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Impact of Dietary Supplement Usage on Nutrient Adequacy and the Risk of Nutrient Excess Among Korean Adults

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ABSTRACT

Objectives: The growing popularity of frequent dietary supplements (DS) use raises concerns about DS overconsumption, posing challenges in achieving nutritional balance while avoiding excessive intake. Nonetheless, most studies have compared DS users with non-users without examining specific usage patterns. This study aimed to identify the varying DS usage patterns, frequencies, and associated nutrient adequacy and excess in 9889 Korean adults from the 2019–2020 KNHANES.

Methods: Dietary intake was assessed using a 24-h recall. DS use was assessed using structured questionnaires. Nutrient intakes from foods and DS were compared to reference levels, including estimated average requirements (EAR) and tolerable upper intake levels (UL), according to daily DS tablet consumption level. The mean adequacy ratio (MAR) was also calculated to assess overall nutritional adequacy.

Results: Fifty-six percent of Korean adults used DS, and 61% of DS users consumed two or more DS products. Among multiple DS users, multivitamins were the most commonly used types of DS, often taken with single vitamins, and mineral products. Compared to food alone, nutrient intake at any level of daily DS tablet consumption was mostly associated with a lower prevalence of intake below the EAR (p-trend < 0.001). However, the prevalence of exceeding UL increased with the use of a greater daily DS tablet consumption for vitamin C, iodine, iron, magnesium (all p-trend ≤ 0.022), while the MAR improvements plateaued.

Conclusions: While frequent DS use reduces micronutrient inadequacy, it may increase the risk of excessive intake, yielding only diminished gains in overall nutritional adequacy.

Abbreviations: AI, adequate intake; BMI, body mass index; DS, dietary supplements; EAR, estimated average requirements; KDCA, Korea Disease Control and Prevention Agency; KDRI, Korean Dietary Reference Intakes; KNHANES, Korea National Health and Nutrition Examination Survey; MAR, mean adequacy ratio; MM, multimineral; MV, multivitamin; MVM, multivitamin and mineral; NAR, nutrient adequacy ratio; PAF, population attributable fraction; RDA, recommended dietary allowance; RNI, recommended nutrient intake; UL, tolerable upper intake levels U.S.United States.

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Summary

- This is the first nationally representative study in Korea to quantify diet supplement (DS) overuse, usage patterns, and their benefits and risks for nutrient adequacy and tolerable upper intake level (UL) exceedance in a dose–response manner.
- Our study found widespread multiple DS uses in Korean adults; among DS users, 61% consumed two or more diet supplement products, with multivitamins being the most commonly consumed DS types, often taken alongside single vitamin and mineral products.
- While greater DS use reduced nutrient deficiencies, the gains in overall nutritional adequacy plateaued at higher consumption levels, increasing the risk of excessive intake.
- These results caution against over-reliance of DS use beyond addressing nutritional gaps and emphasize moderate use of DS to complement a diet.

1 | Introduction

The widespread use of dietary supplements (DS) [1–6], which typically contain bioactive compounds such as vitamins, minerals, proteins, and fatty acids, is a global phenomenon, driven primarily for the pursuit of better health and disease prevention [7, 8]. Approximately 56% of adults in the United States (US) [2], 17%–33% in the United Kingdom (UK) [5], 30%–59% in the Netherlands [6], 43.2% in Australia [9], and 38.9% in Japan [1] reported to use DS, according to National Surveys. These trends are particularly pronounced in Korea, where 75% of adults reported using any form of DS in 2020 [3], and 55% consumed two or more multiple DS [10].

While substantial evidence supports that DS can address micronutrient deficiencies such as low levels of iron, vitamin D, and calcium in the general population and reduce deficiency related conditions, including anemia, neural tube defects, and osteoporosis [11, 12], their overall health benefits beyond meeting nutritional requirements remains controversial. Excessive DS use may lead to intakes above the tolerable upper intake levels (UL) [13–17]. Several meta-analyses of randomized controlled trials [18–20] or a cohort [21] also reported that high-dose supplementation of certain nutrients (e.g., calcium (≥ 500 mg/day) [18], vitamin E (15 mg/day) [20], beta-carotene (9.6 mg/day) [20], folate (≥ 400 μg/day) [19]) and multivitamins (≥ 10 tablets/week) [21] increases risks of cardiovascular diseases by 13%-16% [18], prostate cancer by 24% [19], and all-cause mortality by 3%-58% [20, 21]. Consequently, public health authorities such as US Preventive Service Task Force [22] have issued cautionary statements regarding DS use.

