caloric intake by the caloric content per package of the selected formula and rounding to the nearest whole number. For patients with impaired glucose tolerance, blood glucose management during hospitalization was conducted in accordance with the treatment algorithm recommended by the Japan Diabetes Society [10].

Enteral feeding was initiated on the day after PEG placement at approximately 25% to 30% of the target caloric requirement. Intermittent gastric feeding was used in all patients, and GRV was measured before each feeding. Feeding tolerance was assessed clinically. Intolerance was defined as the presence of excessive GRV ($>100$ mL/day), nausea, vomiting, abdominal distension, abdominal pain, or diarrhea. Signs suggestive of aspiration were also assessed, including cough during or after feeding, wet voice, respiratory distress, oxygen desaturation, increased sputum, and newly developed abnormal lung sounds.

Feeding volume was increased stepwise only when neither excessive GRV nor aspiration-related signs were present. Once the target intake was attained without adverse events, that level was maintained. When the target intake could not be achieved because of poor tolerance, the highest caloric intake that could be delivered without adverse events was defined as the final caloric intake.

### Selection of enteral formula

Enteral formula type was included as a candidate explanatory variable because formula characteristics may influence gastrointestinal tolerance and thereby affect the amount of nutrition that can be delivered after PEG placement. During the study period, two enteral formulas were available at our institution: a pectin-containing oligomeric formula (POF) (HINEX E-Gel, Otsuka Pharmaceutical Co. Ltd.) and a standard polymeric formula (SPF)

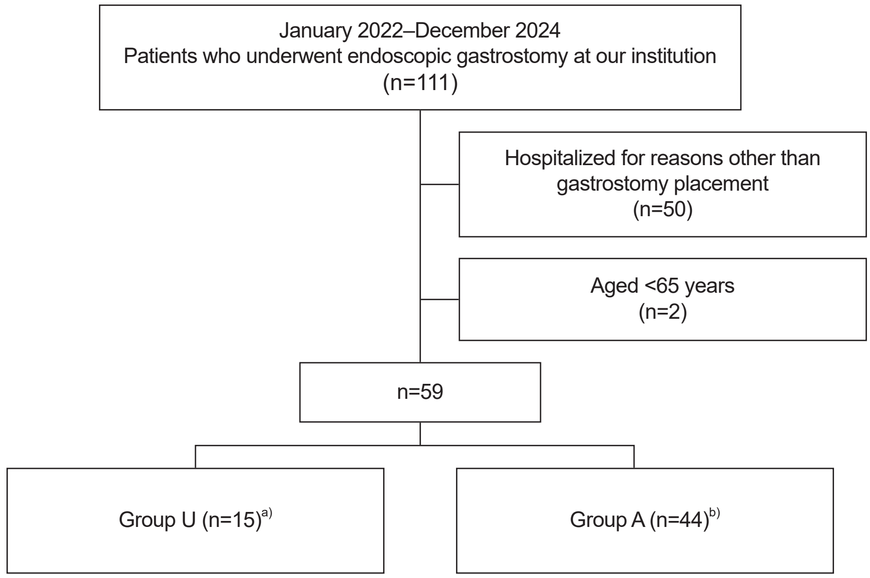


**Fig. 1.** Patient screening flowchart. TaNIAR = Final actual calorie intake/basal energy expenditure × 100 (%). [a)]Underfeeding group (target nutritional intake achievement rate [TaNIAR] <100%); [b)]Appropriate-feeding group (TaNIAR ≥100%).

(Peptamen, Nestlé Health Science). Formula selection was left to the discretion of the attending physician, and no standardized institutional protocol or uniform selection criteria were used. Multiple physicians selected the formula independently on the basis of clinical judgment, taking into account each patient's general condition, gastrointestinal tolerance, and prior feeding response. Thus, formula selection reflected routine clinical practice at our institution.

The POF used in this study has an energy density of 0.8 kcal/mL and contains low-molecular-weight peptides, including collagen peptides and soy peptides, together with free amino acids. It also contains soluble dietary fiber including pectin and has an osmolality of approximately 360 mOsm/L. The SPF used in this study has an energy density of 1.5 kcal/mL and is a peptide-based enteral formula without pectin supplementation.

## Data collection

Clinical data were retrospectively extracted from electronic medical records. Candidate variables were selected on the basis of their clinical relevance to one of the following domains: estimated energy requirement, overall clinical condition, gastrointestinal tolerance, or upper gastrointestinal/swallowing-related findings that could influence enteral feeding after PEG.

Collected variables included age, sex, body mass index (BMI), BEE, Eastern Cooperative Oncology Group performance status, Glasgow Coma Scale (GCS), comorbidities, medication history, and the type of enteral formula used during hospitalization. Medication history was reviewed with particular attention to drugs that could affect bowel function, including those associated with constipation or diarrhea. Stool consistency was evaluated using the Bristol Stool Scale (BSS). Post-PEG clinical outcomes included post-PEG complications, the duration required to reach the final caloric intake (DuFiCI), and post-PEG hospital stay (PPhs). Endoscopic findings, including the presence of hiatal hernia and the Hyodo-Komagane score, were also recorded because they may be relevant to swallowing function, reflux risk, and feeding tolerance [11,12].

## Statistical analysis

TaNIAR was calculated as the ratio of final delivered calories to BEE. Patients were then categorized into an underfeeding group (TaNIAR <100%) or an appropriate-feeding group (TaNIAR ≥100%). Continuous variables are presented as median (range) and were compared using the Mann-Whitney U test or the independent-samples t test, as appropriate. Categorical variables were compared using the chi-square test or Fisher exact test, as appropriate.

Receiver operating characteristic (ROC) curve analysis was performed for continuous variables, and cutoff values were determined using the Youden index. Variables that demonstrated significant associations in univariable analyses were entered into a multivariable logistic regression model to identify factors inde-

**Table 1.** Patients' demographics, comorbidities, medication history, and endoscopic findings during percutaneous endoscopic gastrostomy

| Characteristic | Group U (n=15)[a] | Group A (n=44)[b] | P-value |
|---|---|---|---|
| Sex | | | 0.003 |
| Male | 12 (80.0) | 16 (36.4) | |
| Female | 3 (20.0) | 28 (63.6) | |
| Age (yr) | 82 (66–93) | 83 (65–97) | 0.628 |
| BMI (kg/m$^2$) | 19.40 (15.67–24.74) | 18.47 (12.29–24.96) | 0.317 |
| BEE (kcal) | 1,126.73 (807.27–1,330.96) | 919.83 (702.16–1,202.68) | <0.001 |
| BEE ≤990 (kcal) | 3 (20.0) | 32 (72.7) | <0.001 |
| ECOG PS | | | 0.259 |
| 3 | 1 (6.7) | 9 (20.5) | |
| 4 | 14 (93.3) | 35 (79.5) | |
| GCS | | | |
| Eye opening | | | 0.56 |
| 3 | 0 (0) | 3 (6.8) | |
| 4 | 15 (100) | 41 (93.2) | |
| Verbal response | | | 0.882 |
| 1 | 0 (0) | 1 (2.2) | |
| 2 | 8 (53.3) | 25 (56.8) | |
| 3 | 2 (13.3) | 5 (11.4) | |
| 4 | 5 (33.3) | 12 (27.3) | |
| 5 | 0 (0) | 1 (2.2) | |
| Motor response | | | 0.349 |
| 3 | 5 (33.3) | 8 (18.2) | |
| 4 | 6 (40.0) | 17 (38.6) | |
| 5 | 4 (26.7) | 17 (38.6) | |
| 6 | 0 (0) | 2 (4.5) | |
| History of enteral feeding via the nasogastric tube | 15 (100) | 44 (100) | NA |
| Comorbidity | | | |
| Neurological | | | |
| Cerebral hemorrhage | 3 (20.0) | 13 (29.5) | 0.74 |
| Subarachnoid hemorrhage | 2 (13.3) | 5 (11.4) | >0.999 |
| Cardioembolic stroke | 3 (20.0) | 2 (4.5) | 0.1 |
| Atherothrombotic stroke | 5 (33.3) | 18 (40.9) | 0.76 |
| Alzheimer's disease | 1 (6.7) | 2 (4.5) | >0.999 |
| Lewy body dementia | 0 (0) | 2 (4.5) | >0.999 |
| Vascular dementia | 0 (0) | 1 (2.3) | >0.999 |
| Frontotemporal dementia | 0 (0) | 4 (9.1) | 0.56 |
| Parkinson's disease | 2 (13.3) | 3 (6.8) | 0.59 |
| Neurodegenerative disease | 1 (6.7) | 1 (2.3) | 0.46 |
| Cardiovascular | | | |
| Coronary artery disease | 1 (6.7) | 4 (9.1) | >0.999 |
| Chronic heart failure | 2 (13.3) | 7 (15.9) | >0.999 |
| Arrhythmia | 3 (20.0) | 6 (13.6) | 0.68 |
| Nephroendocrinological | | | |
| Type 2 diabetes mellitus | 3 (20.0) | 10 (22.7) | >0.999 |
| Chronic kidney failure | 1 (6.7) | 0 (0) | 0.25 |
| Orthopedic | | | |
| Femoral neck fracture | 1 (6.7) | 4 (9.1) | >0.999 |
| Lumbar compression fracture | 0 (0) | 1 (2.3) | >0.999 |
| Medication history drugs likely to induce constipation | 5 (33.3) | 18 (40.9) | 0.76 |
| Opioids | 0 (0) | 0 (0) | NA |
| Anticholinergics | 2 (13.3) | 7 (15.9) | >0.999 |

(Continued to the next page)

**Table 1.** Continued

| Characteristic | Group U (n=15)[a] | Group A (n=44)[b] | P-value |
|---|---|---|---|
| Calcium channel blockers | 3 (20.0) | 8 (18.2) | >0.999 |
| Iron supplements | 1 (6.7) | 2 (4.5) | >0.999 |
| Calcium supplements | 0 (0) | 4 (9.1) | 0.56 |
| Vitamin D supplements | 0 (0) | 4 (9.1) | 0.56 |
| Drugs likely to induce diarrhea | 3 (20.0) | 9 (20.5) | >0.999 |
| Antiemetics | 0 (0) | 0 (0) | NA |
| Metformin | 0 (0) | 4 (9.1) | 0.56 |
| Any laxative | 3 (20.0) | 5 (11.4) | 0.41 |
| Alpha-glucosidase inhibitor | 0 (0) | 2 (4.5) | >0.999 |
| Endoscopic finding | | | |
| Hiatal hernia | 4 (26.7) | 15 (34.1) | 0.75 |
| Hyodo-Komagane score | | | |
| 9 | 5 (33.3) | 17 (38.6) | 0.68 |
| 10 | 3 (20.0) | 11 (25.0) | |
| 11 | 5 (33.3) | 8 (18.2) | |
| 12 | 2 (13.3) | 8 (18.2) | |

Values are presented as number (%) or median (range).
BMI, body mass index; BEE, basal energy expenditure, ECOG PS, Eastern Cooperative Oncology Group performance status; GCS, Glasgow Coma Scale; NA, not available.
[a]Underfeeding group (target nutritional intake achievement rate [TaNIAR] <100%); [b]Appropriate-feeding group (TaNIAR ≥100%).

pendently associated with achieving TaNIAR ≥ 100%. Due to the limited sample size, the multivariable analysis was conducted as an exploratory analysis with a restricted number of variables in the final model. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. Model fit was assessed using the Hosmer-Lemeshow test. All statistical analyses were performed using IBM SPSS ver. 28 (IBM Corp.), and a two-sided P-value $< 0.05$ was considered statistically significant.

## RESULTS

### Baseline characteristics

The final analysis included a total of 59 patients. Of these patients, 15 were classified into the underfeeding group (TaNIAR < 100%), while 44 were classified into the appropriate-feeding group (TaNIAR ≥ 100%). The baseline characteristics of the study participants are enumerated in Table 1. The feeding group that received adequate nourishment included a significantly higher proportion of female patients than the underfeeding group. Furthermore, BEE was found to be significantly lower in the appropriate-feeding group. Prior to PEG placement, all patients had received enteral nutrition via a nasogastric tube. No significant between-group differences were observed in age, BMI, comorbidities, medication history, or endoscopic findings, including hiatal hernia and Hyodo-Komagane score.

**Table 2.** Patients' outcomes after percutaneous endoscopic gastrostomy

| Variable | Group U (n=15)[a] | Group A (n=44)[b] | P-value |
|---|---|---|---|
| Type of nutritional formula | | | <0.001 |
| SPF | 11 (73.3) | 6 (13.6) | |
| POF | 4 (26.7) | 38 (86.4) | |
| BSS | | | 0.011 |
| 4 | 0 (0) | 2 (4.5) | |
| 5 | 5 (33.3) | 33 (75.0) | |
| 6 | 4 (26.7) | 4 (9.1) | |
| 7 | 6 (40.0) | 5 (11.4) | |
| ≤5 | 5 (33.3) | 35 (79.5) | 0.003 |
| Complication (any) | 3 (20.0) | 2 (4.5) | 0.10 |
| DuFiCI (day) | 6 (4–20) | 4 (4–18) | <0.001 |
| DuFiCI ≤6 days | 4 (26.7) | 37 (84.1) | <0.001 |
| PPhs (day) | 8 (6–27) | 7 (2–31) | 0.005 |
| PPhs ≤7 days | 4 (26.7) | 37 (84.1) | <0.001 |

Values are presented as number (%) or median (range).
SPF, standard polymeric formula; POF, pectin-containing oligomeric formula; BSS, Bristol Stool Scale; DuFiCI, duration required to reach the final target calorie intake; PPhs, post-percutaneous endoscopic gastrostomy hospital stay.
[a]Underfeeding group (target nutritional intake achievement rate [TaNIAR] <100%); [b]Appropriate-feeding group (TaNIAR ≥100%).

### Post-PEG nutritional outcomes

The post-PEG clinical outcomes are outlined in Table 2. The type of enteral formula administered during hospitalization differed significantly between the two groups. In the underfeeding group, 11 patients (73.3%) received the SPF, while four patients (26.7%)

received the POF. Conversely, in the appropriate-feeding group, six patients (13.6%) received SPF and 38 (86.4%) received POF. Consequently, POF utilization was found to be considerably more prevalent in the appropriate-feeding group.

Furthermore, a substantial variation in stool consistency was observed among the study groups. According to the BSS, the appropriate-feeding group exhibited a distribution that shifted toward more favorable stool consistency in comparison with the underfeeding group. The DuFiCI was significantly shorter in the appropriate-feeding group than in the underfeeding group. Furthermore, the duration of hospital stay following PEG was found to be significantly reduced in the group receiving appropriate-feeding.

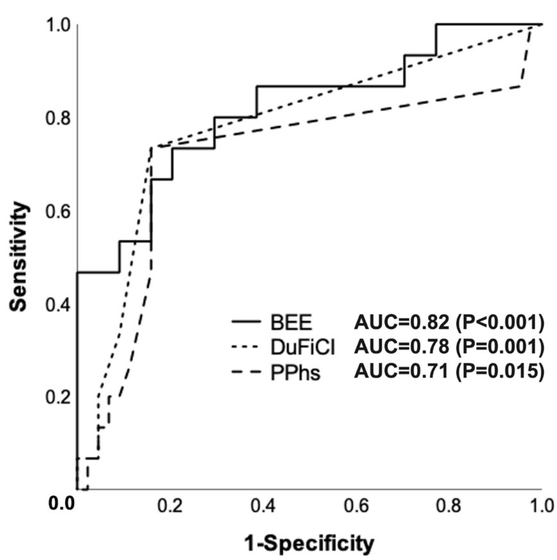


**Fig. 2.** Receiver operating characteristic curves for target nutritional intake achievement rate ≥100% occurrence and each factor. AUC, area under curve; BEE, Basal Energy Expenditure; DuFiCI, duration required to reach the final target calorie intake; PPhs, post-percutaneous endoscopic gastrostomy hospital stay.

The absolute final caloric intake achieved during hospitalization demonstrated a relatively narrow distribution in both groups. The median final caloric intake was 1,200 kcal (range, 600–1,200 kcal) in the underfeeding group and 1,200 kcal (range, 900–1,400 kcal) in the appropriate-feeding group. Despite the inherent differences in the definition of TaNIAR across groups, the absolute amount of calories delivered during hospitalization remained comparable.

### ROC analysis and multivariable analysis

ROC curve analysis identified cutoff values of 990 kcal/day for BEE, 6 days for DuFiCI, and 7 days for PPhs (Fig. 2). Variables that demonstrated significant associations in univariable analyses were subsequently entered into the multivariable logistic regression model. In the multivariable analysis, POF use and BEE ≤990 kcal/day were independently associated with achieving TaNIAR ≥100%. The utilization of POF was associated with an OR of 32.8 (95% CI, 3.7–292.9; P=0.002). Furthermore, BEE ≤990 kcal/day was associated with an OR of 29.5 (95% CI, 3.1–277.7; P=0.003) (Table 3). Among patients with BEE >990 kcal/day, those who received POF achieved TaNIAR ≥100% more frequently than those who received SPF.

## DISCUSSION

In this study, lower BEE and the use of a POF were found to be independently associated with achieving a TaNIAR of at least 100% immediately after PEG placement. Conversely, the absolute final caloric intake achieved during hospitalization was comparable between the two groups. The findings suggest that the attainment of TaNIAR was influenced not solely by the calculated energy requirement but also by the amount of enteral nutrition that could

**Table 3.** Analysis of factors capable of achieving target nutritional intake achievement rate≥100% after percutaneous endoscopic gastrostomy

| Variable | Univariate | | Multivariate | |
|---|---|---|---|---|
| | OR (95% CI) | P-value | OR (95% CI) | P-value |
| Type of enteral formula (POF) | 11.9 (3.2–45.1) | <0.001 | 32.8 (3.7–292.9) | 0.002 |
| Female sex | 7.9 (1.9–31.7) | 0.004 | - | 0.190 |
| BEE ≤990 kcal | 10.7 (2.6–43.7) | 0.001 | 29.5 (3.1–277.7) | 0.003 |
| BSS ≤5 | 5.8 (1.7–20.0) | 0.005 | - | 0.900 |
| DuFiCI ≤6 days | 10.2 (2.8–37.5) | <0.001 | - | 0.530 |
| PPhs ≤7 days | 10.7 (2.7–37.1) | <0.001 | - | 0.280 |

OR, odds ratio; CI, confidence interval; POF, pectin-containing oligomeric formula; BEE, Basal Energy Expenditure; BSS, Bristol Stool Scale; DuFiCI, duration required to reach the final target calorie intake; PPhs, post-percutaneous endoscopic gastrostomy hospital stay; -, not available.

be tolerated and delivered.

In the present cohort, the median final caloric intake was 1,200 kcal in both groups, despite differences in BEE. This finding suggests that the delivered caloric intake tended to cluster within a relatively limited range in routine clinical practice. As TaNIAR was defined as the ratio of delivered calories to BEE, patients with lower BEE were more likely to reach 100% of their estimated requirement within that range. Conversely, patients with higher BEE were less likely to do so. This interpretation aligns with prior reports indicating that enteral feeding is often hindered, interrupted, or discontinued due to feeding intolerance, including elevated GRV, vomiting, and diarrhea. These occurrences can result in a reduction of the actual nutritional delivery, despite predefined caloric objectives [2-4]. Consequently, our findings align with the hypothesis that the early caloric adequacy after PEG is constrained by practical feeding tolerance as well as by estimated energy requirement. The concept of a strict physiological ceiling cannot be established from this retrospective study alone; however, the observed clustering of delivered calories suggests the presence of a practical upper boundary of tolerable gastric feeding in this clinical setting.

The association between POF use and achievement of TaNIAR ≥100% is also clinically meaningful. In this study, the use of POF remained independently associated with adequate caloric delivery even after adjustment in the multivariable model. Furthermore, patients with BEE >990 kcal/day who received POF more frequently achieved TaNIAR ≥100% than those who received the SPF. This finding suggests that the efficacy of nutritional delivery subsequent to PEG is influenced by patient-related factors as well as nutritional strategy. One potential explanation for this phenomenon is that pectin-containing formulas enhance gastrointestinal tolerance. Increased viscosity may reduce gastroesophageal reflux, and soluble fiber, such as pectin, may help stabilize stool consistency and improve intestinal handling of enteral nutrition. These effects may facilitate stepwise advancement of feeding and allow a greater amount of nutrition to be delivered without interruption. This interpretation aligns with the findings of previous studies that reported enhanced tolerance and a reduction in gastrointestinal adverse events with pectin-containing enteral formulas [13,14].