Nevertheless, globally, there is limited understanding of effective and safe DS usage, raising the concerns of potential misuse or overuse of DS and associated health risks. To date, only one US study has examined such patterns [23]. In Korea, prior studies mainly compared DS users and non-users, for a limited range of six to seven nutrients [14, 24–29]. Addressing this gap by examining common DS usage patterns and providing insights into both nutritional benefits and potential risks related to nutrient intake is therefore timely and necessary, yet remains understudied. Therefore, we conducted the first nationwide study in Korea to identify DS usage patterns and frequencies and rigorously evaluate its impact on nutrient adequacy and excess in the Korea National Health and Nutrition Examination Survey (KNHANES) [30].

2 | Materials and Methods

2.1 | Study Design and Study Population

This study utilized data from the KNHANES 2019–2020, an annual, cross-sectional survey conducted by the Korea Disease Control and Prevention Agency (KCDA) to assess the health and nutritional status of the civilian, non-institutionalized Korean population [30]. Participants were selected using a complex, stratified, multistage cluster probability sampling method to ensure national representation [30]. Data on sociodemographics, health, and nutritional status were collected through health interviews, health examinations, and nutrition surveys conducted by trained staff.

Of 15,469 adults within KNHANES 2019–2020, we excluded those aged < 19 years ($N = 2{,}730$), without food or DS intake data ($N = 2159$), with implausible energy intake (< 500 kcal/day or > 5000 kcal/day) ($N = 180$) [3], or missing survey weights ($N = 511$), leaving a total of 9,889 participants in the final analysis (Figure 1). Informed consent was obtained from all participants. All KNHANES protocols were approved by the institutional review boards of the KCDC, and participants provided written informed consent. This study adheres to the principles of the Helsinki Declaration and was approved by the institutional Review Board of Ewha Womans University (IRB no. ewha-202309-0032-03).

2.2 | Nutrient Intake From Food

Dietary intake was assessed using a 24-h recall conducted by trained staff who received standardized and systematic training on the 24-h recall protocol, including interviewing techniques, use of portion-size estimation aids, and coding procedures, to ensure data quality [30]. The 24-h recall interview employed a structured, multi-stage approach to minimize recall bias and omissions, including sequential collection of meal and food items consumed, eating occasions and time, portion-size estimation, detailed information on food preparation methods and ingredients, and final respondent confirmation [30].

Daily nutrient intakes were estimated by multiplying the amount of each food item consumed by its nutrient content per gram, and summing these values across all reported foods, based on the 10th edition of the Korean Food Composition Table (2022) [31].

2.3 | Nutrient Intake From DS

As part of the KNHANES nutrition survey, participants completed a DS questionnaire. Those who answered 'yes' to 'Have

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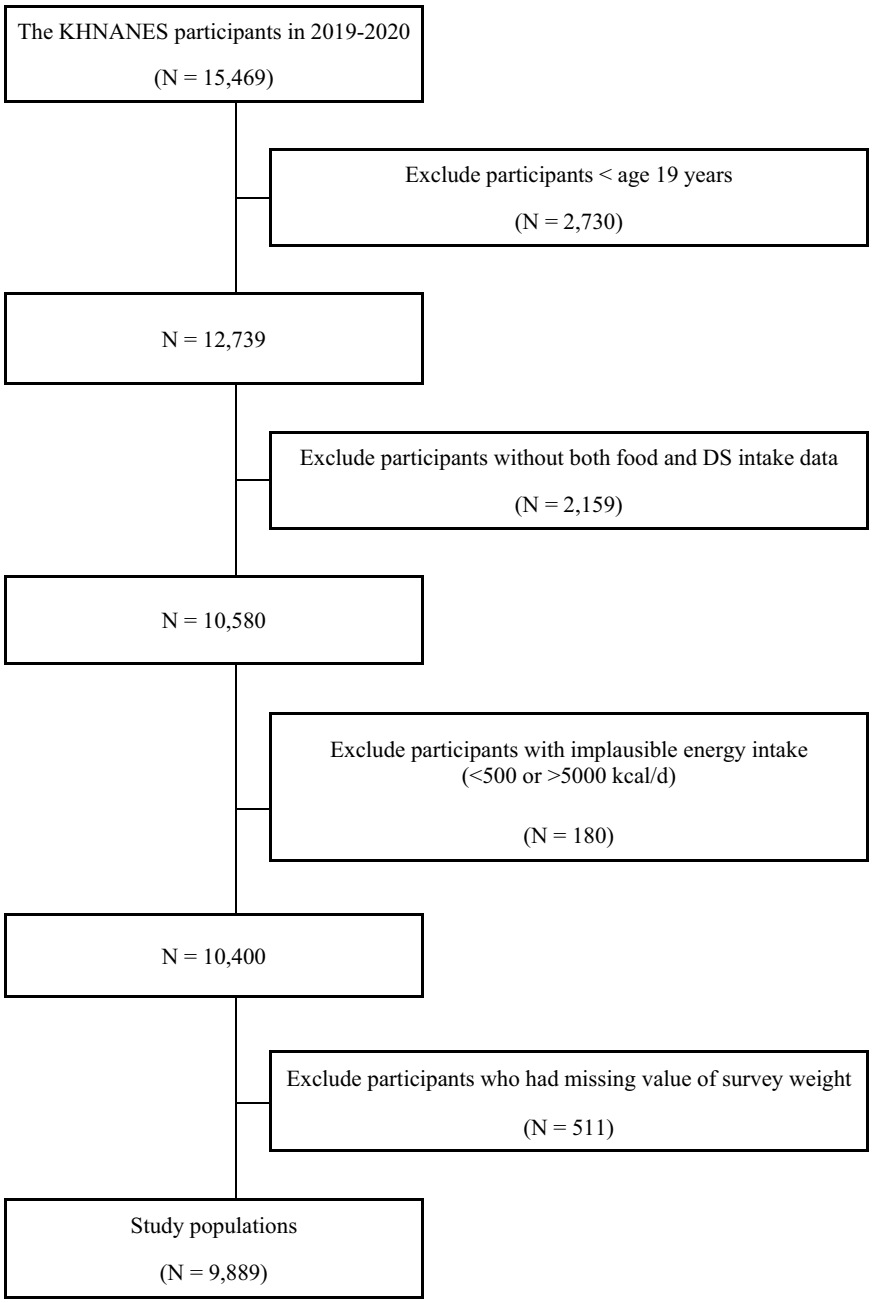


FIGURE 1 | Flow chart of the study population selection. DS, dietary supplements; KNHANES, Korean National Nutrition and Health Survey.

you taken dietary supplements for more than 2 weeks in the past year?' were subsequently asked to provide additional details up to four currently used DS products, including frequency, duration, typical amount consumed, the brands and manufacturers. Based on this information, participants were categorized either by the number of DS products used or by the number of tablets consumed per day [21].

Daily nutrient intake from DS was calculated using the DS database we developed following the protocol from a prior study [14]. Nutrient composition data for the DS products were compiled from various sources, including the Korean Ministry of Food and Drug Safety website (foodsafetykorea.go.kr), Druginfo (Druginfo.co.kr), manufacturer websites, or product distributor websites. The DS database covered 4203 DS products (84.6%) out of the 4967 products reported in KNHANES 2019–2020, including product name, manufacturer, standard serving size, and nutrient content. Daily nutrient intake from DS was calculated by multiplying daily frequency of each DS product by its nutrient content per participants' typical serving size and summing across all reported DS products.