Concurrently, the observed association between POF utilization and caloric adequacy should be interpreted with caution. The selection of formula was not standardized and was left to the discretion of the attending physician. Therefore, the possibility of confounding by indication cannot be ruled out. It is plausible that physicians selected POF for patients whom they considered more likely to benefit from a better-tolerated formula. Furthermore, unmeasured clinical factors may have influenced both formula selection and feeding outcomes. Consequently, the present findings should not be interpreted as definitive evidence that POF is superior to standard formulas. Instead, they suggest that formula selection is a potentially modifiable factor that merits further prospective evaluation.

It is imperative to acknowledge the limitations of the present study. First, it should be noted that this was a retrospective single-center study. Therefore, the identified relationships should be interpreted as statistical associations rather than causal effects. Second, the sample size was limited, and the multivariable model yielded large ORs with wide CIs. These findings suggest possible model instability and limited precision of the estimated associations. Third, despite the final model's restriction to a limited number of variables, residual confounding remains a possibility. This is due to the fact that clinically relevant factors such as baseline nutritional reserve, disease severity, and gastrointestinal functional status were not fully captured. Fourth, TaNIAR was defined using BEE as the reference value. As a component of the patient's total energy expenditure, the BEE is an important metric in determining the patient's basal metabolic demand. However, it is important to note that BEE does not fully represent total energy requirements in all hospitalized patients, particularly those with stress-related or disease-related metabolic changes. Consequently, classification based on TaNIAR may not accurately reflect the nutritional adequacy in every patient. It is imperative to acknowledge that the cutoff values derived from the ROC analysis should be regarded as exploratory in nature and necessitate external validation prior to their clinical implementation.

Notwithstanding these limitations, the present study offers clinically relevant information regarding early nutritional management after PEG placement in older adults. The findings suggest that the successful achievement of caloric intake relative to estimated requirements is contingent on both the magnitude of the requirement and the amount of nutrition that can be delivered. The findings also identify enteral formula selection as a potentially modifiable component of early PEG management. The necessity for prospective multicenter studies is evident in order to confirm these associations and to determine whether formula-based strategies can improve early nutritional delivery after PEG placement.

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### Data availability
All data generated or analyzed during this study are included in this article, with additional data available from the corresponding author upon reasonable request.

## REFERENCES

1. Li Q, Wang J. The application and mechanism analysis of enteral nutrition in clinical management of chronic diseases. Nutrients 2025;17:450.
2. Misirlioglu M, Yildizdas D, Ekinci F, et al. An assessment of intermittent and continuous enteral feeding in critically ill children. Nutrients 2025;17:301.
3. Kasti AN, Theodorakopoulou M, Katsas K, et al. Factors associated with interruptions of enteral nutrition and the impact on macro- and micronutrient deficits in ICU patients. Nutrients 2023;15:917.
4. Petros S, Engelmann L. Enteral nutrition delivery and energy expenditure in medical intensive care patients. Clin Nutr 2006;25:51-9.
5. Gauderer MW, Ponsky JL, Izant RJ Jr. Gastrostomy without laparotomy: a percutaneous endoscopic technique. J Pediatr Surg 1980;15:872-5.
6. Vanis N, Saray A, Gornjakovic S, Mesihovic R. Percutaneous endoscopic gastrostomy (PEG): retrospective analysis of a 7-year clinical experience. Acta Inform Med 2012;20:235-7.
7. Nicholson FB, Korman MG, Richardson MA. Percutaneous endoscopic gastrostomy: a review of indications, complications and outcome. J Gastroenterol Hepatol 2000;15:21-5.
8. Allepaerts S, Buckinx F, Bruyere O, Reginster JY, Paquot N, Gillain S. Clinical impact of nutritional status and energy balance in elderly hospitalized patients. J Nutr Health Aging 2020;24:1073-9.
9. Ganpule AA, Tanaka S, Ishikawa-Takata K, Tabata I. Interindividual variability in sleeping metabolic rate in Japanese subjects. Eur J Clin Nutr 2007;61:1256-61.
10. Bouchi R, Kondo T, Ohta Y, et al. A consensus statement from the Japan Diabetes Society: a proposed algorithm for pharmacotherapy in people with type 2 diabetes – 2nd edition (English version). J Diabetes Investig 2024;15:1326-42.
11. Hyodo M, Nishikubo K, Hirose K. New scoring proposed for endoscopic swallowing evaluation and clinical significance. Nihon Jibiinkoka Gakkai Kaiho 2010;113:670-8.
12. Chiba Y, Sano D, Ikui Y, et al. Predictive value of the Hyodo score in endoscopic evaluation of aspiration during swallowing. Auris Nasus Larynx 2018;45:1214-20.
13. Maruyama M, Goshi S, Kashima Y, Mizuhara A, Higashiguchi T. Clinical effects of a pectin-containing oligomeric formula in tube feeding patients: a multicenter randomized clinical trial. Nutr Clin Pract 2020;35:464-70.
14. Huang HB, Zhu YB, Yu DX. Use of pectin-supplemented enteral nutrition in intensive care: a systematic review and meta-analysis. Clin Nutr ESPEN 2025;68:62-70.

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CLINICAL NUTRITION RESEARCH

# Short-chain fatty acid–producing psychobiotics in mood disorders: mechanistic insights into the microbiota-gut-brain axis

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Mood disorders, including major depressive disorder, bipolar disorder, generalized anxiety disorder, and posttraumatic stress disorder, constitute a primary source of global disability, and with conventional monoamine-targeted pharmacotherapy, approximately one-third of patients remain with treatment-resistant disease. Over the past decade, the microbiota-gut-brain axis (MGBA) has emerged as a systems-level pathophysiological framework that explains the chronic neuroinflammation, hypothalamic-pituitary-adrenal axis hyperactivity, and impaired neuroplasticity that characterize treatment-resistant mood disorders. Short-chain fatty acids (SCFAs) are key molecular mediators in MGBA signaling, exerting epigenetic regulation through the inhibition of histone deacetylase, suppression of microglial toll-like receptor 4/nuclear factor-kappa B signaling, reinforcement of intestinal and blood-brain barrier integrity, and rebalancing of tryptophan–kynurenine metabolism. A few small randomized controlled trials and meta-analyses have reported that restoring SCFA output using next-generation psychobiotics (*Faecalibacterium prausnitzii*, *Akkermansia muciniphila*, and *Clostridium butyricum*), prebiotic-rich dietary patterns, defined synbiotics, and direct postbiotic supplementation is associated with symptom improvement, although the evidence base remains preliminary, and have been proposed as candidate prognostic biomarkers. This narrative review synthesizes 2022 to 2026 mechanistic and clinical evidence on SCFA-producing psychobiotics in mood disorders; integrates these findings within a clinical nutrition framework that positions dietary fiber, microbiota-accessible carbohydrates, and targeted psychobiotic supplementation as legitimate adjuncts to conventional psychopharmacology; and discusses the translational challenges of strain specificity, dosing variability, and precision-psychobiotic medicine. Nevertheless, current evidence remains dominated by preclinical models, with human trials constrained by size, duration, and number.

**Keywords:** Fatty acids; Microbiota; Brain-gut axis; Major depressive disorder

## INTRODUCTION

Major depressive disorder (MDD), generalized anxiety disorder, bipolar disorder (BD), and posttraumatic stress disorder (PTSD) collectively constitute one of the most urgent global health crises of the 21st century, with the World Health Organization estimating that mood and anxiety disorders together affect more than 580 million people worldwide and represent the single largest contributor to years lived with disability [1]. Despite this escalating epidemiological pressure, conventional pharmacotherapy anchored in the monoamine hypothesis, primarily selective serotonin reuptake inhibitors (SSRIs) and serotonin–norepinephrine reuptake inhibi-

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tors (SNRIs), has reached an unmistakable efficacy plateau, with delayed onset of action, modest initial remission rates, and substantial gastrointestinal and metabolic adverse effects continuing to undermine clinical utility. Approximately one-third of patients with MDD fail to achieve remission after two or more adequate antidepressant trials, fulfilling current criteria for treatment-resistant depression (TRD) [2]. Moreover, the persistent neurobiological hallmarks of TRD, such as chronic low-grade neuroinflammation, aberrant synaptic plasticity, hippocampal volumetric loss, and sustained hypothalamic-pituitary-adrenal (HPA) axis hyperactivity, argue compellingly for therapeutic strategies that move beyond the narrow synaptic monoamine framework toward systemic, multiorgan pathophysiology.

Within this context, biological psychiatry has undergone an intense paradigm shift over the past decade, recognizing the gastrointestinal tract and its resident microbial ecosystem as a profound modulator of central nervous system (CNS) function through the microbiota-gut-brain axis (MGBA) [3]. The human gut harbors more than 100 trillion microorganisms whose collective metagenome significantly exceeds the host genome and engage in continuous bidirectional crosstalk with the CNS through neural, endocrine, immune, and metabolic pathways. Compelling causal evidence has emerged from fecal microbiota transplantation (FMT) experiments in which the transfer of microbiota from depressed patients into germ-free or antibiotic-treated rodents was found to induce depression- and anxiety-like phenotypes accompanied by neuroinflammation and diminished hippocampal brain-derived neurotrophic factor (BDNF) expression [4]. Correspondingly, a 2025 meta-analysis of randomized controlled trials (RCTs) encompassing 681 participants reported that FMT significantly alleviated depressive symptoms compared with placebo [5], strengthening the translational relevance of microbiota-targeted interventions in human psychiatric disease.

Among the myriad bioactive metabolites elaborated by the gut microbiota, short-chain fatty acids (SCFAs), including predominantly acetate, propionate, and butyrate generated through anaerobic fermentation of dietary fiber, have emerged as one of the most extensively investigated mediators in MGBA signaling, exerting pleiotropic neuroactive, immunomodulatory, and epigenetic effects through histone deacetylase (HDAC) inhibition, free fatty acid receptor activation, and direct modulation of microglial polarization, blood-brain barrier (BBB) integrity, and tryptophan–kynurenine flux [6,7]. Recent mechanistic studies have substantially extended this picture. In parallel, a 2025 systematic review of 19 RCTs reported symptom amelioration across the included trials, although with substantial heterogeneity in strain, dose, and duration after psychobiotic intervention [8], and a 2026 meta-analysis reported an SCFA-deficit signature in individuals with MDD compared with that in healthy controls [9].

From a clinical nutrition perspective, these accumulated findings reframe dietary fiber intake, fermentable substrate selection, and targeted psychobiotic supplementation as legitimate, mechanism-based nutritional interventions for mood disorders rather than peripheral lifestyle recommendations. Accordingly, the present review synthesizes 2022–2026 mechanistic and clinical evidence on SCFA-producing psychobiotics in mood disorders; dissects the molecular bases by which SCFAs modulate neurotransmission, microglial polarization, BBB integrity, and HPA reactivity; summarizes recent RCTs of next-generation psychobiotic (NGP) strains and direct postbiotic SCFA supplementation; and integrates these findings within a clinical nutrition framework intended to inform integrative care for patients with treatment-resistant mood disorders.

## THE MGBA: A BIDIRECTIONAL COMMUNICATION NETWORK

The MGBA operates as a highly integrated, bidirectional communication network in which neural, endocrine, immune, and metabolic conduits act synchronously to translate luminal microbial activity into measurable changes in CNS function and emotional behavior (Fig. 1) [3,10]. These pathways converge upon overlapping molecular hubs that include free fatty acid receptors, toll-like receptor 4 (TLR4), aryl hydrocarbon receptor (AhR), corticotropin-releasing hormone (CRH) signaling, and microglial reactivity. Consequently, the perturbation of one arm can propagate through the others and generate the systems-level dysregulation that underlies MDD, BD, anxiety disorders, and PTSD. The next four subsections outline each pathway at the conceptual level, and the molecular details by which SCFAs intercept these circuits are reserved for 'MOLECULAR MECHANISMS OF SCFA-MEDIATED MOOD REGULATION' section.

### Neural pathway: vagus nerve and enteric nervous system

The neural arm of the MGBA represents the most rapid information channel between the gut and brain and is anatomically grounded in the enteric nervous system, which is an autonomous plexus of more than 100 million neurons distributed across the submucosal and myenteric layers of the gastrointestinal tract, to-

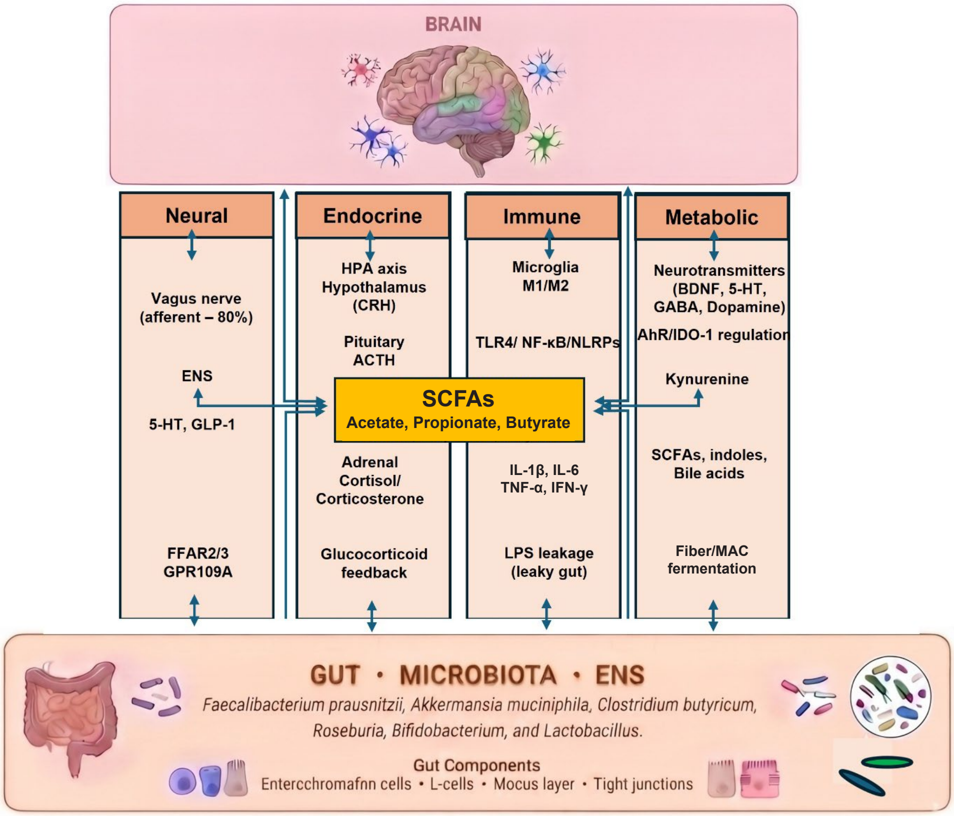


**Fig. 1.** Microbiota-gut-brain axis (MGBA) and the central role of SCFAs. Four bidirectional communication pathways link the gut microbiota and central nervous system. The neural arm is anchored in the ENS and the vagus nerve (about 80% afferent), with enterochromaffin cells releasing 5-HT and GLP-1. The endocrine arm operates through the HPA axis (CRH, adrenocorticotropic hormone, and cortisol). The immune-inflammatory arm is dominated by LPS translocation, TLR4/NF-κB signaling, NLRP3 inflammasome, and proinflammatory cytokines (IL-1β, IL-6, TNF-α, IFN-γ). The metabolic arm generates SCFAs, indoles (with downstream AhR signaling and IDO-1 regulation), bile acids, and GABA. SCFAs (acetate, propionate, and butyrate) produced by *Faecalibacterium prausnitzii*, *Akkermansia muciniphila*, *Clostridium butyricum*, *Roseburia*, *Bifidobacterium*, and *Lactobacillus* represent a convergence point linking the four pathways. ENS, enteric nervous system; 5-HT, 5-hydroxytryptamine; GLP-1, glucagon-like peptide-1; FFAR, free fatty acid receptor; GPR109A, hydroxycarboxylic acid receptor 2; HPA, hypothalamic-pituitary-adrenal; CRH, corticotropin-releasing hormone; TLR4, toll-like receptor 4; NF-κB, nuclear factor-kappa B; NLRP3, NLR family pyrin domain containing 3; IL-1β, interleukin 1β; IL-6, interleukin 6; TNF-α, tumor necrosis factor α; IFN-γ, interferon γ; LPS, lipopolysaccharide; SCFA, short-chain fatty acid; BDNF, brain-derived neurotrophic factor; GABA, γ-aminobutyric acid; AhR, aryl hydrocarbon receptor; IDO-1, indoleamine 2,3-dioxygenase 1; MAC, microbiota-accessible carbohydrates.

gether with the vagus nerve, whose afferent fibers comprise approximately 80% of total vagal axons and project gut-derived sensory information directly to the nucleus tractus solitarius and onward to limbic structures, including the amygdala, insular cortex, hypothalamus, and prefrontal cortex [10]. The enteric nervous system continuously monitors luminal contents through specialized epithelial sensors, including enteroendocrine cells, enterochromaffin (EC) cells, and neuropod cells, each equipped with a battery of G-protein-coupled receptors that decode microbial metabolites. Microbial SCFAs and other small molecules engage free fatty acid receptors on EC cells, triggering the paracrine release of peptide YY, glucagon-like peptide-1, and approximately 90% of the body's peripheral serotonin (5-hydroxytryptamine [5-HT]), all of which converge upon vagal afferents to shape interoceptive signaling and emotional tone [11]. Reigstad et al. [12] demonstrated in gnotobiotic mice that SCFAs directly upregulate tryptophan hydroxylase 1 transcription in colonic EC cells, suggesting a molecular association between microbial fermentation and host serotonergic capacity. Bayrer et al. [13] reported that genetically defined EC-cell ablation suppressed visceral pain and anxiety-like behaviors in mice, providing causal evidence in mice that intestinal sensory cells modulate higher-order affective processing.

Recent loss-of-function experiments support a causally essential role for the vagal conduit in rodent models for microbiota-driven mood pathology. For instance, Siopi et al. [14] demonstrated that fecal transfer of stress-altered microbiota induced depressive-like behavior and impaired adult hippocampal neurogenesis only in vagus-intact recipient mice, whereas subdiaphragmatic vagotomy abolished both phenotypes. The classical demonstration by Bravo et al. [15] that subdiaphragmatic vagotomy abolishes the anxiolytic and antidepressant-like effects of *Lactobacillus rhamnosus* JB-1, including changes in central γ-aminobutyric acid (GABA)-A and GABA-B receptor expression, remains a foundational demonstration for this paradigm.

### Endocrine pathway: the HPA axis

The endocrine arm is dominated by the HPA axis, which acts simultaneously as the primary mediator of psychological stress and as a sensitive readout of microbial status. Hypothalamic CRH drives pituitary adrenocorticotropic hormone release, which in turn stimulates adrenal cortisol secretion, and chronic glucocorticoid exposure subsequently degrades intestinal barrier function, reshapes microbial community composition toward a proinflammatory dysbiotic state, and alters bile acid and SCFA metabolism in a self-perpetuating feedback loop [10]. The seminal observation of Sudo et al. [16] that germ-free mice display exaggerated plasma corticosterone and adrenocorticotropic hormone responses to acute restraint stress, accompanied by reduced hippocampal BDNF and glucocorticoid receptor expression, provided early evidence that postnatal microbial colonization contributes to program normal HPA reactivity. A particularly striking recent advance came from Tofani et al. [17], who reported in *Cell Metabolism* that the gut microbiota gates the HPA-axis responsiveness in a strictly circadian manner, with antibiotic-induced microbial depletion phase-shifting corticosterone peaks and uncoupling adaptive stress responses from time-of-day cues. This finding suggests a chronobiological dimension of MGBA endocrine signaling and partially explains why disrupted circadian rhythms, a near-universal feature of depressive and bipolar disorders, are so tightly coupled to gut dysbiosis. The molecular details of how SCFA-producing psychobiotics diminish CRH transcription and attenuate cortisol responses are addressed in 'neuroendocrine recalibration: HPA axis dampening' section.

### Immune-inflammatory pathway

The immune-inflammatory arm provides the molecular substrate for the long-standing "cytokine hypothesis of depression." In this framework, dysbiosis-driven intestinal hyperpermeability ("leaky gut") permits the systemic translocation of pathogen-associated molecular patterns (most importantly lipopolysaccharide [LPS]), which engage TLR4 on circulating monocytes and, after BBB transit or endothelial relay, on parenchymal microglia, driving the nuclear translocation of nuclear factor-kappa B (NF-κB) and the elaboration of proinflammatory cytokines, including interleukin (IL)-1β, IL-6, and tumor necrosis factor (TNF)-α [3]. Cumulative meta-analytic evidence has confirmed increased peripheral IL-6 and C-reactive protein levels among the most consistently replicated inflammatory biomarkers of MDD across independent cohorts, with effect sizes particularly pronounced in treatment-resistant cases [18]. A 2025 systematic review of antidepressant-naive, first-episode patients further demonstrated increases in IL-6, TNF-α, IL-2, IL-10, IL-4, and interferon-γ levels before any pharmacological exposure. This finding suggests that immune dysregulation is not solely attributable to medication [19]. Cao et al. [20] recently reported evidence in germ-free mice consistent with microbial transmission of affective vulnerability, demonstrating that fecal microbiota from prenatally depressed mothers transferred to germ-free recipients induced depressive-like behaviors and hippocampal microglial activation through the LPS–TLR4–myeloid differentiation primary response 88 (MyD88)–NF-κB pathway. The downstream mechanisms by which SCFAs reverse this immune-inflammatory cascade are described in 'Microglial reprogramming: TLR4/NF-κB and NLRP3 suppression' section.

### Metabolic pathway: microbial metabolites

The metabolic arm comprises the most diverse and therapeutically tractable conduit of the MGBA, with the gut microbiota functioning as a virtual endocrine organ that continuously generates a vast bioactive metabolome impinging on brain physiology [6]. SCFAs are among the most abundant and best characterized of these metabolites and are described in detail in 'SCFAs: BIOSYNTHESIS, TRANSPORT, AND RECEPTOR PHARMACOLOGY' and 'MOLECULAR MECHANISMS OF SCFA-MEDIATED MOOD REGULATION' sections. Beyond SCFAs, microbially deconjugated and dehydroxylated secondary bile acids activate Takeda G-protein-coupled receptor 5 and the farnesoid X receptor to modulate hepatic energy homeostasis, peripheral immunity, and central neuroinflammation. Microbial catabolism of dietary tryptophan represents an equally critical metabolic axis.

Specifically, gut commensals generate indole derivatives such as indole, indole-3-propionic acid, indole-3-aldehyde, and indole-3-acetic acid. These metabolites traverse the BBB and engage AhR on astrocytes and microglia to suppress the activation of NLR family pyrin domain containing 3 (NLRP3) inflammasome, preserve barrier integrity, and exert antidepressive effects [21]. Critically, this microbial tryptophan circuitry is sensitive to inflammation and reciprocally controlled by the SCFA-mediated regulation of indoleamine 2,3-dioxygenase 1 (IDO-1), as detailed in 'Tryptophan flux rebalancing and the kynurenine pathway' section. Additional microbial metabolites also converge upon overlapping receptor systems, which include GABA generated through *Lactobacillus* and *Bifidobacterium* glutamate decarboxylase activity, trimethylamine N-oxide, and branched-chain amino acid derivatives. Their convergence suggests that the metabolic arm functions less as a parallel conduit than an integrated chemical language through which neural, immune, and endocrine arms are coordinately tuned.

## PSYCHOBIOTICS: CONCEPTUAL FRAMEWORK AND CLASSIFICATION

### Conceptual evolution

The conceptual framework of "psychobiotics" was originally articulated in 2013 by Dinan and Cryan [22], who proposed a deliberately narrow definition encompassing live organisms that, when ingested in adequate amounts, produce a health benefit in patients with psychiatric illness. However, over the past decade, rapid progress in microbiome science, multiomics profiling, and translational psychiatry has rendered this initial framework highly restrictive. Therefore, Sarkar et al. [23] have expanded the term to encompass any microbiota-targeted intervention, whether live or nonviable, that exerts a bacterially mediated, positive effect on brain-behavior relationships through the MGBA. Under this expanded definition, psychobiotics now include conventional live probiotics, prebiotics, synbiotics, postbiotics, paraprobiotics, FMT, and engineered live biotherapeutic products (LBPs), unified by a shared mechanistic logic rather than a particular pharmaceutical form. The core therapeutic actions of modern psychobiotics revolve around four interlocking axes. The first is restoration of intestinal barrier integrity through tight-junction protein induction. The second is suppression of systemic and central inflammation through the downregulation of TLR4/NF-κB signaling. The third is normalization of HPA axis hyperactivity through reduced CRH and corticosterone output. The fourth is biochemical reprogramming of the gut into a factory for neuroactive metabolites, including SCFAs, GABA, serotonin precursors, and indole derivatives [24]. Comprehensive 2024–2025 systematic reviews have consolidated this expanded definition by demonstrating that probiotic, prebiotic, synbiotic, and postbiotic interventions confer statistically significant improvement in depressive symptomatology compared with placebo, thereby supporting the view that "psychobiotic" is a functional rather than a structural designation [25].

### Functional taxonomy: probiotics, prebiotics, synbiotics, and postbiotics

Psychobiotic therapeutics are structurally classified into four functionally complementary categories (Table 1). Probiotics are live beneficial microorganisms, most prominently strains of *Lactobacillus* and *Bifidobacterium* genera. They transiently colonize the gut and exert three major actions, viz., production of neurochemicals (especially GABA via glutamate decarboxylase activity), suppression of inflammatory cytokine secretion, and modulation of vagal afferent signaling. Prebiotics are selectively fermented dietary fibers and nondigestible oligosaccharides, including galacto-oligosaccharides (GOS), fructo-oligosaccharides (FOS), inulin, and resistant starches. These substrates expand native SCFA-producing commensals such as *Faecalibacterium prausnitzii*, *Roseburia*, and *Coprococcus*. Synbiotics leverage the rationally matched combination of live probiotics and prebiotic fibers. This pairing ensures that the introduced strains receive appropriate fermentable substrates, allowing them to survive gastrointestinal transit and maximize SCFA output upon colonic arrival. Postbiotics encompass nonviable microbial cells, cell wall fragments, extracellular vesicles, and purified functional metabolites such as synthesized sodium butyrate and tributyrin. They have emerged as highly stable, immunologically safer alternatives and are particularly attractive for immunocompromised individuals. By bypassing the engraftment risks associated with live bacterial therapy, postbiotics retain the capacity to inhibit HDACs, suppress NLRP3 inflammasome activation, and curtail neuroinflammation. Specific clinical evidence for each category is detailed in 'THERAPEUTIC STRATEGIES AND CLINICAL EVIDENCE' section.

Besides these defined categories, dietary patterns rich in microbiota-accessible carbohydrates merit specific mention. Berding et al. [26] demonstrated in healthy adults that a 4-week prebiotic-rich "psychobiotic diet" significantly reduced perceived stress and stabilized microbial diversity, providing rare nutritional-grade evidence that fiber-focused dietary modification alone can modulate stress reactivity—a finding of direct relevance to clinical nutri-

**Table 1.** Functional taxonomy of psychobiotic interventions for mood disorders

| Category | Definition | Representative agent | Primary mechanism of SCFA modulation | Key evidence in mood disorder |
|---|---|---|---|---|
| Probiotic | Live microorganisms that, when ingested in adequate amounts, confer mental health benefit through MGBA signaling | *Lactobacillus rhamnosus* JB-1<br>*Bifidobacterium breve* CCFM1025<br>*Bifidobacterium longum* 1714<br>Multistrain *Lactobacillus/ Bifidobacterium* formulations | Indirect SCFA elevation via cross-feeding networks; direct GABA biosynthesis through glutamate decarboxylase activity; vagal afferent modulation | Bravo et al. [15], 2011; Tian et al. [49], 2022 RCT; Nikolova et al. [50], 2023 RCT |
| Prebiotic | Selectively fermented nondigestible dietary substrates that support the expansion of native SCFA-producing commensals | FOS, GOS, inulin, β-glucans (oats, barley), resistant starches, pectin; psychobiotic dietary patterns | Direct expansion of *Faecalibacterium*, *Roseburia*, and *Coprococcus*, with a consequent increase in colonic butyrate, propionate, and acetate output | Berding et al. [26], 2023 dietary RCT |
| Synbiotic | Rationally matched combinations of live probiotic strains with prebiotic substrates designed for cross-feeding optimization | *Faecalibacterium prausnitzii*+FOS+GOS<br>Multistrain *Lactobacillus/ Bifidobacterium*+inulin | Optimized colonic SCFA output via substrate–strain pairing ensures viable colonic delivery and maximal fermentative yield | Palepu et al. [29], 2024 TRD synbiotic |
| Postbiotic | Nonviable microbial cells, cell wall components, extracellular vesicles, or purified bacterial metabolites with retained bioactivity | Sodium butyrate, tributyrin, Amuc_1100 (*Akkermansia muciniphila* outer membrane protein), bacterial extracellular vesicles, heat-killed *Lactobacillus* preparations | Direct HDAC inhibition (butyrate); receptor-independent epigenetic effects; bypass live strain engraftment risks; suitable for immunocompromised patients | Han et al. [37], 2014; Cheng et al. [31], 2021; Ma et al. [41], 2025 |

SCFA, short-chain fatty acid; MGBA, microbiota-gut-brain axis; GABA, γ-aminobutyric acid; RCT, randomized controlled trial; FOS, fructooligosaccharides; GOS, galactooligosaccharides; TRD, treatment-resistant depression; HDAC, histone deacetylase.

tion practice.

## NGPs and LBPs

The frontier of psychiatric microbiome therapy is rapidly shifting away from conventional, broad-spectrum, dairy-associated *Lactobacillus/Bifidobacterium* preparations toward NGPs, which are highly specific commensal anaerobes identified through comparative metagenomic profiling of healthy versus depressed populations and characterized at strain-level mechanisms. Three NGPs have advanced furthest in psychiatric translation. It must be emphasized at the outset that, for *F. prausnitzii* and *Akkermansia muciniphila*, the available psychiatric evidence is entirely preclinical, and no RCT of either organism has been conducted in patients with mood disorders. For *Clostridium butyricum*, the only clinical evidence is derived from a single uncontrolled open-label trial [27]. First, *F. prausnitzii* is a highly abundant obligate anaerobe that serves as a major contributor to colonic butyrate synthesis. Preclinical research has demonstrated that *F. prausnitzii* ATCC 27766 attenuates chronic unpredictable mild stress (CUMS)-induced anxiolytic and antidepressant-like deficits in rats by increasing cecal SCFA levels and reducing C-reactive protein and corticosterone levels [28]. Building on this evidence, a 2024 synbiotic formulation incorporating this strain together with FOS and GOS rescued TRD-like behaviors in rats by simultaneously restoring multiple gut-brain axis nodes [29]. Second, *A. muciniphila* is the mucin-degrading sentinel of the colonic mucus layer. In chronic-restraint-stress depression models, this organism restores HPA axis function, normalizes corticosterone levels, reestablishes dopaminergic homeostasis, and rescues hippocampal BDNF expression [30]. Mechanistically, its outer membrane protein Amuc_1100 alone attenuated CUMS-induced depression-like behavior in mice. The protein exerts this effect by increasing colonic and serum 5-HT levels, upregulating hippocampal BDNF/tropomyosin receptor kinase B signaling, and inhibiting microglial activation through TLR2-dependent pathways [31]. A 2025 systematic review and meta-analysis reported that live *A. muciniphila*, its pasteurized form, Amuc_1100, and *A. muciniphila*-derived extracellular vesicles were associated with the alleviation of anxiety-like, depression-like, and stress-related behaviors and rescue memory deficits across multiple stress paradigms in rodent models [32]. Third, *C. butyricum*, a robust SCFA generator, demonstrated efficacy across both preclinical and clinical settings, wherein an 8-week prospective open-label trial of *C. butyricum* MIYAIRI 588 as an adjunct to standard antidepressants in patients with TRD reported a 70% response rate with > 50% reduction in HAMD-17 scores [27], thereby providing preliminary, uncontrolled clinical data; however, the open-label design without a placebo arm precludes causal inference.

Beyond individual strain therapy, the regulatory category of LBPs has matured rapidly. LBPs are biological products containing live organisms intended for the prevention, treatment, or cure of human disease. Recent FDA approvals (2022–2023) of microbiome-based therapies for recurrent *Clostridioides difficile* infection have established the regulatory pathway. The 2025 Asia-Pacific Microbiota Consortium position statement on LBP development codified manufacturing, quality control, and clinical evaluation standards specifically tailored to neuropsychiatric indications [33]. Recent precision-psychobiotics frameworks emphasize that strain selection, dose, fermentation substrate, and host–microbiome compatibility must be optimized at the individual level rather than applied as one-size-fits-all formulations [34].

## SCFAS: BIOSYNTHESIS, TRANSPORT, AND RECEPTOR PHARMACOLOGY

SCFAs are aliphatic monocarboxylic acids generated predominantly through anaerobic bacterial fermentation of indigestible dietary fibers in the cecum and proximal colon. The three predominant species are acetate (C2), propionate (C3), and butyrate (C4), which together constitute >95% of the colonic SCFA pool in an approximate 3:1:1 molar ratio [6,7]. Their biosynthesis is taxonomically partitioned. Acetate is produced widely by *Bifidobacterium* and *Akkermansia*. Propionate is generated predominantly by Bacteroidetes via the succinate or propanediol pathways. Butyrate, the most extensively investigated with respect to neuroactive effects, is produced primarily by *F. prausnitzii*, *Roseburia*, *Coprococcus*, and *Clostridium* species. Several of these butyrate producers are found to be depleted in MDD and chronic stress models. Butyrate is consumed locally as the principal energy substrate of colonocytes, whereas acetate and propionate enter the portal circulation. Circulating acetate reaches systemic concentrations of 100 to 200 μM in humans.

Once in systemic circulation, SCFAs cross the BBB through proton-coupled monocarboxylate transporter 1 and sodium-coupled monocarboxylate transporter 1, yielding measurable cerebrospinal fluid concentrations (acetate up to 171 μM, propionate up to 6 μM, and butyrate up to 2.8 μM) [7]. Mechanistically, SCFAs act as endogenous ligands for free fatty acid receptor 2 (FFAR2/GPR43), free fatty acid receptor 3 (FFAR3/GPR41), and hydroxycarboxylic acid receptor 2 (HCAR2/GPR109A). All three are G-protein-coupled receptors expressed on enteroendocrine L-cells, peripheral immune cells, and CNS targets, including the cerebrovascular endothelium, microglia, and astrocytes. FFAR2 couples primarily to Gi/o and Gq, whereas FFAR3 couples to Gi/o. Both engage downstream protein kinase pathways and ion-channel modulation, which translate luminal SCFA availability into systemic neuroendocrine and immune signals. GPR109A also recognizes the vitamin niacin. It is enriched on colonocytes, adipocytes, and microglia and mediates the anti-inflammatory effects of butyrate at relatively high local concentrations.

A second mechanistic dimension operates intracellularly. SCFAs, particularly butyrate, act as competitive inhibitors of class I and class IIa HDACs. Among physiological SCFAs, butyrate demonstrates the highest potency. By increasing histone acetylation marks, such as histone H3 lysine 9 acetylation and histone H3 lysine 18 acetylation, at promoters of genes relevant to mood and synaptic plasticity (especially *Bdnf*), SCFAs exert chromatin-level transcriptional regulation independent of receptor engagement. Altogether, the BBB-permeable transport, surface-receptor architecture, and intrinsic HDAC-inhibitory activity position SCFAs to engage the downstream mechanisms described in 'MOLECULAR MECHANISMS OF SCFA-MEDIATED MOOD REGULATION.' From a clinical nutrition perspective, endogenous SCFA synthesis depends critically on the availability of fermentable substrates. The most important of these substrates are microbiota-accessible carbohydrates such as resistant starches, β-glucans, inulin, FOS, and GOS. This dependence directly motivates the prescription of dietary fibers as a foundational, mechanism-based intervention for mood disorders.

## MOLECULAR MECHANISMS OF SCFA-MEDIATED MOOD REGULATION

Unless otherwise specified, the mechanistic evidence summarized in this section is derived from rodent and *in vitro* studies; the only human data addressing these pathways directly are the acute cortisol findings discussed in 'Neuroendocrine recalibration: HPA axis dampening' section [35]. The extent to which these mechanisms operate at physiological SCFA concentrations in the human brain remains to be established.

The cumulative mechanistic findings outlined above converge upon six interlocking molecular axes through which SCFAs—particularly butyrate, propionate, and acetate—mediate antidepressant-like and anxiolytic-like effects (Fig. 2). The following subsections systematically dissect each mechanism, integrating

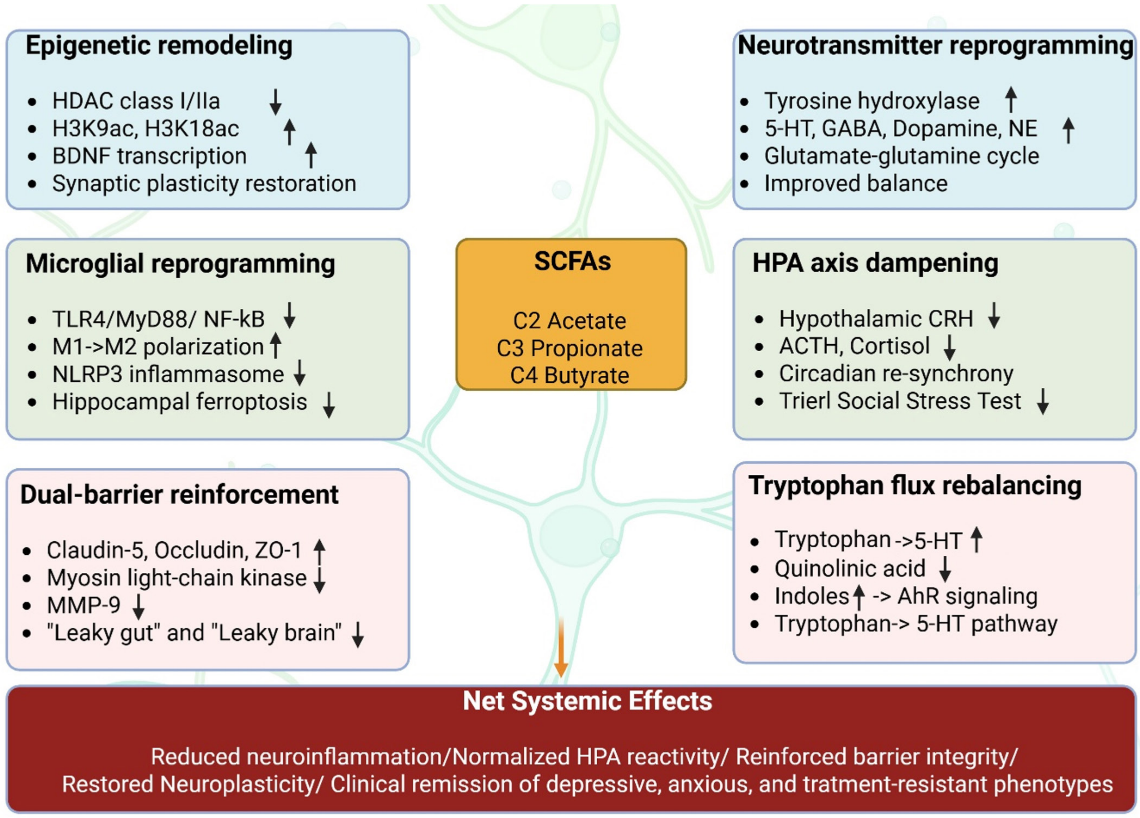


**Fig. 2.** Six molecular mechanisms of SCFA-mediated mood regulation. SCFAs, including primarily acetate (C2), propionate (C3), and butyrate (C4), exert convergent antidepressant- and anxiolytic-like actions through six interconnected molecular mechanisms ('MOLECULAR MECHANISMS OF SCFA-MEDIATED MOOD REGULATION' section). (1) Epigenetic remodeling: butyrate inhibits class I and IIa HDAC, increasing histone H3K9ac and H3K18ac at the BDNF promoter to restore synaptic plasticity. (2) Neurotransmitter reprogramming: enhanced tyrosine hydroxylase expression and increased biosynthesis of 5-HT, GABA, dopamine, and NE stabilize the glutamate–glutamine cycle and restore neurotransmitter balance. (3) Microglial reprogramming: suppression of TLR4/MyD88/NF-κB signaling promotes M1 to M2 polarization, attenuates NLRP3 inflammasome activation, and reduces hippocampal ferroptosis. (4) Neuroendocrine recalibration: HPA axis dampening—reductions in hypothalamic CRH, ACTH, and cortisol output restore circadian stress-response synchrony, resulting in measurable attenuation of Trier Social Stress Test responses. (5) Dual-barrier reinforcement: upregulation of claudin-5, occludin, and ZO-1, coupled with the downregulation of myosin light-chain kinase and MMP-9, restores intestinal and blood-brain barrier integrity. (6) Tryptophan flux rebalancing and the kynurenine pathway: suppression of indoleamine 2,3-dioxygenase 1 redirects tryptophan away from the neurotoxic kynurenine pathway toward serotonin synthesis, whereas sustained microbial indole production engages AhR signaling to modulate microglial and astrocytic function. The integrated outcome of these mechanisms is reduced neuroinflammation, restored neuroplasticity, normalized HPA reactivity, reinforced barrier integrity, and clinical remission of depressive, anxious, and treatment-resistant phenotypes. HDAC, histone deacetylase; H3K9ac, histone H3 lysine 9 acetylation; H3K18ac, histone H3 lysine 18 acetylation; BDNF, brain-derived neurotrophic factor; TLR4, toll-like receptor 4; MyD88, myeloid differentiation primary response 88; NF-κB, nuclear factor-kappa B; NLRP3, NLR family pyrin domain containing 3; ZO-1, zonula occludens 1; MMP-9, matrix metalloproteinase 9; SCFA, short-chain fatty acid; 5-HT, 5-hydroxytryptamine; GABA, γ-aminobutyric acid; NE, norepinephrine; CRH, corticotropin-releasing hormone; ACTH, adrenocorticotropic hormone; AhR, aryl hydrocarbon receptor; HPA, hypothalamic-pituitary-adrenal.

the above-described relevant components of MGBA signaling into a coherent therapeutic framework.