2.4 | Total Nutrient Intake

Total nutrient intake from food sources and DS was estimated by summing the intake from both foods and DS sources. The correlation of total nutrient intake estimated from our study and the KNHANES dataset with a limited set of nutrient information were high ranging from 0.74 to > 0.99 (Table S1).

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2.5 | Assessment of Nutrient Adequacy

Participants were categorized by sex and age groups (19–29, 30–49, 50–64, 65–74, and ≥ 75 years) according to the 2020 Dietary Reference Intakes for Koreans. Individual nutrient adequacy was assessed comparing intake levels to age- and sex-specific reference values, including the Estimated Average Requirement (EAR), Recommended Nutrient Intake (RNI) or Adequate intake (AI), and UL. Nutrient intake below the EAR or AI was considered inadequate, while intake above UL was excessive. Overall nutritional adequacy, reflecting the extent to which daily nutrient requirements were met, was evaluated using the mean adequacy ratio (MAR) [32]. The MAR was calculated as the average of nutrient adequacy ratio (NAR) for each of 19 nutrients (See Table 4 for the list of nutrients) [32]; Each NAR, defined as the ratio of a participant's nutrient intake to the RNI or AI, was truncated at 1 to avoid overestimation of MAR due to excessive intake of certain nutrients [32]. The MAR values range from 0 to 1, with higher values indicating a greater fulfillment of overall nutritional requirements.

2.6 | Assessment of Other Covariates

Information on socio-demographics (age, sex, household income, education level, marital status), health behaviors (alcohol consumption, smoking, physical activity), and health status (self-perceived health status, current diseases) was collected using self-reported, standardized questionnaires [30]. Based on reported history and frequencies, alcohol and smoking status were classified as never, past, or current. Participants were considered physically active if they engaged in at least 2.5 h of moderate-intensity activity, 1.25 h of vigorous-intensity activity, or an equivalent combination of moderate- and vigorous-intensity activities weekly. Body mass index (BMI) was calculated from measured weight and height (kg/m^2). Self-perceived health status was categorized as 'good' or 'poor'. Chronic disease comorbidity was estimated by counting diagnosed or currently treated conditions, including hypertension, diabetes, cancer, dyslipidemia, cardiovascular disease, and liver disease.

2.7 | Statistical Analysis

All analyses accounted for the complex KNHANES sampling design using PROC SURVEY procedures in SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) applying sampling weights to ensure national representativeness.

Population characteristics across DS usage categories were described using frequencies and percentages, with group differences tested by the chi-square test. To identify the DS consumption patterns and assess the nutrient adequacy of commercial DS products available in Korea, the DS products were categorized into five types: multivitamin-mineral (MVM) supplement containing at least three vitamins and one mineral [33]; multivitamin (MV) supplement containing two or more vitamins; multimineral (MM) containing two or more minerals; single vitamin or mineral supplement; and others. The most consumed DS patterns were then ranked separately by the number of DS products used. To evaluate whether the nutrient levels in DS available on the Korean market are appropriate, nutrient content distributions across DS types were summarized by median and interquartile range and compared with the RNI or AI values for women aged 30–49 years, the predominant DS users in Korea [3].

Total nutrient intake and MAR were log-transformed to improve normality, and geometric means and standard error across daily tablet consumption, as well as percentage contributions of nutrient intake from DS, were estimated using multivariable-adjusted linear regression [29]. The prevalence of inadequate intake (below the EAR) and excess intake (above the UL) were estimated by calculating adjusted probabilities from multivariable-adjusted logistic regression [34]. All models were adjusted for *a priori* selected potential confounding factors previously reported as predictors of DS use, including age, sex, education level, household income, body mass index, physical activity, and total energy intake [14, 21, 29]. A missing indicator for missing covariate data was used, if applicable. Test for trend was conducted by treating daily tablets counts as a continuous term. The population attributable fraction (PAF) for exceeding the UL for each nutrient due to consuming > 2 tablets per day was calculated to better understand the contribution of DS overuse to excessive nutrient intake. Additionally, sensitivity analyses stratified by age and sex were conducted across all nutrient adequacy metrics, including the EAR, UL, NAR, and MAR. Statistical significance for all analyses set at a two-sided $p < 0.05$.