## Epigenetic remodeling: HDAC inhibition and BDNF transcription

One of the most extensively documented mechanisms by which SCFAs mitigate depression operates through epigenetic remodeling. Among SCFAs, butyrate is the most potent HDAC inhibitor. Through competitive inhibition of class I and class IIa HDACs, it promotes the accumulation of acetyl groups on histone tails and relaxes chromatin into a transcriptionally permissive state in brain regions that regulate mood [36]. In the hippocampus and prefrontal cortex, SCFA-induced HDAC inhibition upregulates BDNF transcription in the rodent brain, with the associated restoration of neuronal survival, dendritic arborization, and activity-dependent synaptic plasticity. In chronic restraint and CUMS rodent models, sodium butyrate reverses stress-induced reductions in the expression of phosphorylated cAMP response element-binding protein, acetylated histone H3, and BDNF; normalizes the expression of HDAC2 and HDAC5; and rescues behavioral despair in forced swim and tail suspension tests [37]. These epigenetic effects are accompanied by parallel reductions in DNA methyltransferase activity in stressed animals, suggesting that SCFA-driven antidepressant-like actions involve dual remodeling at both histone and DNA methylation levels.

### Neurotransmitter reprogramming

SCFAs modulate the biosynthesis and turnover of central neurotransmitters regulating the affective state. Propionate and butyrate increase tyrosine hydroxylase expression in the frontal cortex, improving dopamine and norepinephrine biosynthetic capacity [7]. Acetate, the most BBB-permeable SCFA, is taken up by astrocytes and incorporated into the glutamate–glutamine–GABA cycle, balancing excitatory glutamatergic and inhibitory GABAergic pools and providing biochemical stabilization against the excitotoxicity and hyperarousal characteristic of anxiety and depression. Synbiotic administration of GABA-producing *Lactobacillus* and *Bifidobacterium* strains together with butyrate-yielding fibers increases the expression of both peripheral GABA and hippocampal GABA-A receptors in stressed animals, mechanistically linking SCFA-mediated cross-feeding to inhibitory neurotransmission [15]. SCFA enrichment also improves the peripheral and central serotonergic tone through the induction of tryptophan hydroxylase 1 in EC cells, as described above [12], thereby integrating monoaminergic and amino-acid neurotransmitter pathways through a single fermentation-derived signal.

### Microglial reprogramming: TLR4/NF-κB and NLRP3 suppression

The landmark study by Erny et al. [38] demonstrated that germ-free mice exhibit severely malformed microglia, substantially rescued by the oral administration of SCFA mixture, indicating that microbiota-derived SCFAs are essential for normal microglial maturation in mice. Building on the immune-inflammatory framework described above, SCFAs promote a shift in microglia phenotype from a proinflammatory M1 phenotype toward an anti-inflammatory M2 phenotype enriched in arginase-1 and IL-10. Sodium butyrate attenuates microglia-mediated neuroinflammation through coordinated TLR4/MyD88/NF-κB inhibition in cardiac arrest mice [39], and rifaximin-induced enrichment of Lachnospiraceae and Ruminococcaceae increases brain butyrate levels and reverses CUMS-induced microglial proinflammatory polarization in adolescent rats [40]. SCFA-mediated activation of GPR109A on microglia engages the nuclear factor erythroid 2-related factor 2 (Nrf2)/heme oxygenase-1 antioxidant pathway and inhibits NLRP3 inflammasome assembly, with the associated protection of neurons in preclinical models. Recent research has demonstrated that butyric and valeric acids attenuate stress-induced hippocampal ferroptosis and depressive-like behaviors by suppressing iron-dependent neuroinflammation [41], thus adding ferroptosis to the expanding repertoire of SCFA-targeted neurodegenerative pathways.

### Neuroendocrine recalibration: HPA axis dampening

Beyond the broader microbiota-mediated HPA modulation discussed above, SCFAs themselves function as the active molecular effectors of this regulation. Experimental administration of SCFAs or FMT from SCFA-enriched donors significantly downregulates hypothalamic CRH and its cognate receptors. This downregulation attenuates the initiation of the stress cascade. It translates into marked reductions in circulating corticosterone and cortisol levels after acute and chronic stressors [10]. Critically, Dalile et al. [35] provided rare clinical-grade evidence in a randomized placebo-controlled trial that colon-delivered SCFA mixtures attenuate cortisol responses to the Trier Social Stress Test in healthy men, using an acute laboratory stressor rather than a clinical population, directly linking microbial fermentation products to top-down HPA modulation. Moreover, the recent demonstration that the gut microbiota gates HPA axis responsiveness in a strictly circadian manner suggests that SCFA-producing psychobiotics exert anxiolytic effects partially by restoring circadian stress-response synchrony—a hypothesis with direct implications for the timing of nutritional and psychobiotic interventions [17].

### Dual-barrier reinforcement: intestinal and BBB integrity

SCFAs, and butyrate in particular, are important regulators of barrier integrity at both the intestinal epithelium and BBB. They potently upregulate transcription and proper membrane localization of essential tight-junction proteins at both interfaces. These proteins include claudin-5, which serves as the master gatekeeper of paracellular BBB permeability, and occludin and zonula occludens-1. Mechanistically, SCFAs inhibit the myosin light-chain kinase pathway and downregulate matrix metalloproteinase-9 (MMP-9), potentially interrupting the proposed cycle of "leaky gut" and "leaky brain." Monocolonization of germ-free mice with SCFA-producing strains reversed BBB hyperpermeability and restored the cerebral expression of tight-junction proteins [42]. Greene et al. [43] established claudin-5 as a depression- and schizophrenia-relevant gatekeeper whose dysregulation is associated with behavioral phenotypes in animal models, thus supporting tight-junction reinforcement as a plausible therapeutic target in mood disorders.

### Tryptophan flux rebalancing and the kynurenine pathway

As outlined above, tryptophan metabolism is linked with AhR signaling. Building on that framework, SCFAs exert specific control over the inflammatory diversion of tryptophan away from serotonin and toward neurotoxic kynurenine metabolites. Under inflammatory conditions, proinflammatory cytokines such as interferon-γ and TNF-α upregulate IDO-1 in both peripheral macrophages and brain microglia. This upregulation shunts tryptophan flux away from serotonin synthesis and toward neurotoxic kynurenine metabolites, including 3-hydroxykynurenine and quinolinic acid. Quinolinic acid is a potent N-methyl-D-aspartate receptor agonist and drives glutamatergic excitotoxicity, hippocampal neuronal apoptosis, and depressive symptomatology [44]. SCFAs counteract this diversion through multiple complementary mechanisms. First, they suppress the upstream microglial inflammatory activation that induces IDO-1. Second, they directly downregulate IDO-1 expression in the gut and hippocampus. Third, they sustain the microbial production of indole derivatives. These indoles engage AhR on astrocytes and microglia to suppress NLRP3 inflammasome activation, modulate type I interferon responses, and preserve barrier integrity [21,45]. Vascular-depression rodent studies have confirmed that SCFA administration potently suppresses IDO-1 expression in both the gut and hippocampus, restores tryptophan flux toward serotonin, and mitigates depressive-like behavior [46]. By redirecting tryptophan metabolism away from the neurotoxic kynurenine cascade and toward mood-elevating serotonin and AhR-engaging indoles, SCFAs may serve as a convergence point linking the immune, neurotransmitter, and metabolic arms of the MGBA into a unified therapeutic node.

## THERAPEUTIC STRATEGIES AND CLINICAL EVIDENCE

### Disease-stratified therapeutic rationale: a largely preclinical framework

The therapeutic rationale for SCFA-generating psychobiotics is anchored in disease-specific microbial and metabolic signatures documented across the spectrum of affective disorders. In MDD, large-scale multiomics analyses have frequently reported the depletion of *Faecalibacterium*, *Roseburia*, *Coprococcus*, and *Subdoligranulum*. This taxonomic depletion is accompanied by reduced levels of fecal and serum acetate, propionate, and butyrate. Rodent FMT experiments support a contributory causal role wherein depression-associated microbiota were transferred into rodents [4]. In a TRD rat model generated by CUMS plus adrenocorticotropic hormone, FMT from TRD donors transferred severe anxiety-like and depression-like behavior to recipients, whereas supplementation with a synbiotic combining *F. prausnitzii* with FOS and GOS rescued these behavioral deficits and restored the levels of hippocampal BDNF, monoamines, and tight-junction proteins [29]. Anxiety disorders share a similar dysbiotic footprint marked by reduced acetate and propionate levels that fail to appropriately tune inhibitory GABAergic signaling required to suppress amygdala hyperreactivity [47]. PTSD-associated dysbiosis is dominated by the depletion of butyrate-producing Lachnospiraceae and Ruminococcaceae and an overgrowth of proinflammatory taxa, resulting in LPS leakage that perpetuates microglial activation and impairs fear-extinction circuitry [48]. In vascular depression, chronic-cerebral-hypoperfusion rodent studies have demonstrated that SCFA supplementation attenuated microglial activation, oxidative stress, and IDO-1-driven tryptophan depletion in the hippocampus, thus providing a preclinical rationale for further investigation [46].

### Probiotics and synbiotics: mood-modulating efficacy

Although conventional *Lactobacillus* and *Bifidobacterium* preparations primarily produce lactic and acetic acids, they orchestrate a beneficial cross-feeding environment that increases colonic butyrate production, exerting psychobiotic effects through indirect elevation of SCFA levels. A 4-week double-blind RCT of *Bifidobacterium breve* CCFM1025 ($10^9$ CFUs/day) in 45 patients with MDD demonstrated significant reductions in 24-item Hamilton

Depression Rating Scale (HDRS-24) and Montgomery–Asberg Depression Rating Scale scores accompanied by increased levels of fecal SCFAs, modulated tryptophan metabolism, and decreased serotonin turnover, consistent with neuroactive effects, although the small sample (n = 45) and 4-week duration limit inference [49]. Furthermore, a 2023 RCT published in JAMA Psychiatry confirmed the acceptability and putative benefit of multistrain probiotic adjunctive therapy in adults with MDD [50]. Among next-generation strains, *F. prausnitzii* ATCC 27766 robustly reverses CUMS-induced anxiety- and depression-like deficits by increasing cecal SCFA levels and reducing C-reactive protein and corticosterone levels [28], whereas live *A. muciniphila* and its outer membrane protein Amuc_1100 normalize HPA function, restore hippocampal BDNF levels, and rescue dopaminergic homeostasis across multiple stress paradigms [30-32].

Synbiotics are combinations of live probiotics with rationally matched prebiotic fibers. They optimize colonic SCFA output and have demonstrated promising preclinical efficacy in treatment-resistant models. For instance, a synbiotic combining *F. prausnitzii* with FOS and GOS reversed TRD-like behaviors in a rat model induced by CUMS plus adrenocorticotropic hormone. This effect was achieved by simultaneously restoring cecal SCFA concentrations, hippocampal neurogenesis, and gut-barrier integrity [29]. Microbiota-accessible carbohydrates include resistant starches, β-glucans, inulin, FOS, and GOS, which selectively expand native *Bifidobacterium* and butyrate-producing Firmicutes. In healthy adults, a 4-week dietary intervention with a prebiotic-rich psychobiotic diet significantly reduced perceived stress and stabilized microbial diversity [26].

## Postbiotic SCFA delivery

Postbiotic strategies involve the direct administration of purified microbial metabolites or nonviable bacterial components. They bypass the engraftment complexities of live bacterial therapy and represent particularly attractive options for severe, treatment-resistant cases. Direct administration of sodium butyrate or tributyrin has demonstrated efficacy in preclinical paradigms across multiple preclinical paradigms. These postbiotics act as potent acute HDAC inhibitors and restore histone acetylation, rescue hippocampal BDNF expression, rebuild BBB tight junctions, and attenuate behavioral despair in rodents [36,37]. In high-fructose-fed mice, an SCFA mixture rescued hippocampal neurogenesis decline and BBB damage, demonstrating that postbiotic supplementation can reverse diet-induced affective deterioration [42]. Recent research on butyric and valeric acids has further demonstrated the attenuation of stress-induced hippocampal ferroptosis and depressive-like behaviors [41]. Postbiotic formats currently advancing toward clinical translation include nonviable *Lactobacillus* preparations, *A. muciniphila*-derived Amuc_1100, and bacterial extracellular vesicles [32].

## Clinical translation: RCTs and meta-analyses (2022–2026)

The clinical translation of SCFA-generating psychobiotics has substantially accelerated over the past 4 years. Table 2 summarizes the key RCTs and meta-analyses. A 2025 systematic review of 19 RCTs reported that all included trials demonstrated significant amelioration of depression status with probiotic or psychobiotic intervention. The intervention was used as a standalone therapy in five trials and as an adjunct to antidepressants in 10 trials [8]. Furthermore, a 2025 meta-analysis of FMT trials encompassing 681 participants reported a standardized mean difference of −1.21 (95% confidence interval, −1.87 to −0.55; P = 0.0003) for depressive symptom reduction, providing the largest pooled clinical estimate to date, although the wide confidence interval and heterogeneity across small trials warrant caution for microbiota transfer in depression [5]. Another 2025 case-control study demonstrated that baseline circulating SCFA concentrations significantly predicted 6-month remission in patients with MDD. This finding supports the dual role of SCFAs as biomarkers and therapeutic targets. Moreover, a 2026 meta-analysis quantitatively confirmed a robust SCFA-deficit signature in MDD individuals versus healthy controls. The signature consisted of reduced acetate, propionate, butyrate, and isobutyrate levels [9]. Although multistrain formulations generally outperform single-strain preparations, their efficacy remains heavily dependent on baseline severity, dosage, and intervention duration, with interventions exceeding 8 weeks tending to demonstrate superior outcomes. The open-label trial by Miyaoka et al. [27] demonstrating that *C. butyricum* MIYAIRI 588 as an adjunct to standard antidepressants achieved a 70% response rate in patients with TRD remains the only available clinical dataset for a single-strain NGP, although the trial was uncontrolled.

## Clinical nutrition perspective: integrating dietary fiber, MAC, and psychobiotics

From a clinical nutrition viewpoint, the foregoing mechanistic and clinical evidence reframes three elements as legitimate, mechanism-based nutritional interventions for mood disorders rather than peripheral lifestyle recommendations. These elements are di-

**Table 2.** Key clinical trials and meta-analyses of SCFA-producing psychobiotics in mood disorders (2018–2026)

| Study | Design/population | Intervention | Duration | Key outcome | Evidence level |
|---|---|---|---|---|---|
| Miyaoka et al. [27] (2018) | Open-label prospective trial: 40 TRD patients | *Clostridium butyricum* MIYAIRI 588 (60 mg/day) adjunct to standard antidepressant | 8 wk | 70% response rate; >50% HAMD-17 reduction; only clinical dataset for a single-strain NGP to date; no placebo arm, precluding causal inference | Clinical-open-label, uncontrolled |
| Dalile et al. [35] (2020) | Double-blind placebo-controlled RCT (66 healthy men) | Colon-delivered SCFA mixture (acetate/propionate/butyrate) | Acute (TSST) | Significant attenuation of cortisol response to psychosocial stress; principal human evidence linking SCFAs to HPA modulation; acute laboratory stressor in healthy men | Clinical-RCT healthy volunteers, surrogate endpoint |
| Tian et al. [49] (2022) | Double-blind RCT (45 MDD patients) | Bifidobacterium breve CCFM1025 ($10^9$ CFU/day) | 4 wk | Significant reduction in HDRS-24 and MADRS scores; increased fecal SCFA levels; modulated tryptophan metabolism; decreased serotonin turnover | Clinical RCT, MDD, small (n=45) |
| Berding et al. [26] (2023) | RCT; healthy adults | Prebiotic-rich “psychobiotic diet” (high MAC, fermented foods) | 4 wk | Significant reduction in perceived stress; stabilized microbial diversity; early nutritional evidence for fiber-focused modulation of perceived stress | Clinical-RCT, healthy adults, nonclinical endpoint |
| Nikolova et al. [50] (2023) | Double-blind RCT; adults with MDD | Multistrain probiotic adjunct to standard antidepressants | 8 wk | Improved depressive symptomatology; favorable acceptability and tolerability profile | Clinical-RCT, MDD, and feasibility/acceptability |
| Khalili et al. [32] (2025) | Systematic review and meta-analysis; preclinical depression/anxiety/stress models | Live *Akkermansia muciniphila*, pasteurized *A. muciniphila*, Amuc_1100, *A. muciniphila*-derived extracellular vesicles | - | Alleviation of anxiety-, depression-, and stress-related behaviors and memory deficits in rodent models | Preclinical meta-analysis of rodent studies |
| Menni et al. [8] (2025) | Systematic review (19 RCTs in adults with depression) | Probiotic or psychobiotic interventions, standalone (5 trials) or as an adjunct to antidepressants (10 trials) | - | All 19 trials demonstrated significant amelioration of depression status; multistrain formulations generally outperformed single-strain formulations | Clinical-systematic review |
| Zhang et al. [5] (2025) | Meta-analysis of RCTs (681 participants) | Fecal microbiota transplantation | - | SMD=−1.21 (95% CI, −1.87 to −0.55; P=0.0003) for depressive symptom reduction; largest pooled clinical estimate to date; wide CI and heterogeneity across small trials warrant caution | Clinical meta-analysis of RCTs |
| Do et al. [9] (2026) | Meta-analysis (MDD vs. healthy controls) | Circulating SCFA profile comparison | - | Reported an SCFA-deficit signature (reduced acetate, propionate, butyrate, isobutyrate levels) in MDD versus healthy controls | Clinical meta-analysis, biomarker (not intervention) |

SCFA, short-chain fatty acid; TRD, treatment-resistant depression; HAMD-17, 17-item Hamilton Depression Rating Scale; NGP, next-generation psychobiotic; RCT, randomized controlled trial; TSST, Trier Social Stress Test; HPA axis, hypothalamic-pituitary-adrenal axis; MDD, major depressive disorder; CFU, colony-forming unit; HDRS-24, 24-item Hamilton Depression Rating Scale; MADRS, Montgomery–Åsberg Depression Rating Scale; MAC, microbiota-accessible carbohydrate; SMD, standardized mean difference; CI, confidence interval.

etary fiber intake, fermentable substrate selection, and targeted SCFA-generating psychobiotic supplementation. Several actionable principles emerge for clinical nutrition practice. First, baseline dietary fiber intake should be evaluated and optimized. Typical adult intakes in numerous populations are well below 25 to 38 g/day generally recommended for adults. Habitual low fiber intake may not support sufficient endogenous generation of SCFAs. Second, the dietary diversity of microbiota-accessible carbohydrates maximizes the substrate range required to support a diverse SCFA-producing microbial consortium. Practical food sources include resistant starches from cooled potatoes and legumes, β-glucans from oats and barley, inulin and FOS from chicory, garlic, leeks, and onions, GOS from legumes, and pectin from apples and citrus fruits. Third, traditional fermented foods such as kimchi, yogurt, kefir, and miso provide live *Lactobacillus* and *Bifidobacterium* that, although rarely engrafting permanently, transiently support cross-feeding networks that increase butyrate output. Fourth, defined synbiotic formulations and postbiotic SCFA preparations may be considered adjuncts to conventional psychopharmacology in patients with TRD, anxiety with prominent gastrointestinal symptoms, or vascular depression with documented dysbiosis. Personalized nutritional protocols integrating these elements provide a biologically rational complement to monoamine-targeted therapy and simultaneously address the gastrointestinal and metabolic comorbidities that frequently accompany mood disorders.

## CHALLENGES, FUTURE DIRECTIONS, AND CONCLUSION

The intense exploration of the MGBA over the past decade has substantially expanded our conception of mood disorders, transforming the pathophysiological framework from an isolated, brain-centric defect toward a systemic derangement involving the intestinal microbiome and its metabolic output. SCFAs, particularly butyrate, propionate, and acetate, have emerged as important molecular mediators within this network. They can exert epigenetic regulation through HDAC inhibition, may attenuate neuroinflammation by modulating microglial TLR4/NF-κB and NLRP3 signaling, may reinforce the structural integrity of the BBB and intestinal mucosa, and may rebalance the metabolic flow of monoamines and the tryptophan-to-kynurenine pathway. Restoration of these depleted microbial metabolites through targeted administration of NGPs, prebiotics, synbiotics, and direct postbiotic supplementation represents a rapidly advancing therapeutic frontier that has demonstrated promise in preclinical models of treatment-resistant phenotypes. Nonetheless, whether that promise extends to patients depends on how the field confronts the limitations and translational hurdles described in the next section.

### Limitations and knowledge gaps

Several limitations of the current evidence base, and of this review itself, warrant explicit acknowledgment.

#### *First, the mechanistic–clinical asymmetry*

The molecular mechanisms rest almost entirely on rodent and *in vitro* studies. Direct human evidence is confined to a single acute-stress RCT in healthy men [35], three small trials in patients with depression [27,49,50], a dietary intervention trial in healthy adults [26], and observational biomarker studies. No RCT has yet evaluated *F. prausnitzii* or *A. muciniphila* in a psychiatric population, and no trial has demonstrated that clinical improvement is mediated by SCFA elevation rather than merely accompanied by it.

#### *Second, pharmacokinetic uncertainty*

Reported cerebrospinal fluid concentrations of butyrate (up to approximately 2.8 μM) are two to three orders of magnitude less than those required for HDAC inhibition *in vitro* [7]. Whether butyrate acts as a direct central HDAC inhibitor at physiological concentrations or whether central histone acetylation changes are mediated indirectly via acetate-derived acetyl-CoA in astrocytes, peripheral receptor signaling, or vagal relay remains unresolved.

#### *Third, the assumption of uniform benefit*

This review has emphasized beneficial SCFA actions; however, the literature is not uniformly positive. Propionate administration causes behavioral and neuroinflammatory abnormalities in some rodent paradigms, increased rather than reduced SCFA levels have been reported in certain patient cohorts, and FFAR2/FFAR3 signaling is context- and cell-type-dependent. Therefore, the effects of SCFAs may be dose-, timing-, and host-dependent rather than monotonically beneficial.

#### *Fourth, risk of publication and small-study bias*

The observation that all 19 trials in a recent systematic review reported significant benefit is itself atypical for a heterogeneous intervention literature and raises the possibility that null trials are underreported [8]. Existing trials are small, short, and rarely include an intention-to-treat analysis or long-term follow-up. Hence, pooled effect estimates such as the FMT standardized mean difference of −1.21 must be considered provisional [5].

*Fifth, limitations of this review*

As a narrative rather than a systematic review, this synthesis did not use a preregistered protocol, systematic search strategy, or formal risk-of-bias assessment and is consequently subject to selection bias in the cited studies.

These gaps define the priorities for the next phase of research, viz., adequately powered, placebo-controlled trials of defined strains in well-characterized clinical populations, with prespecified SCFA mediation analyses and long-term follow-up. Realizing that agenda requires confronting several translational hurdles.

## Translational challenges and future directions

*Strain specificity*

Psychobiotic effects appear to be largely strain-specific and cannot be safely generalized across taxonomic genera, or in some cases even across strains of the same species. Therefore, clinical trials require standardized identification and reporting at the strain level, together with the deposition of characterized strains in public culture collections.

*Methodological standardization*

Existing trials are inconsistent in two key parameters, viz., dosing ranges from $10^8$ to $10^{10}$ CFU and intervention duration typically spans 4 to 12 weeks. Beyond the abovementioned interpretive difficulties, this variability has prevented the field from establishing dose-response relationships or a minimum effective duration—both prerequisites for evidence-based prescription. Consensus reporting standards for strain, dose, viability at administration, and fermentable substrate co-intake are necessary.

*Delivery and formulation*

The rapid hepatic first-pass metabolism and short systemic half-life of exogenous SCFAs constrain sustained delivery. The central concentrations achievable by this route may be inadequate for the mechanisms most frequently invoked. Colon-targeted and sustained-release formulations, prodrug approaches such as tributyrin, and strategies that stimulate endogenous colonic production rather than supplying exogenous SCFAs each warrant systematic head-to-head comparison.

*Interindividual variability*

The human microbiome is highly individualized, shaped by host genetics, habitual diet, geography, and lifetime antibiotic exposure. This individuality may restrict the reliability of one-size-fits-all formulations and argues for a shift toward precision-psychobiotic medicine, guided by the following three pillars: multiomics profiling supported by computational and machine-learning approaches; validated SCFA-based biomarker panels incorporating circulating SCFA ratios, the kynurenine-to-tryptophan balance, and microbial enterotypes; and rigorously standardized clinical-grade manufacturing under emerging LBP regulatory frameworks [33,34].

*Therapeutic positioning*

Psychobiotics must not be positioned as standalone replacements for conventional pharmacotherapy. Their most plausible near-term value lies in adjunctive integration with SSRIs and SNRIs, where preclinical evidence suggests additive or synergistic antidepressant-like effects together with possible mitigation of the gastrointestinal and metabolic adverse effects associated with monoaminergic drugs [37]. Neither observation has yet been confirmed in humans, and adequately powered add-on trials with prespecified tolerability endpoints represent an immediate priority.

From a clinical nutrition perspective, four translational priorities stand out as most immediate. The first is to integrate validated assessment of dietary fiber and microbiota-accessible carbohydrate intake into routine psychiatric and clinical nutrition consultation. The second is to develop evidence-based synbiotic and postbiotic formulations standardized for psychiatric indications. The third is to register psychobiotic nutrition interventions prospectively within structured clinical trial frameworks, including the reporting of null results. The fourth is to educate dietitians and clinicians on strain-level mechanism, dosing, and duration of psychobiotic interventions, so that emerging evidence is translated neither prematurely nor with undue delay.

## Conclusion

The field is advancing toward precision medicine and toward the strategic integration of microbiota-targeted therapies with conventional psychopharmacology. Within this trajectory, SCFA-modulating interventions hold promise as a complementary approach in psychiatric care, although current evidence remains dominated by preclinical models, and the human trials conducted to date are limited in size, duration, and number. Personalized nutritional protocols integrating microbiota-accessible carbohydrates, defined synbiotic formulations, and postbiotic SCFA preparations provide a biologically rational adjunct to conventional psychiatric pharmacotherapy, one that may simultaneously address the gastrointestinal, metabolic, and neurobehavioral dimensions of disease. As the evidence base matures, and provided the above-described methodological and translational requirements are met, microbiota-targeted nutritional therapy may become a useful component of integrative clinical care for patients with TRD and other mood disorders.

## ARTICLE INFORMATION

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### Authors' contributions

All the work was done by JS.

### Conflict of interest

None.

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### Data availability

Not applicable.

## REFERENCES

1. GBD 2019 Mental Disorders Collaborators. Global, regional, and national burden of 12 mental disorders in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet Psychiatry 2022;9:137-50.
2. Fabbri C, Corponi F, Souery D, et al. The genetics of treatment-resistant depression: a critical review and future perspectives. Int J Neuropsychopharmacol 2019;22:93-104.
3. Morais LH, Schreiber HL, Mazmanian SK. The gut microbiota-brain axis in behaviour and brain disorders. Nat Rev Microbiol 2021;19:241-55.
4. Kelly JR, Borre Y, O' Brien C, et al. Transferring the blues: depression-associated gut microbiota induces neurobehavioural changes in the rat. J Psychiatr Res 2016;82:109-18.
5. Zhang X, Li Y, Guo Y, Sun J, Yang Y. Clinical efficacy of fecal microbiota transplantation in alleviating depressive symptoms: a meta-analysis of randomized trials. Front Psychiatry 2025;16:1656969.
6. Dalile B, Van Oudenhove L, Vervliet B, Verbeke K. The role of short-chain fatty acids in microbiota-gut-brain communication. Nat Rev Gastroenterol Hepatol 2019;16:461-78.
7. Silva YP, Bernardi A, Frozza RL. The role of short-chain fatty acids from gut microbiota in gut-brain communication. Front Endocrinol (Lausanne) 2020;11:25.
8. Menni AE, Theodorou H, Tzikos G, et al. Rewiring mood: precision psychobiotics as adjunct or stand-alone therapy in depression using insights from 19 randomized controlled trials in adults. Nutrients 2025;17:2022.
9. Do QL, Malau IA, Nguyen HT, Liu J, Chang JP, Su KP. Circulating short-chain fatty acid (SCFA) profiles as a biomarker of gut-brain axis dysfunction: a meta-analysis for the SCFA signature in major depression. Biomed J 2026;49:100968.
10. Margolis KG, Cryan JF, Mayer EA. The microbiota-gut-brain axis: from motility to mood. Gastroenterology 2021;160:1486-501.
11. Yano JM, Yu K, Donaldson GP, et al. Indigenous bacteria from the gut microbiota regulate host serotonin biosynthesis. Cell 2015;161:264-76.
12. Reigstad CS, Salmonson CE, Rainey JF, et al. Gut microbes promote colonic serotonin production through an effect of short-chain fatty acids on enterochromaffin cells. FASEB J 2015;29:1395-403.
13. Bayrer JR, Castro J, Venkataraman A, et al. Gut enterochromaffin cells drive visceral pain and anxiety. Nature 2023;616:137-42.
14. Siopi E, Galerne M, Rivagorda M, et al. Gut microbiota changes require vagus nerve integrity to promote depressive-like behaviors in mice. Mol Psychiatry 2023;28:3002-12.
15. Bravo JA, Forsythe P, Chew MV, et al. Ingestion of Lactobacillus strain regulates emotional behavior and central GABA receptor expression in a mouse via the vagus nerve. Proc Natl Acad Sci U S A 2011;108:16050-5.
16. Sudo N, Chida Y, Aiba Y, et al. Postnatal microbial colonization programs the hypothalamic-pituitary-adrenal system for stress response in mice. J Physiol 2004;558:263-75.
17. Tofani GS, Leigh SJ, Gheorghe CE, et al. Gut microbiota regulates stress responsivity via the circadian system. Cell Metab 2025;37:138-53.
18. Kohler CA, Freitas TH, Maes M, et al. Peripheral cytokine and chemokine alterations in depression: a meta-analysis of 82 studies. Acta Psychiatr Scand 2017;135:373-87.
19. Gedek A, Modrzejewski S, Materna M, Iwanski M, Wichniak A, Dominiak M. Altered cytokine levels in the first episode of major depression and in antidepressant-naive patients: a systematic review and meta-analysis. Int J Mol Sci 2025;26:10362.
20. Cao Y, Fan X, Zang T, et al. Prenatal depression-associated gut mi-

crobiota induces depressive-like behaviors and hippocampal neuroinflammation in germ-free mice. Transl Psychiatry 2025;15:383.
21. Miyamoto K, Sujino T, Kanai T. The tryptophan metabolic pathway of the microbiome and host cells in health and disease. Int Immunol 2024;36:601-16.
22. Dinan TG, Cryan JF. Melancholic microbes: a link between gut microbiota and depression? Neurogastroenterol Motil 2013;25:713-9.
23. Sarkar A, Lehto SM, Harty S, Dinan TG, Cryan JF, Burnet PW. Psychobiotics and the manipulation of bacteria-gut-brain signals. Trends Neurosci 2016;39:763-81.
24. Cocean AM, Vodnar DC. Exploring the gut-brain axis: potential therapeutic impact of psychobiotics on mental health. Prog Neuropsychopharmacol Biol Psychiatry 2024;134:111073.
25. Dai LY, Chen RR, Chen HR, et al. Potential clinical benefits of probiotics, prebiotics, synbiotics, and postbiotics for depression via the microbiota-gut-brain axis. World J Psychiatry 2025;15:98436.
26. Berding K, Bastiaanssen TF, Moloney GM, et al. Feed your microbes to deal with stress: a psychobiotic diet impacts microbial stability and perceived stress in a healthy adult population. Mol Psychiatry 2023;28:601-10.
27. Miyaoka T, Kanayama M, Wake R, et al. Clostridium butyricum MIYAIRI 588 as adjunctive therapy for treatment-resistant major depressive disorder: a prospective open-label trial. Clin Neuropharmacol 2018;41:151-5.
28. Hao Z, Wang W, Guo R, Liu H. Faecalibacterium prausnitzii (ATCC 27766) has preventive and therapeutic effects on chronic unpredictable mild stress-induced depression-like and anxiety-like behavior in rats. Psychoneuroendocrinology 2019;104:132-42.
29. Palepu MS, Bhalerao HA, Sonti R, Dandekar MP. Faecalibacterium prausnitzii, FOS and GOS loaded synbiotic reverses treatment-resistant depression in rats: restoration of gut-brain crosstalk. Eur J Pharmacol 2024;983:176960.
30. Ding Y, Bu F, Chen T, et al. A next-generation probiotic: Akkermansia muciniphila ameliorates chronic stress-induced depressive-like behavior in mice by regulating gut microbiota and metabolites. Appl Microbiol Biotechnol 2021;105:8411-26.
31. Cheng R, Xu W, Wang J, Tang Z, Zhang M. The outer membrane protein Amuc_1100 of Akkermansia muciniphila alleviates the depression-like behavior of depressed mice induced by chronic stress. Biochem Biophys Res Commun 2021;566:170-6.
32. Khalili L, Park G, Nagpal R, Bhide P, Salazar G. The impact of Akkermansia muciniphila on mouse models of depression, anxiety, and stress: a systematic review and meta-analysis. Curr Neuropharmacol 2025;23:1423-41.
33. Tseng CH, Wong S, Yu J, et al. Development of live biotherapeutic products: a position statement of Asia-Pacific Microbiota Consortium. Gut 2025;74:706-13.
34. Slykerman RF, Davies N, Vlckova K, et al. Precision psychobiotics for gut-brain axis health: advancing the discovery pipelines to deliver mechanistic pathways and proven health efficacy. Microb Biotechnol 2025;18:e70079.
35. Dalile B, Vervliet B, Bergonzelli G, Verbeke K, Van Oudenhove L. Colon-delivered short-chain fatty acids attenuate the cortisol response to psychosocial stress in healthy men: a randomized, placebo-controlled trial. Neuropsychopharmacology 2020;45:2257-66.
36. Stilling RM, van de Wouw M, Clarke G, Stanton C, Dinan TG, Cryan JF. The neuropharmacology of butyrate: the bread and butter of the microbiota-gut-brain axis? Neurochem Int 2016;99:110-32.
37. Han A, Sung YB, Chung SY, Kwon MS. Possible additional antidepressant-like mechanism of sodium butyrate: targeting the hippocampus. Neuropharmacology 2014;81:292-302.
38. Erny D, Hrabe de Angelis AL, Jaitin D, et al. Host microbiota constantly control maturation and function of microglia in the CNS. Nat Neurosci 2015;18:965-77.
39. Sun J, Lu L, Lian Y, et al. Sodium butyrate attenuates microglia-mediated neuroinflammation by modulating the TLR4/MyD88/NF-κB pathway and microbiome-gut-brain axis in cardiac arrest mice. Mol Brain 2025;18:13.
40. Li H, Xiang Y, Zhu Z, et al. Rifaximin-mediated gut microbiota regulation modulates the function of microglia and protects against CUMS-induced depression-like behaviors in adolescent rat. J Neuroinflammation 2021;18:254.
41. Ma X, Shi W, Wang Z, et al. Butyric acid and valeric acid attenuate stress-induced ferroptosis and depressive-like behaviors by suppressing hippocampal neuroinflammation. J Transl Med 2025;23:974.
42. Tang CF, Wang CY, Wang JH, et al. Short-chain fatty acids ameliorate depressive-like behaviors of high fructose-fed mice by rescuing hippocampal neurogenesis decline and blood-brain barrier damage. Nutrients 2022;14:1882.
43. Greene C, Hanley N, Campbell M. Claudin-5: gatekeeper of neurological function. Fluids Barriers CNS 2019;16:3.
44. Cervenka I, Agudelo LZ, Ruas JL. Kynurenines: tryptophan's metabolites in exercise, inflammation, and mental health. Science 2017;357:eaaf9794.
45. Rothhammer V, Mascanfroni ID, Bunse L, et al. Type I interferons and microbial metabolites of tryptophan modulate astrocyte activity and central nervous system inflammation via the aryl hydrocarbon receptor. Nat Med 2016;22:586-97.
46. Xiao W, Li J, Gao X, et al. Involvement of the gut-brain axis in vascular depression via tryptophan metabolism: a benefit of short chain

fatty acids. Exp Neurol 2022;358:114225.
47. Nuss P. Anxiety disorders and GABA neurotransmission: a disturbance of modulation. Neuropsychiatr Dis Treat 2015;11:165-75.
48. Laudani S, Torrisi SA, Alboni S, et al. Gut microbiota alterations promote traumatic stress susceptibility associated with p-cresol-induced dopaminergic dysfunctions. Brain Behav Immun 2023;107:385-96.
49. Tian P, Chen Y, Zhu H, et al. Bifidobacterium breve CCFM1025 attenuates major depression disorder via regulating gut microbiome and tryptophan metabolism: a randomized clinical trial. Brain Behav Immun 2022;100:233-41.
50. Nikolova VL, Cleare AJ, Young AH, Stone JM. Acceptability, tolerability, and estimates of putative treatment effects of probiotics as adjunctive treatment in patients with depression: a randomized clinical trial. JAMA Psychiatry 2023;80:842-7.

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CLINICAL NUTRITION RESEARCH

# Personalized nutrition interventions using digital technologies for older adults: a scoping review

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**Objective:** As global populations age, nutrition management is important for healthy aging. Digital technologies, including mobile applications, web-based platforms, messaging tools, and artificial intelligence (AI)-enabled systems, are used in personalized nutrition interventions. However, evidence on their characteristics, effectiveness, and user experiences remains limited. This scoping review examined technology-based personalized nutrition interventions for older adults.
**Methods:** This review followed the Joanna Briggs Institute methodology and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews guidelines. PubMed, Embase, and Web of Science were searched for studies published from January 1, 2010, to June 30, 2026. Among 2,727 records, 2,044 were screened after duplicate removal, 28 full-text articles were assessed, and 13 articles representing 12 studies were included.
**Results:** Technologies included mobile, messaging, web-based, information and communications technology, tablet-based, and AI-supported systems. Interventions involved dietary recording, personalized feedback, remote counseling, coaching, and self-monitoring. Outcomes included dietary intake and quality, nutritional status, physical function, frailty, cognition, cardiometabolic indicators, engagement, usability, and acceptability. Findings were more consistent for dietary behaviors and individualized nutrition management. Evidence for physical function, frailty, cognition, cardiometabolic health, and quality of life was limited and often based on small or multidomain studies. Familiar interfaces and professional support were accepted, whereas low digital literacy, complex navigation, and limited food databases were barriers.
**Conclusion:** Digital personalized nutrition interventions may support dietary behavior change and individualized nutrition management in older adults. Larger studies and user-centered systems addressing digital literacy, usability, cultural context, and AI-feedback validation are needed.

**Keywords:** Aged; Digital health; Nutrition therapy; Scoping review; Artificial intelligence

## INTRODUCTION

Globally, population aging is accelerating due to longer life expectancy and declining fertility rates. The World Health Organization estimated that 1 billion of the global population aged ≥ 60 years in 2019 and that this number is expected to reach 1.4 and 2.1 billion by 2030 and 2050, respectively [1]. These demographic changes underscore the importance of healthy aging, which extends beyond longevity to maintaining physical, cognitive, and social functions in later life [2,3]. Nutrition plays a pivotal role in maintaining

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physical function, preserving cognitive function, and preventing and managing chronic diseases during aging. Inadequate nutritional status is closely associated with frailty, sarcopenia, cognitive decline, and reduced quality of life [4-7]. Therefore, intervention strategies to enhance nutritional status should be developed and assessed in geriatric healthcare [8,9].

Recent advances in information and communications technology (ICT) have rapidly expanded digital health interventions using mobile applications, web-based platforms, wearable devices, remote monitoring systems, and artificial intelligence (AI)-based tools [10-13]. These digital technologies facilitate automated dietary recording, continuous collection of health and dietary data, real-time feedback, remote counseling, and monitoring, addressing the limitations of traditional face-to-face interventions [14,15]. Particularly, personalization strategies that provide tailored information and feedback based on individual nutritional status, dietary intake, health risks, physical function, food preferences, and stages of behavioral change have become increasingly well known for their potential to improve engagement and adherence and sustain behavioral change [16,17].

However, older adults may be hesitant to accept and use digital technologies due to differences in previous experience with digital devices and digital literacy levels, as well as age-related declines in sensory and cognitive functions and physical limitations [18,19]. Therefore, technological efficiency, usability, accessibility, acceptability, and the potential for sustained engagement should be considered in designing digital technology-based nutrition interventions for older adults [20,21]. Furthermore, an integrated review should be conducted to assess the criteria used to develop personalization strategies, the digital technologies through which these strategies are delivered, and their effects on nutritional status, health outcomes, and user experiences [14].

Various countries and settings have implemented digital technology-based nutrition interventions for older adults. However, only a few studies have comprehensively synthesized the types of technologies employed, personalization criteria, intervention delivery modes, outcome measures, and user experiences [14,15]. Although emerging technologies, such as AI-based dietary recognition, algorithm-based recommendations, and wearable-linked feedback, have been introduced into nutrition interventions, a systematic review is needed to determine how these technologies are applied in digital nutrition interventions for older adults.

Accordingly, this study used a scoping review approach to explore digital technology-based personalized nutrition interventions for older adults and systematically summarize their characteristics and current applications. Specifically, this study aimed to (1) determine the types of digital technologies and delivery modes adopted in these interventions; (2) examine the criteria and methods used for personalization strategies; (3) synthesize the main outcome measures and findings, including nutritional status, physical function, cognitive function, cardiovascular health, usability, and acceptability; and (4) identify implications and research gaps for the future design of digital nutrition interventions for older adults.

## METHODS

### Ethics statement

This scoping review used previously published studies and did not involve human participants or primary data collection. Hence, Institutional Review Board approval and informed consent were not required.

### Study design

This scoping review systematically explores digital technology-based personalized nutrition interventions for older adults in accordance with the Joanna Briggs Institute methodology for scoping reviews [22]. Study selection and reporting followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines. The population, concept, and context (PCC) framework was used to develop the research question and eligibility criteria. The review process consisted of developing a search strategy, conducting the literature search, selecting studies, extracting data, mapping evidence, and synthesizing findings. No review protocol was registered. Due to the absence of a registered protocol, the PCC framework was used to predefine the research question and eligibility criteria, and the search, study selection, and data extraction procedures were established before screening and used consistently throughout the review.

### Search strategy

The PubMed, Embase, and Web of Science databases were searched on June 30, 2026, covering articles published from January 1, 2010, through June 30, 2026. Search terms were developed according to the PCC framework and combined terms: older adults ("older adults," "elder," "elderly," and "senior"), nutrition interventions ("nutrition intervention," "dietary intervention," "nutrition education," "nutrition counseling," "dietary advice," "dietary modification," "nutrition program," "nutrition therapy," and "nutritional intervention"), digital and AI technologies ("digital health," "eHealth," "mHealth," "mobile health," "mobile app," "mobile application," "telehealth," "telemedicine," "artificial intelligence," "AI," "machine learning," "algorithm," "chatbot," "wearable," and "remote"), and personalization ("personalized," "tailored," "individualized," "customized," "adaptive," "targeted," "feedback," and "recommendation"). The search strategy was adapted to the search structure of each database. Title/abstract fields in PubMed, title/abstract/keyword fields in Embase, and topic fields in Web of Science were searched for original peer-reviewed journal articles published in English between 2010 and 2026. Theses, conference abstracts, commentaries, editorials, letters, news articles, and other nonoriginal publications were excluded.

### Inclusion and exclusion criteria

The inclusion criteria were as follows: studies involving adults aged ≥60 years; studies evaluating nutrition or dietary improvement interventions delivered through digital technologies (e.g., mobile applications, web-based programs, remote counseling, AI, chatbots, text messaging, wearable devices, or ICT); studies with intervention content or feedback personalized according to individual nutritional and health statuses, dietary intake, food preferences, physical function, disease-related information, or behavioral data; original intervention studies (e.g., randomized and nonrandomized controlled trials [RCTs] as well as quasi-experimental, pilot, feasibility, mixed-methods, and observational intervention studies); and peer-reviewed journal articles published in English. The exclusion criteria were as follows: studies involving children, adolescents, younger adults, or mixed-age populations without separate outcomes for older adults; evaluating only exercise, cognitive, or disease management interventions without a nutrition intervention component; studies involving face-to-face interventions without digital technology; including interventions that provided only standardized general nutrition information or dietary recording without personalized feedback; usability, perception, technology development, or algorithm development studies; examining only the validity of nutrition assessment applications or tools without implementing an actual nutrition intervention; and protocol papers, theses, conference abstracts, commentaries, editorials, letters, news articles, animal studies, and cell studies.

### Study selection process

After removing duplicates, the retrieved articles were screened using the predefined inclusion and exclusion criteria. First, titles and abstracts were screened based on the target population, intervention components, use of digital technologies, inclusion of personalization strategies, and study type. Subsequently, full-text articles were reviewed to identify final eligibility. During the full-text review, studies were reviewed for eligibility by considering the involvement of older adults, inclusion of a nutrition intervention, use of digital technologies, incorporation of personalized feedback or intervention tailoring, implementation of an actual intervention, and meeting the publication type and language criteria. The final study selection process was documented using a PRISMA flow diagram, with results presented in Fig. 1. Study screening and full-text review were performed based on the predefined criteria, and the research teams evaluated studies with unclear eligibility until a final decision was made. Articles reporting on the same participant cohort were retained but treated as a single study.

### Data extraction and analysis

Data, including author and publication year, country, study design, participant characteristics and age, sample size, intervention duration, intervention setting, type of digital technology used, delivery mode, study objective, nutrition intervention components, personalization criteria and methods, AI use, main outcome measures, effectiveness outcomes, and user perception and acceptability-related findings, were extracted from included studies and descriptively summarized based on study characteristics, types of digital technologies, intervention delivery modes, and personalization strategies. The main outcomes were categorized and synthesized across the following domains: dietary intake and diet quality, nutritional status, physical function and frailty, cognitive function, cardiovascular and health-related indicators, behavioral change and engagement, usability, and acceptability. Qualitative findings associated with user experience, acceptability, usability, and feasibility were thematically summarized based on recurring patterns across the included studies.

## RESULTS

### Study selection process

The database search identified 2,727 records. After removing 683 duplicate records, 2,044 were screened based on their titles and abstracts using the predefined inclusion and exclusion criteria (Table 1). Eligible studies involved adults aged ≥60 years, included nutrition intervention components, incorporated digital or AI-enabled technologies, and used personalization strategies. During this process, 2,016 records that did not meet the inclusion criteria

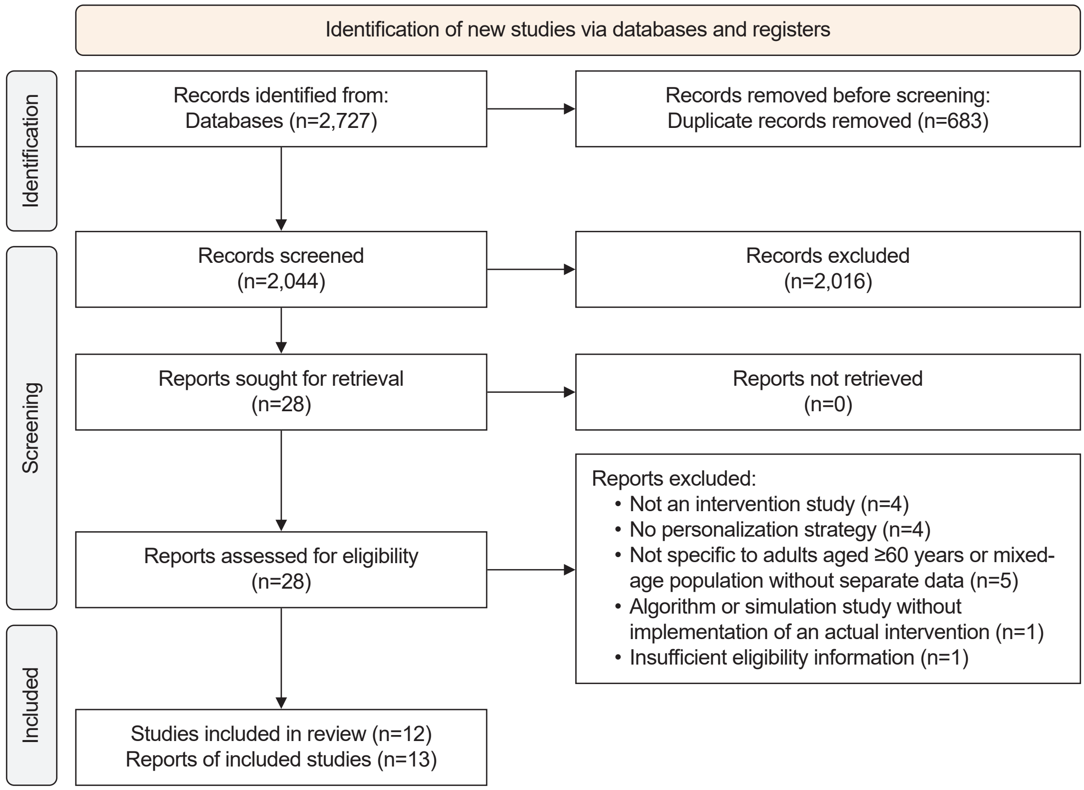


**Fig. 1.** Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow diagram of study selection.

were excluded, and 28 articles were subsequently subjected to a full-text review. All full-text articles were retrieved, and none were excluded due to unavailability. After the full-text review, 15 articles were excluded: non-intervention studies (n = 4), lack of personalization strategy (n = 4), inclusion of populations other than adults aged ≥ 60 years or mixed-age populations without separately reported data for this age group (n = 5), algorithm or simulation studies without implementation of an actual intervention (n = 1), and insufficient information to assess eligibility (n = 1). Finally, 13 articles representing 12 unique studies were included in the analysis. The study selection process is shown in Fig. 1.

## Review scope according to the PCC framework

This scoping review was defined using the PCC framework (Table 2). The study population comprised older adults aged ≥ 60 years, including community-dwelling older adults, frail or prefrail individuals, those at risk of malnutrition, and those residing in nursing homes or long-term care facilities. The concept was defined as personalization strategies incorporated into digital or AI-enabled nutrition interventions, such as personalized dietary feedback, individualized nutrition counseling, meal planning, self-monitoring, and algorithm- or AI-based recommendations. The context included community, home-based, clinical, institutional, long-term care, remote, and telehealth-based settings.

## General characteristics of the included studies

The 13 included articles, representing 12 unique studies, were conducted in various countries and regions, including the Netherlands, Thailand, the United States, the United Kingdom, Chile, France, Japan, Taiwan, Germany, and Singapore, as well as multinational studies conducted in Europe and Japan (Table 3). The study designs included RCTs, pilot RCTs, quasi-experimental studies, feasibility or pilot studies, cluster RCTs, iterative design and pilot studies, as well as usability and development evaluation studies. Most studies were designed as pilot or feasibility studies to examine intervention feasibility before conducting a full-scale effectiveness evaluation. Study participants were mainly community-dwelling older adults aged ≥ 60 or 65 years. Some studies targeted specific at-risk populations, such as older adults at risk of frailty, cognitive decline, or dementia, overweight older adults at risk of diabetes, and rehabilitation inpatients. Sample sizes ranged from 15 to 224 participants. Although many interventions were

**Table 1.** Inclusion and exclusion criteria

| Category | Inclusion criteria | Exclusion criteria |
|---|---|---|
| Population | Studies targeting older adults aged ≥60 years and reviewing community-dwelling, institutionalized, frail, prefrail, nutritionally at risk, or sarcopenia-risk older adults, as well as older adults with chronic conditions | Studies targeting children, adolescents, younger adults, or mixed-age populations that did not separately identify data for older adults |
| Concept: nutrition intervention | Studies focusing on nutrition education, counseling, dietary feedback, meal planning, dietary behavior change, nutrition monitoring, or malnutrition prevention/management | Studies without nutrition or dietary intervention components |
| Concept: digital or AI-enabled component | Studies using apps, web platforms, telehealth, messaging tools, ICT platforms, wearable devices, algorithms, AI, or image-based dietary assessment to implement or support the intervention | Face-to-face-only interventions without digital, remote, ICT, or AI-enabled components |
| Concept: personalization strategy | Studies designing the intervention based on dietary intake, nutritional status, health status, preferences, physical function, frailty, behavior, user profile, app data, wearable data, or AI-generated recommendations | Studies providing only standardized general information without individualized feedback, tailoring, goal setting, or recommendations |
| Study type | RCTs, nonrandomized trials, quasi-experimental studies, pilot/feasibility studies, mixed-methods studies, and observational intervention studies | Reviews, editorials, commentaries, letters, conference abstracts, theses, animal studies, cell studies, and non-intervention studies |
| Publication type | Peer-reviewed journal articles | Gray literature and non-peer-reviewed documents |
| Language | English | Non-English articles |
| Publication year | Articles published from January 1, 2010, through June 30, 2026 | Articles published before January 1, 2010, or after the final search date |

AI, artificial intelligence; ICT, information and communications technology; RCT, randomized controlled trial.

**Table 2.** PCC framework for scoping review

| PCC element | Definition in this review |
|---|---|
| Population (P) | Older adults aged ≥60 years, including community-dwelling, institutionalized, frail, prefrail, and nutritionally at risk older adults |
| Concept (C) | Personalization strategies in digital or AI-enabled nutrition interventions, such as individualized dietary feedback, tailored nutrition counseling, meal planning, self-monitoring, and algorithm- or AI-supported recommendations |
| Context (C) | Community, home-based, clinical, institutional, long-term care, and remote or telehealth-based settings |

AI, artificial intelligence.

short-term (approximately 3 months), some implemented longer interventions up to 12 months. Mobile applications were frequently used to deliver interventions. Other technologies included messaging platforms, such as LINE, web-based platforms, tablet-based applications, wearable devices, and AI-based image recognition or recommendation systems. The intervention delivery modes ranged from fully automated approaches offering recommendations or feedback via digital technologies alone to those that combined digital tools with support from dietitians, coaches, researchers, or care staff.

## Intervention characteristics and main findings

The intervention objectives and contents varied across the included studies (Table 4). Some studies evaluated the development and field applicability of personalized dietary recording, assessment, or feedback tools. Conversely, others aimed to enhance diet quality, manage nutritional status, prevent frailty, improve physical function, prevent cognitive decline or diabetes, or maintain quality of life in older adults. The intervention components included personalized dietary recommendations, dietary recording, nutrition counseling, dietary self-monitoring, education on the Mediterranean diet or healthy dietary patterns, protein intake counseling, multidomain lifestyle interventions, and AI-based dietary analysis and feedback. Several studies reported positive changes in diet quality, dietary adherence, protein intake, cardiovascular health indicators, physical function, frailty-related indicators, and cognitive function. Specifically, studies providing personalized feedback based on individual dietary intake or health status using digital tools reported positive findings in terms of dietary behavior change and sustained engagement. Users generally considered mobile applications, messaging platforms, web-based platforms, tablet-based e-coaches, and AI-based image recognition functions acceptable. However, some studies also reported limitations, such as small sample sizes, limited food databases, usability challenges, and the burden of digital technology use.

## Mapping of the reported effectiveness outcomes

To enhance evidence mapping, effectiveness outcomes reported

**Table 3.** Characteristics of the included studies

| Study | Country | Design | Population | Age (yr) | No. of participants | Duration | Setting | Digital technology | Delivery mode |
|---|---|---|---|---|---|---|---|---|---|
| Connelly et al. [23] (2025) | United Kingdom | Co-design/ facilitation test | Care home older adults and staff | Older adults; not specified | 154 participants | 2-wk test | Care homes | Mobile app; AI system | AI-assisted assessment |
| Gaewkhiew et al. [24] (2025) | Thailand | Pilot RCT | Older dental patients | ≥60 | 30 | 3 mon | Community | LINE app | Blended, dietitian-led |
| Su et al. [25] (2023) | United States | Pilot RCT | Frail older adults | 66–77 | 15 | 3 mon | Home-based | Mobile app (Olitor) | App-based feedback |
| Gutierrez et al. [26] (2025) | Chile | Iterative design + pilot | Community-dwelling older adults | Mean 71 | 60 | 3 mon | Home | Mobile app (NeoMayor) | App-based self-monitoring |
| de Souto Barreto et al. [27] (2021) | France | Pilot RCT | Older adults with subjective memory complaints | ≥65 | 120 | 6 mon | Community | Web platform/ tablet | Web-based multidomain |
| Kurotani et al. [28] (2025) | Japan | Quasi-experimental | Community-dwelling frail older adults | ≥65 | 29 | 3 mon | Community | AI-assisted smartphone app | AI feedback |
| Li et al. [29] (2025) | Taiwan | Quasi-experimental | Community-dwelling frail older adults | Mean 74 | 81 | 6 mon | Community center/home | LINE app | Hybrid coaching |
| Gerber et al. [30] (2024) | United States | Pilot RCT | Overweight older adults at risk of diabetes | ≥60 | 20 | Approximately 6 months, 22 sessions | Online | Web/video system | Remote coach-led |
| Happe et al. [31] (2023) | Germany | Pilot study | Older rehabilitation inpatients | ≥70 | 21 | 9 wk | Rehabilitation/ home | Tablet app; ECA | E-coach |
| Rainero et al. [32] (2021) | Europe/ Japan | RCT | Community-dwelling older adults at risk of frailty | Mean 70 | 201 | 12 mon | Home | ICT platform, sensors, and app | Algorithm-based package |
| van den Helder et al. [33] (2020) | Netherlands | Cluster RCT | Community-dwelling older adults | Mean 72 | 224 | 6 mon | Community/ home | Tablet app (VITAMIN) | Blended app + expert coaching |
| Li et al. [34] (2025) | Taiwan | Quasi-experimental | Community-dwelling frail/ pre-frail older adults | ≥65 | 81 | 6 mon | Community care center/home | LINE app | Hybrid coaching |
| Chew et al. [35] (2024) | Singapore | Quasi-experimental | Community-dwelling older adults at risk of cognitive decline | ≥60 | 150 | 6 mon | Senior center/ app | AI toolkit, mobile app, Kinect | AI-supported multidomain toolkit |

References 29 and 34 are companion reports from the same FANS study cohort and were counted as one unique study.
AI, artificial intelligence; ECA, embodied conversational agent; ICT, information and communication technology; RCT, randomized controlled trial.

**Table 4.** Intervention characteristics and key findings of the included studies

| Study | Objective | Intervention description | Outcome: efficacy | Outcome: users' perceptions |
|---|---|---|---|---|
| Connelly et al. [23] (2025) | To design and evaluate a digital nutrition assessment tool for identifying food preferences and malnutrition risk among older adults in care homes. | A mobile app and AI-supported system were used for meal photo recording, preference documentation, symptom monitoring, and malnutrition risk alerts using care-home menu data. | The system demonstrated potential to alleviate documentation burden and support malnutrition risk identification through AI-assisted food image recognition. | Older adults and care staff perceived the tool as useful, particularly because image-based input reduced manual recording burden. Limited food database coverage was noted. |
| Gaewkhiew et al. [24] (2025) | To examine the impact of nutrition counseling delivered via an online application on dietary intake among older adults. | The participants received individualized nutrition counseling through LINE based on 3-day dietary records, health conditions, and eating habits. | Retention was 100%. Energy and protein intake exhibited improvement trends, and nutritional status assessed by MNA-SF was monitored. | LINE was considered familiar and accessible for older adults, supporting the feasibility of remote expert-led nutrition counseling. |

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**Table 4.** Continued

| Study | Objective | Intervention description | Outcome: efficacy | Outcome: users' perceptions |
|---|---|---|---|---|
| Su et al. [25] (2023) | To evaluate a mobile intervention designed to support healthy eating among frail older adults. | The Olitor mobile app supported Mediterranean diet recording and provided visual feedback by comparing individual MedD scores with recommended levels. | Adherence to the Mediterranean diet significantly improved in the intervention group. Physical function indicators, such as SPPB, were also assessed. | The small pilot study suggested that visual feedback was acceptable and could motivate dietary behavior change among frail older adults. |
| Gutierrez et al. [26] (2025) | To develop and pilot-test the NeoMayor mHealth app for promoting healthy lifestyles among older adults in Chile. | The app provided lifestyle recommendations based on Life's Essential 8, including nutrition-related feedback, self-monitoring, and personalized images/messages based on baseline health scores. | Cardiovascular health scores significantly improved, as well as diet quality indicators, including the MIND score, following the intervention. | The participants generally accepted the app-based self-monitoring approach, although the study sample was predominantly female and relied on self-reported data. |
| de Souto Barreto et al. [27] (2021) | To evaluate the feasibility of a web-based multidomain lifestyle intervention for older adults with subjective memory complaints. | A web platform or tablet delivered multidomain lifestyle content, including cognitive training, physical activity, and nutrition education, with regular online contact. | The intervention demonstrated good feasibility and acceptability. Cognitive function and nutritional status indicators, including MNA, were evaluated. | Regular online contact and structured web content were perceived as feasible, although imbalance in participant characteristics limited the interpretation. |
| Kurotani et al. [28] (2025) | To determine whether an AI-assisted smartphone application could improve diet quality among community-dwelling frail older adults. | The app enabled recording of 10 food groups and provided AI-assisted personalized feedback using image analysis and text-based recommendations. | The intervention group demonstrated a significant improvement in the dietary balance score compared with the control group. | The AI-assisted feedback was considered useful for real-time dietary self-management, although the study was small and nonrandomized. |
| Li et al. [29] (2025) | To evaluate the effects of the Fitness and Nutrition Program for Seniors on frailty prevention and physical function among older adults. | A hybrid intervention combined face-to-face sessions with LINE-based remote coaching, nutrition education, and monitoring of dietary behavior. | The SPPB score and 4-m gait speed significantly improved. BMI and calf circumference were maintained during the intervention. | The hybrid model was feasible during the COVID-19 pandemic and supported continued engagement through familiar mobile communication. |
| Gerber et al. [30] (2024) | To evaluate the feasibility of an eHealth diabetes prevention program adapted for older adults at risk of diabetes. | A web-based/video-delivered lifestyle intervention based on the Diabetes Prevention Program employed remote coaching, behavioral strategies, and individualized progress reports. | Participation was high, and body weight exhibited a favorable decreasing trend. Adherence and session completion were also evaluated. | The participants demonstrated high engagement with the remote program, supporting the feasibility of counselor-supported eHealth coaching for older adults. |
| Happe et al. [31] (2023) | To evaluate the usability and feasibility of a tablet-based e-coach for older adults in rehabilitation. | A tablet app with an embodied conversational agent supported nutrition and exercise diary, stage-based goal setting, and tailored guidance based on the transtheoretical model. | The average SUS score was favorable, and adherence to nutrition-related recommendations improved during the intervention. | The e-coach format was perceived as usable and supportive. However, the study had no control group and experienced attrition. |
| Rainero et al. [32] (2021) | To determine whether the My-AHA ICT platform could prevent declines in quality of life among older adults at risk of frailty. | An ICT platform integrating apps and sensors provided multidomain interventions, including nutrition, cognition, physical activity, and sleep management, matched to individual needs. | The intervention helped prevent declines in quality of life compared with the control group. Nutritional status indicators, such as MNA, were also monitored. | The platform demonstrated feasibility for integrating multidomain risk assessment and individualized intervention delivery in older adults. |
| van den Helder et al. [33] (2020) | To evaluate the effects of blended home-based exercise and dietary protein intervention on physical function in community-dwelling older adults. | A tablet-supported program combined resistance exercise with dietary protein counseling. App-recorded dietary data were utilized to facilitate expert nutrition coaching. | Protein intake significantly increased in the exercise-plus-protein group. Physical performance outcomes, including m-PPT, were evaluated. | The blended approach supported home-based coaching, although the high dropout rate and nonblinded design were noted as limitations. |

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**Table 4.** Continued

| Study | Objective | Intervention description | Outcome: efficacy | Outcome: users' perceptions |
|---|---|---|---|---|
| Li et al. [34] (2025) | To determine whether the FANS program improved frailty status and health-related quality of life among frail or pre-frail older adults. | The program used community center sessions and LINE-based home care. Monthly individualized home and group tasks were adjusted according to behavioral stage and cognitive-behavioral strategies. | The frailty scores and instrumental activities of daily living significantly improved compared with the control group. More than 80% of the participants reached the maintenance stage for dietary behavioral change. | The hybrid intervention was considered practical for frail older adults and supported sustained behavioral change through stage-based personalization. |
| Chew et al. [35] (2024) | To assess the ADL+ digital toolkit for multidomain cognitive, physical, and nutritional interventions among older adults at risk of cognitive decline. | The AI-based mobile toolkit utilized image-based dietary records, AI nutrition analysis, Kinect-based activities, and cognitive prediction models to adjust intervention intensity. | Global cognitive scores improved in the intervention group, particularly in processing speed. Activity levels were maintained in the intervention group compared with the control group. | Gamified and AI-supported features promoted engagement and social interaction; however, differences in digital literacy may have influenced cognitive burden. |

References 29 and 34 are companion reports derived from the same FANS study cohort and were counted as one unique study.
AI, artificial intelligence; MNA-SF, Mini Nutritional Assessment-Short Form; MedD, Mediterranean diet; SPPB, short physical performance battery; COVID-19, coronavirus disease 2019; SUS, System Usability Scale; ICT, information and communication technology; m-PPT, modified Physical Performance Test; FANS, fitness and nutrition program for seniors; ADL, activity of daily living.

across the included studies were organized into broad outcome categories (Table 5) used for descriptive purposes and not mutually exclusive, as several studies reported outcomes across more than one area. Regarding dietary intake, diet quality, and dietary adherence, personalized nutrition counseling, mobile app-based feedback, AI-based dietary analysis, and web-based dietary management interventions improved diet quality or adherence to healthy dietary patterns. Reported dietary changes included improved adherence to the Mediterranean diet, increased legume intake, and improved meal balance scores. Interventions that included protein counseling reported increased protein intake. For nutritional status, risk of malnutrition, and anthropometric measures, digital assessment tools utilized in long-term care settings supported the identification of malnutrition risk and food preferences. Some studies reported reductions in waist circumference, improvements in cardiovascular health indicators, and changes in mid-upper arm or calf circumference. Regarding physical function, frailty, and activities of daily living, positive changes were observed in indicators such as the short physical performance battery (SPPB), gait speed, Timed Up and Go test, muscle strength, physical activity levels, frailty-related indicators, and activities of daily living. Cognitive outcomes were assessed mainly in digital multidomain interventions targeting older adults at risk of cognitive decline, although findings were inconsistent across studies. Cardiovascular and other health-related outcomes included cardiovascular health scores, body weight, blood pressure, and selected cardiovascular indicators. Several studies reported high participant retention rates, strong adherence to self-monitoring, progression to the maintenance stage of behavioral change, and sustained app use regarding behavioral change, engagement, and retention. User-related outcomes, such as usability, acceptability, and user perceptions, positively perceived simple and familiar interfaces, image-based dietary recording, AI-based automated recognition, familiar platforms such as LINE, and professional support.

## User-related findings

Findings associated with user experience, acceptability, usability, and feasibility were grouped by recurring considerations in all included studies (Table 6). Older adults perceived digital interventions more positively when tools were simple, familiar, and directly associated with their daily dietary practices. Automated or simplified dietary recording methods, including image-based dietary recording and AI-based food recognition, reduced the burden of manual dietary recording and facilitate more efficient nutrition

**Table 5.** Objectives and findings of the included studies

| Outcome variable | Study | Results |
|---|---|---|
| Dietary intake, diet quality, and dietary adherence | Gaewkhiew et al. [24] (2025) | No between-group differences in nutrient intake; both groups showed decreased energy/nutrient intake over time (P<0.05) |
| | Su et al. [25] (2023) | Mediterranean diet adherence improved (adjusted P=0.04); legume intake increased (adjusted P<0.01) |
| | Kurotani et al. [28] (2025) | Dietary quality improved (+9.5 points; 95% CI, 2.3–16.7; P=0.01) |
| | van den Helder et al. [33] (2020) | Protein intake increased (+0.32 g/kg/day, P<0.001) |
| Nutritional status, malnutrition risk, and anthropometric outcomes | Connelly et al. [23] (2025) | Malnutrition risk and food preference identification supported. P-value not reported |
| | Gaewkhiew et al. [24] (2025) | No between-group difference in body measurements |
| | Gutierrez et al. [26] (2025) | Waist circumference decreased, and CVH index improved (P<0.001) |
| | Li et al. [29] (2025) | Mid-upper arm circumference increased (P<0.001); calf circumference improved (P<0.01) |
| Physical function, frailty, and daily functioning | Li et al. [29] (2025) | SPPB improved (P<0.05); Five Times Sit-to-Stand test performance improved (P<0.05); TUG test performance improved (P<0.001); physical activity level increased (P<0.001) |
| | van den Helder et al. [33] (2020) | m-PPT, no difference (HBex, P=0.933; HBex-Pro, P=0.730); gait speed, improved (P=0.001); muscle strength, improved (P=0.001); muscle mass, improved (P=0.017) |
| | Li et al. [34] (2025) | Frailty and daily activities improved; exact P-value not reported in the abstract |
| Cognitive and brain-related outcomes | Chew et al. [35] (2024) | NTB composite score improved (between-group difference=0.17; 95% CI, 0.071–0.27; P=0.001) |
| | Rainero et al. [32] (2021) | Stroop C incongruent time improved (P=0.012); stroop C incongruent errors improved (P=0.015) |
| | de Souto Barreto et al. [27] (2021) | No significant effect for most cognitive outcomes |
| Cardiometabolic and health-related indicators | Gutierrez et al. [26] (2025) | CVH index improved from 64 to 68 (P<0.001) |
| | Gerber et al. [30] (2024) | Intervention group lost 9.5% body weight; control group gained 2.4%; 90% lost ≥5% body weight |
| | Su et al. [25] (2023) | HOMA-IR, no difference (adjusted P=0.85) |
| Behavioral change, engagement, and maintenance | Gaewkhiew et al. [24] (2025) | Retention, 100% |
| | Su et al. [25] (2023) | Retention, 100%; average app use, about 12 min/wk |
| | Gerber et al. [30] (2024) | Attendance and self-monitoring adherence, 100%; greater weight loss among eating behavioral change participants (−12.0% vs. −5.0%, P<0.005) |
| | Happe et al. [31] (2023) | Nutrition recommendation achievement increased from 24% to 66%; physical activity recommendation achievement increased from 33% to 71%. P-value not reported |
| | Li et al. [29] (2025) | Dietary behavioral action/maintenance stage reached by 81.4% |
| Usability, acceptability, and users' perceptions | Connelly et al. [23] (2025) | AI-assisted food image recording reduced documentation burden. P-value not reported |
| | Happe et al. [31] (2023) | SUS, 78.6 |
| | Li et al. [29] (2025) | Satisfaction, 9.25/10 |
| | Chew et al. [35] (2024) | High adherence; average usability |

CI, confidence interval; CVH, cardiovascular health; SPPB, Short Physical Performance Battery; TUG, Timed Up and Go; m-PPT, modified Physical Performance Test; HBex, home-based exercise; HBex-Pro, home-based exercise plus protein; HOMA-IR, homeostatic model assessment of insulin resistance; SUS, System Usability Scale.

monitoring. Tailored feedback based on dietary intake, nutritional status, health risks, stages of behavioral change, food preferences, or activity data supported dietary behavioral change and intervention engagement. Human support was also commonly reported as an important component of digital interventions. Several studies reported that dietitians, counselors, coaches, or care staff interpreted information collected using digital tools and provided individualized guidance. Combining digital tool use and professional guidance may be particularly useful for older adults who experience difficulties using digital technologies. Several challenges

**Table 6.** Qualitative outcomes of the included studies

| Identified theme | Description |
|---|---|
| Acceptability of digital nutrition interventions | Several studies showed that digital nutrition interventions were generally acceptable to older adults when the tools were simple, familiar, and directly related to their daily dietary practices. Mobile apps, web-based platforms, and messaging applications, such as LINE, were considered feasible delivery methods, particularly when supporting dietary self-monitoring, nutrition education, or remote counseling. |
| Reduced burden through automated or simplified dietary recording | Image-based dietary recording, AI-assisted food recognition, and structured app-based food logs alleviated the burden of manual dietary recording. These approaches were specifically relevant for older adults and care staff as they reduced the effort required to document meals and supported more efficient nutrition monitoring. |
| Importance of personalization and feedback | Personalized feedback based on dietary intake, nutritional status, health risk, behavioral stage, food preference, or activity data was considered useful for supporting behavioral changes. Studies using visual feedback, individualized goals, expert counseling, or algorithm-based recommendations reported that personalization may enhance engagement and adherence to nutrition-related behaviors. |
| Role of human support in digital interventions | Although digital tools were widely used, several interventions relied on nutritionists, counselors, coaches, or care staff to interpret data and offer individualized guidance. Blended models combining digital platforms with professional support appeared particularly useful for older adults, who may require additional encouragement, clarification, or motivational support. |
| Digital literacy and usability challenges | Some studies showed barriers associated with low digital literacy, unfamiliarity with digital platforms, complex navigation, or difficulties using digital devices. Older adults preferred clear instructions, simple interfaces, readable visual materials, and direct messages. These findings underscore the need for age-friendly design in digital nutrition interventions. |
| Engagement and behavior maintenance | Interventions including goal setting, self-monitoring, regular contact, tailored tasks, or stage-based behavioral change strategies appeared to support continued engagement. Structured digital follow-up and ongoing professional contact may help older adults sustain nutrition-related behaviors. |
| Feasibility of AI-enabled approaches | AI-enabled approaches, such as image recognition, algorithm-based recommendations, and generative AI feedback, potentially supported real-time and individualized dietary guidance. However, AI use remained limited across studies, and issues such as food database coverage, food recognition accuracy, small sample sizes, and validation of AI-generated recommendations should be considered. |
| Need for culturally and contextually appropriate design | Included studies revealed that digital nutrition interventions should consider care settings, user preferences, digital literacy, and available resources. Familiar communication tools and practical support from healthcare professionals or care staff may improve the relevance and usability of interventions for older adults. |

AI, artificial intelligence.

were also identified, such as low digital literacy, limited familiarity with web-based platforms, complex navigation structures, and difficulties using digital devices. Continued participation was supported by goal setting, self-monitoring, regular contact, tailored tasks, and strategies based on stages of behavioral change. AI-based image recognition and algorithm-based recommendations can potentially support real-time personalized dietary guidance. AI-enabled approaches may facilitate dietary assessment and personalized feedback. However, current evidence is limited; therefore, the clinical validity of algorithm-based nutrition recommendations remains unclear. Furthermore, intervention designs that accounted for care environments, user preferences, and available resources enhanced the relevance and usability of digital nutrition interventions for older adults.

## DISCUSSION

This scoping review analyzed 13 articles representing 12 unique studies on digital technology-based personalized nutrition interventions for older adults and synthesized evidence on the types of digital technologies used, personalization strategies, intervention effectiveness, and user perceptions across the included studies [23-35]. The included studies used various digital technologies: mobile applications, web-based platforms, tablet-based e-coaches, ICT platforms, messaging applications, wearable devices, and AI-based food recognition and recommendation systems. Moreover, interventions considerably varied across studies, comprising personalized dietary feedback to improve diet quality, nutritional status management, protein intake promotion, combined exercise and nutrition interventions for frailty prevention, programs for physical function improvement, multidomain interventions for cognitive decline prevention, cardiovascular health management, diabetes prevention programs, and strategies for maintaining quality of life [25,26,28,29,32-35]. These findings reveal that digital technology-based personalized nutrition interventions have evolved beyond the simple delivery of nutrition information or facilitation of dietary recording. Instead, they are increasingly used as integrated tools for behavioral change that continuously collect dietary and health-related data, offer individualized feedback, and support self-management in everyday life. This shift reflects that sustained dietary behavioral change in older adults requires ongoing monitoring and personalized support rather than one-time nutrition education [23,25,28,30,31,35].

Personalized interventions in this review were implemented in different ways across studies. Some studies offered tailored feedback based on dietary intake, food preferences, nutritional requirements, health status, physical function, frailty level, and stage of behavioral change [24-26,29,31,33,34]. Conversely, other studies conducted algorithm- or AI-based analyses to assess dietary intake and provide personalized interventions [23,28,35]. These findings reveal that personalized nutrition interventions are evolving from simple rule-based tailored messages to more comprehensive approaches that consider individual nutritional requirements, health conditions, functional status, dietary habits, living environments, and digital literacy. Such personalization may be particularly important for older adults, as their nutritional needs can vary depending on frailty, chronic diseases, appetite, and physical function. However, due to varied criteria and methods for tailoring across studies, future studies should clearly describe how interventions are tailored to individual participants and determine whether these personalized approaches improve dietary behavioral change and health outcomes. The findings present the broader transition from standardized nutrition education toward personalized nutrition approaches. Future interventions should include interindividual differences in nutritional status, chronic disease burden, functional capacity, dietary preferences, and behavioral readiness. As digital technologies evolve, personalized nutrition interventions may increasingly integrate precision nutrition concepts to provide more adaptive and individualized recommendations. Digital nutrition interventions for older adults should assess malnutrition risk, appetite, unintentional weight loss, muscle status, swallowing difficulties, and disease-specific dietary needs. Nutrition goals should be personalized due to varied priorities between older adults at risk of malnutrition or sarcopenia and those with obesity, diabetes, hypertension, or renal disease. Qualified nutrition professionals should review automated recommendations, particularly when identifying clinically significant nutrition risks. Another important finding of this review is that several studies not only relied on digital tools but also included support from dietitians, coaches, researchers, care staff, or healthcare professionals [24,28-31,33,34]. These professionals reviewed dietary records, health status, and behavioral data collected using digital tools and offered individualized counseling or tailored feedback [24,28-31,33,34]. These findings reveal that professional support and ongoing communication may be as critical as the technology itself in designing digital nutrition interventions for older adults. Differences in digital device experience and digital literacy level among older adults may make fully automated systems burdensome. Therefore, digital nutrition interventions for older adults should be designed to combine digital tools with professional support, rather than relying solely on technology.

Using familiar digital platforms was also identified as an important factor influencing the acceptability and use of interventions among older adults. Messaging platforms such as LINE may be useful as they are already familiar to many older adults and can promote intervention participation and ongoing communication with healthcare professionals [24,29,34]. In contrast, newly developed applications can offer various functions; however, processes such as installation, login, screen navigation, and notification management may be burdensome for older users [25,26,28]. Therefore, ease of use in daily life should be prioritized over the number of new functions when designing digital interventions for older adults.

AI-based technologies represent one of the most rapidly developing areas of personalized nutrition. However, most applications in the reviewed studies were largely limited to food image recognition or dietary assessment rather than AI-driven personalized decision support. Further advances will require more sophisticated algorithms that can incorporate dietary intake, nutritional status, chronic diseases, physical function, and behavioral data to generate adaptive nutrition recommendations [23,28,35]. Food photo records and AI-based food recognition can address the burden of written dietary records and allow faster dietary assessment and feedback [23,28]. However, AI-based dietary assessment remains limited in accurately recognizing complex mixed dishes, estimating portion sizes, and identifying hidden ingredients. Limitations in food database coverage may also reduce the accuracy of nutrient estimation. These limitations are especially relevant for older adults with malnutrition, sarcopenia, or chronic diseases. Therefore, algorithm-based nutrition recommendations should be clinically validated and reviewed by qualified nutrition professionals before routine use.

Most studies remain at the development or feasibility evaluation stage. Further research is needed to expand food database coverage, improve the accuracy of food and mixed-dish recognition, and clinically validate AI-generated assessments and feedback [23,28,35].

Regarding effectiveness, several studies have reported positive findings, despite the varied areas of improvement. Reported dietary outcomes included improved adherence to healthy dietary patterns, meal balance scores, diet quality, and protein intake [25,28,33]. Other studies showed positive changes in physical function, frailty-related indicators, cardiovascular health indicators, cognitive function, and quality of life [26,29,32,34,35]. Although multiple outcome domains improved, evidence was relatively stronger for dietary behaviors and diet quality. Conversely, evidence for cognitive function, cardiovascular health, and quality of life was more limited and often derived from multidomain interventions. Therefore, identifying independent contribution of nutritional components remains difficult. However, these effects should be interpreted as the outcome of tailored feedback, professional support, behavioral change strategies, social interaction, and continuous monitoring, rather than the effect of digital technology alone.

Many included studies incorporated nutrition interventions into broader multidomain interventions that also included physical activity, cognitive training, social activities, sleep management, or psychosocial support [26,27,29,32,34,35]. Several included studies combined personalized nutrition with physical activity, cognitive training, or behavioral support. Therefore, observed effects cannot be attributed to nutrition alone. Future studies should compare nutrition-only interventions with combined interventions and assess outcomes such as dietary intake and nutritional status to clarify specific effects of nutrition.

Usability and acceptability also provided important insights. Included studies reported that simple and familiar screen layouts, image-based dietary recording, automated feedback, and professional support may help improve participation and acceptability among older adults [23,24,26,28-31,34,35]. Conversely, some studies reported challenges associated with low digital literacy, limited familiarity with web-based platforms, complex screen designs, and difficulty using devices [26,27,31,35]. Therefore, digital nutrition interventions for older adults should prioritize simplicity and usability rather than additional features. Future intervention development should consider older adult-friendly design features, such as large font sizes, clear instructions, simple input procedures, intuitive screen layouts, repeated user training, and the support of caregivers or care staff.

## Limitations

This review has several limitations. Although the review protocol was not prospectively registered, predefined eligibility, screening, and data extraction procedures were consistently used to enhance methodological transparency. In addition, several included studies were small-scale pilot, feasibility, or short-term intervention [23-26,28-31,34,35], and some had no control group or small sample sizes [23,26,31]. Furthermore, participants were often relatively healthy or familiar with digital devices, which limits finding generalizability among older adults who experience difficulty using digital technologies [26,28,30,31,35]. Therefore, positive findings in this review should be interpreted as preliminary evidence supporting the potential of digital personalized nutrition interventions. Future studies should include RCTs with sufficient sample sizes and long-term follow-up and assess applicability in real-world community and long-term care settings. Collectively, dietary intake, nutritional status, physical function, cognitive function, quality of life, usability, and cost-effectiveness should be evaluated. This scoping review identified digital personalized nutrition interventions for older adults using mobile applications, messaging platforms, web-based systems, and AI-supported tools. The evidence revealed potential benefits for dietary self-monitoring, diet quality, adherence, and individualized nutrition management. However, findings for physical function, frailty, cognition, cardiometabolic health, and quality of life were less consistent and were frequently based on small-scale or multidomain studies. Further rigorous studies and clinical validation are needed before AI-assisted assessment and recommendations can be routinely adopted in geriatric nutrition care.

Overall, this review reveals that digital personalized nutrition interventions are a promising strategy for promoting dietary behavioral change and individualized nutrition management among older adults. Future interventions should shift from technology-centered approaches to person-centered models that integrate personalized nutrition, age-friendly digital design, and continuous professional support to achieve sustainable benefits in older adults.

## Conclusion

This scoping review investigated 13 articles representing 12 unique studies on digital technology-based personalized nutrition interventions for older adults and found that mobile applications, messaging platforms, web-based systems, and AI-supported tools have been used to support dietary behavioral change, nutritional status management, and improvements in physical and cognitive function. In particular, blended approaches integrating digital technologies with healthcare professional support, combined with platforms familiar to older adults, emerged as important strategies for improving intervention acceptability and sustaining engagement. However, current evidence is largely based on small-scale pilot or feasibility studies. Therefore, future studies should include sufficient sample sizes, rigorous study designs, and long-term follow-ups. Furthermore, user-friendly designs should reflect older adults' digital literacy and usability needs, alongside validation of AI-based dietary assessment and feedback. These approaches may help develop sustainable digital nutrition management strategies to support healthy aging among older adults.

## ARTICLE INFORMATION


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### Authors' contributions

Conceptualization: all authors. Methodology: all authors. Data curation: all authors. Investigation: all authors. Data extraction: SJ. Data synthesis and interpretation: all authors. Writing - original draft: SJ. Writing - review & editing: all authors. All authors read and approved the final manuscript.

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None.


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### Data availability

Datasets are not publicly available but are available from the corresponding author upon reasonable request.

## REFERENCES


1. World Health Organization. Ageing and health [Internet]. World Health Organization; 2025 [cited 2026 May 13]. Available from: https://www.who.int/news-room/fact-sheets/detail/ageing-and-health
2. Beard JR, Officer A, de Carvalho IA, et al. The World report on ageing and health: a policy framework for healthy ageing. Lancet 2016;387:2145-54.
3. World Health Organization. WHO's work on the UN decade of healthy ageing (2021–2030) [Internet]. World Health Organization; 2022 [cited 2026 May 13]. Available from: https://www.who.int/initiatives/decade-of-healthy-ageing
4. Arici H, Tor YB, Altinkaynak M, et al. Personalized diet with or without physical exercise improves nutritional status, muscle strength, physical performance, and quality of life in malnourished older adults: a prospective randomized controlled study. Nutrients 2025;17:675.
5. Seo AR, Kim MJ, Kim B, et al. Associations between frailty in older adults and malnutrition in rural areas: 2019 Updated Version of the Asian Working Group for Sarcopenia. Yonsei Med J 2021;62:249-54.
6. Landi F, Sieber C, Fielding RA, Rolland Y, Guralnik J. Nutritional intervention in sarcopenia: report from the International Conference on Frailty and Sarcopenia Research Task Force. J Frailty Aging 2018;7:247-52.
7. Chou HH, Lai TJ, Yen CH, Chang PS, Pan JC, Lin PT. Sarcopenic obesity tendency and nutritional status is related to the risk of sarcopenia, frailty, depression and quality of life in patients with dementia. Int J Environ Res Public Health 2022;19:2492.
8. Bernabei R, Landi F, Calvani R, et al. Multicomponent intervention to prevent mobility disability in frail older adults: randomised controlled trial (SPRINTT project). BMJ 2022;377:e068788.
9. Norman K, Hass U, Pirlich M. Malnutrition in older adults: recent advances and remaining challenges. Nutrients 2021;13:2764.
10. Tabassum N, Biediger-Friedman L, Johnson C, Lane M, Marceaux S. Digital and technology-based nutrition interventions, including Medically Tailored Meals (MTMs) for older adults in the U.S.: a scoping review. Nutrients 2026;18:385.
11. De Santis KK, Mergenthal L, Christianson L, Busskamp A, Vonstein C, Zeeb H. Digital technologies for health promotion and disease prevention in older people: scoping review. J Med Internet Res 2023;25:e43542.
12. Buja A, Grotto G. Digital health interventions for improving nutritional behaviors in older adults: a scoping review. Front Nutr 2026;13:1743189.
13. Olmedo-Aguirre JO, Reyes-Campos J, Alor-Hernandez G, Machorro-Cano I, Rodriguez-Mazahua L, Sanchez-Cervantes JL. Remote healthcare for elderly people using wearables: a review. Biosensors (Basel) 2022;12:73.
14. Brown RC, Cook MA, Berton Weitnauer R, et al. Digital nutrition intervention in Older Americans Act programs impacts knowledge and desire to participate in virtual programming. Front Public Health 2026;14:1695528.
15. Tsai YI, Beh J, Ganderton C, Pranata A. Digital interventions for healthy ageing and cognitive health in older adults: a systematic review of mixed method studies and meta-analysis. BMC Geriatr

2024;24:217.
16. Xu Z, Xu X, Sun L, et al. Effectiveness of personalized meal recommendation in improving dietary behaviors of Chinese community-dwelling elders: study protocol for a cluster randomized controlled trial. Trials 2024;25:252.
17. Mooney P, Lam LT, Todd AR, Partridge SR, Raeside R. The inclusion and impact of digital determinants of health in digital nutrition interventions for adolescents: a systematic review. Health Promot Int 2025;40:daaf154.
18. Khan S, Webster S, Puxty J, Robertson M. Key challenges and barriers to digital literacy for older adults: scoping review. JMIR Aging 2026;9:e80647.
19. Hepburn J, Williams L, McCann L. Barriers to and facilitators of digital health technology adoption among older adults with chronic diseases: updated systematic review. JMIR Aging 2025;8:e80000.
20. Spinello G, Gobbi E, Paoli A, Moro T. Older adults' acceptability and perceived barriers to digital health tools integrating nutrition and physical activity: a focus group study. Front Digit Health 2026;8:1803847.
21. Munoz Esquivel K, Gillespie J, Kelly D, et al. Factors influencing continued wearable device use in older adult populations: quantitative study. JMIR Aging 2023;6:e36807.
22. Peters MD, Marnie C, Tricco AC, et al. Updated methodological guidance for the conduct of scoping reviews. JBI Evid Implement 2021;19:3-10.
23. Connelly J, Swingler K, Rodriguez-Sanchez N, Whittaker AC. Identifying food preferences and malnutrition in older adults in care homes: co-design study of a digital nutrition assessment tool. JMIR Aging 2025;8:e64661.
24. Gaewkhiew P, Chatyanan S, Supavaree S, Chaiueai A, Vimolratchataporn A, Sridonpai P. The impact of nutrition counselling via online application on nutrient intake among Thai older adults during COVID-19: pilot study of randomised controlled trial. BMC Public Health 2025;25:3672.
25. Su Y, Wu KC, Chien SY, Naik A, Zaslavsky O. A mobile intervention designed specifically for older adults with frailty to support healthy eating: pilot randomized controlled trial. JMIR Form Res 2023;7:e50870.
26. Gutierrez M, Cabello V, SanMartin CD, et al. An mHealth app (NeoMayor) to promote healthy lifestyles and brain health in older adults: design and validation study. JMIR Aging 2025;8:e71936.
27. de Souto Barreto P, Pothier K, Soriano G, et al. A web-based multidomain lifestyle intervention for older adults: the eMIND randomized controlled trial. J Prev Alzheimers Dis 2021;8:142-50.
28. Kurotani K, Tanabe H, Yanai K, Sakamoto K, Ohkawara K. An artificial intelligence-assisted smartphone application for improving dietary quality among frail older adults: a quasi-experimental study. Geriatrics (Basel) 2025;10:160.
29. Li PS, Hsieh CJ, Miao NF, et al. Application of the Fitness and Nutrition Program for Seniors (FANS) to improve physical activity and kinanthropometric measures among community-dwelling older adults living with frailty: a quasi-experimental study. BMC Geriatr 2025;25:543.
30. Gerber S, Silver RE, Das SK, et al. Development and feasibility of an ehealth diabetes prevention program adapted for older adults: results from a randomized control pilot study. Nutrients 2024;16:930.
31. Happe L, Sgraja M, Hein A, Quinten V, Diekmann R. Usability and feasibility of a tablet-based e-coach for older adults in rehabilitation units to improve nutrition and physical activity: a prospective pilot study. BMC Geriatr 2023;23:578.
32. Rainero I, Summers MJ, Monter M, et al. The My Active and Healthy Aging ICT platform prevents quality of life decline in older adults: a randomised controlled study. Age Ageing 2021;50:1261-7.
33. van den Helder J, Mehra S, van Dronkelaar C, et al. Blended home-based exercise and dietary protein in community-dwelling older adults: a cluster randomized controlled trial. J Cachexia Sarcopenia Muscle 2020;11:1590-602.
34. Li PS, Hsieh CJ, Miao NF, et al. Enhancing frailty status and health-related quality of life in community-dwelling frail older adults. Gerontology 2025;71:273-91.
35. Chew J, Zeng Z, Tan TH, et al. ADL+: a digital toolkit for multi-domain cognitive, physical, and nutritional interventions to prevent cognitive decline in community-dwelling older adults. Int J Environ Res Public Health 2024;22:42.

# Instructions for authors

Enacted on July 10, 2012
Recently revised on January 1, 2026

CLINICAL NUTRITION RESEARCH

**Table of Contents**



*Clinical Nutrition Research* (CNR), launched in 2012, is the official, open-access, peer-reviewed journal of the Korean Society of Clinical Nutrition. CNR is dedicated to advancing human health and nutrition by disseminating high-quality research that supports clinical application and promotes education in nutrition care. The journal features original articles, reviews, case reports, and research notes related to the field of clinical nutrition, human nutrition, and public health nutrition. It is published quarterly on the last day of January, April, July, and October.

Manuscripts should adhere to the Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly Work in Medical Journals, issued by the International Committee of Medical Journal Editors (ICMJE; http://www.icmje.org/recommendations/), unless otherwise specified.

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For specific study designs, such as randomized controlled trials, diagnostic accuracy studies, meta-analyses, observational studies, and non-randomized studies, authors should follow the relevant reporting guidelines. Recommended sources include the EQUATOR Network (https://www.equator-network.org/) and the National Library of Medicine (https://www.nlm.nih.gov/services/research_report_guide.html). CNR requires compliance with the reporting guidelines summarized in **Table 1** for the listed article types.

**Table 1.** Reporting guidelines for specific study designs

| Initiative | Type of study | Source |
|---|---|---|
| CONSORT | Randomized controlled trials | https://www.equator-network.org/reporting-guidelines/consort/ |
| TREND | Non-randomized controlled studies | https://www.cdc.gov/hivpartners/php/trend-statement/index.html |
| STROBE | Observational studies | https://www.equator-network.org/reporting-guidelines/strobe/ |
| STARD | Diagnostic/prognostic studies | https://www.equator-network.org/reporting-guidelines/stard/ |
| PRISMA | Systematic reviews and meta-analyses | https://www.equator-network.org/reporting-guidelines/prisma/ |
| CARE | Case reports | https://www.equator-network.org/reporting-guidelines/care/ |

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**Organize your manuscript file as follows:**

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Manuscript file: (1) abstract & keywords, (2) main text, (3) references, (4) tables, (5) figure legends (upload figures in separate files)

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This section should include the type of manuscript; manuscript title; running title; full names and affiliations of all authors; full name of institutional affiliation, postal address, and email of the corresponding author; ORCID; authors' contributions; any conflict of interest; any financial assistance; data availability; and acknowledgments.

Title: The title should be a single declarative statement that is brief, informative, and focused on the results presented in the manuscript. It should have the first letter of each major word capitalized, including prepositions and conjunctions of four letters or more.

Running title: Less than 50 characters

Author names: Names of authors should be given in full without abbreviation. In the listing of author names, any degree or professional title, such as MD or PhD, should not be included.

Affiliations: Departments and institutions of the authors. If from multiple institutions, use superscript numbers (1, 2, 3, etc.) to indicate specific affiliations.

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Abstract: For original articles, provide a structured abstract of less than 250 words with the following headings: Objective, Methods, Results, and Conclusion.
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The main text of an original article should contain the following subheadings: Introduction, Methods, Results, and Discussion consisting of no more than 5,000 words (excluding the Abstract, References, Table and Figure legends).

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Study design: Specify the study design (e.g., descriptive analysis, randomized controlled trial, cohort study, case-control study, or meta-analysis).

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Statistical analysis: Describe the statistical analyses in sufficient detail to allow replication. Specify the software used, including the program name, manufacturer, and version. Report measurement error or uncertainty, such as confidence intervals, in addition to P-values.

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**Discussion:** Discussion should emphasize concisely the novel and important aspects of the study and avoid unrelated references and statements. The summary and conclusion should be brief, written in the context of the research purpose.

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All references should be listed in the order of citation in the text, with corresponding numbers. The reference limits are 30 for original articles, 50 for review articles, and 15 for case reports and research notes.

- Identify references in the main text by listed Arabic numerals in brackets and numbered in consecutive order, as they appear in the main text. Use "-" when there are more than 3 references to be cited; for example, [4-7].
- List all authors' names for a reference with up to 6 authors; list first 3 authors' names followed by 'et al.' if more than 6 authors.
- Use the abbreviated journal title according to MEDLINE, available at https://www.ncbi.nlm.nih.gov/journals. For example, "Clinical Nutrition Research" should be written as Clin Nutr Res. Other types of references not described below should follow Citing medicine: the NLM style guide for authors, editors, and publishers (https://www.ncbi.nlm.nih.gov/books/NBK7256/).

Journal articles

1. Jung DH, Moon G, Lee CK, et al. Changes in nutritional status through low-lactose processed milk consumption in Korean adults with lactose intolerance. Clin Nutr Res 2025;14:30-40.
2. Gard CN, Freigeh GE, Janssen EM. Allergic manifestations of actinopathies: a review. J Allergy Clin Immunol 2025;156:1456-64.
3. Sultan T, Brustad N, Kyvsgaard JN, et al. Dominance of IL-5 and CCL17 in nasal cytokine profiles of children with type 2 inflammation. J Allergy Clin Immunol 2025 Dec 4 [Epub]. https://doi.org/10.1016/j.jaci.2025.11.009

Entire book and book chapter

4. Murray PR, Rosenthal KS, Kobayashi GS, Pfaller MA. Medical microbiology. 4th ed. Mosby; 2002.

5. Meltzer PS, Kallioniemi A, Trent JM. Chromosome alterations in human solid tumors. In: Vogelstein B, Kinzler KW, editors. The genetic basis of human cancer. McGraw-Hill; 2002. p. 93-113.

Abstract or supplement

6. Addicott M, Saldana S, Ip E, Oliveto A, Daughters S, Beckham J. Effects of recent smoking and daily hassles on mood and craving during a cigarette quit attempt [abstract]. Drug Alcohol Depend 2005;267 Suppl 1:111422.

Online sources

7. Korean Statistical Information Service (KOSIS). Prevalence of obesity [Internet]. KOSIS; 2024 [cited 2025 Dec 18]. Available from: https://kosis.kr/eng/

**Tables and Figures**

The total number of tables and figures should not exceed 6 for original and review articles, and 2 each for case reports and research notes.

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Each table should begin on a new page, with the table number and title above the table and explanatory notes below. Table numbers must correspond to the order in which they are cited in the main text. Tables should be self-explanatory, and the data presented should not be duplicated in the main text or figures.

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- Avoid unnecessary longitudinal lines.
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Research notes should be 2,000–5,000 words in length, excluding abstract, keywords, main text, references, tables, and figures. The abstract should be no more than 250 words. The number of references is limited to 15, and the number of tables and figures should not exceed 2 each.

Table 2 summarizes each publication type's key features and word count limit.

**Table 2.** Key features and word count limits of publication type[a)]

| Type of article | Abstract (words) | Text (words) | References | Tables and figures |
|---|---|---|---|---|
| Original article | Structured, 250 | 5,000 | 30 | 6 in total |
| Review article[b)] | Unstructured, 250 | 5,000–8,000 | 50 | 6 in total |
| Case report | Unstructured, 250 | 3,000 | 15 | 2 (for each) |
| Research Note | Unstructured, 200 | 2,000–5,000 | 15 | 2 (for each) |

[a)]The limits on word count, references, tables, and figures may be exceeded at the discretion of the editor in chief when justified; [b)]Systematic reviews should be accompanied by a structured abstract, and up to 100 references are permitted.

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☐ Authors have disclosed any conflict of interest related to this article.
☐ Research has been approved by appropriate human subjects research review boards, which are named in the text of the manuscript.
☐ All persons who have made substantial contributions to this work but did not fulfill the authorship criteria are named in the Acknowledgments.

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☐ Running head meets the word count (no more than 50 characters including spaces)
☐ Provides all author's ORCIDs.

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☐ The use of abbreviations is minimized.
☐ Lists two to five keywords/phrases and includes the model for the study. Uses the medical terminology from Index Medicus (MeSH).

**Introduction**

☐ States the hypothesis for the research and supporting objectives to test the hypothesis.
☐ Describes how this study advances human nutrition.
☐ Concise synopsis of relevant literature.

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☐ Methods and materials contains statement providing approval from the Institutional Review Committee for the subjects.
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☐ Technical or editorial assistance are acknowledged. Author's contributions or individual titles are not included.
☐ Financial support for this research is clearly indicated.
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