3 | Results

3.1 | Population Characteristics

Table 1 presents the characteristics of the study population. Overall, 56% of participants reported using DS. Specifically, 22% reported using one DS product, 15% used two DS products, and 20% used three or more DS products. Individuals who used more DS products were more likely to be older, female, urban-dwelling, and married, and have higher household income and education levels. They were also less likely to be current alcohol drinkers and smokers, and more likely to be physically active and had fewer chronic disease conditions (all $p < 0.05$). However, there were no significant differences in the BMI and self-perception health status across levels of DS product use.

3.2 | Patterns of Commonly Used Ds Types and Nutrient Content in DS Products

Among single DS users, 32.4% reported using other supplements, followed by single vitamin or mineral products (29.95%), MVM (29.9%), MV (6.83%), and MM (0.92%) (Table 2). The most frequent combination of DS products consumed were MVM and other supplements (28.88%) for two DS users, and MVM, single vitamin or mineral, and other supplements (57.73%) for users of three or more DS products.

Nutrient levels in the majority of DS products were high relative to nutritional requirements (Table 3). For instance, in MVM products, the median levels of fat-soluble nutrients met 77% to 100% of the RNI or AI. The median levels of water-soluble vitamins often exceeded RNI or AI, with these values ranging from 75% for folate to 458% for vitamin B12, whereas the corresponding values of mineral content varied widely from 23% for calcium to 180% for molybdenum. These high nutrient contents were similarly observed across other types of DS

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TABLE 1 | Study population characteristics in KNHANES 2019–2020[a] ($N = 9889$).

Characteristics	Non-users ($N = 4329$)	1 product users ($N = 2167$)	2 products users ($N = 1450$)	≥ 3 products users ($N = 1943$)	p value[b]
Sociodemographic factors[c]					
Age, years					
19–39	1252 (38.63)	512 (32.17)	335 (29.65)	426 (28.22)	< 0.001
40–64	1713 (40.75)	914 (43.75)	722 (51.41)	1163 (59.50)	
≥ 65	1364 (20.61)	741 (24.09)	393 (18.94)	354 (12.28)	
Sex					
Male	2128 (56.14)	924 (48.97)	573 (46.03)	607 (37.97)	< 0.001
Female	2201 (43.86)	1243 (51.03)	877 (53.97)	1336 (62.03)	
Region					
Urban	3391 (84.41)	1686 (82.61)	1197 (87.86)	1655 (89.80)	< 0.001
Rural	938 (15.59)	481 (17.39)	253 (12.14)	288 (10.20)	
Household income					
Low	1013 (18.03)	455 (15.90)	261 (13.79)	218 (8.64)	< 0.001
Middle-Low	1158 (26.11)	578 (24.23)	328 (21.39)	397 (18.76)	
Middle-High	1084 (27.27)	569 (28.37)	392 (28.21)	542 (28.55)	
High	1054 (28.59)	555 (31.50)	469 (36.61)	781 (44.06)	
Educational level					
Less than elementary school	891 (14.42)	411 (14.11)	219 (10.79)	189 (7.01)	< 0.001
Middle school	358 (7.31)	219 (8.42)	149 (8.33)	164 (6.35)	
High school	1407 (40.38)	622 (32.83)	410 (31.35)	637 (34.75)	
College or higher	1323 (37.89)	760 (44.65)	591 (49.53)	870 (51.88)	
Marital status					
Married	3,403 (70.03)	1,840 (78.36)	1,264 (82.78)	1,703 (83.24)	< 0.001
Single	926 (29.97)	327 (21.64)	186 (17.22)	240 (16.76)	
Healthy behavior factors[c]					
Alcohol drinking					
Never	545 (9.37)	285 (10.00)	159 (7.99)	190 (7.70)	0.030
Occasionally	1,526 (34.12)	798 (35.40)	543 (35.67)	791 (38.48)	
Frequently	2,203 (56.52)	1,064 (54.61)	730 (56.35)	954 (53.82)	
Smoking					
Never	2,431 (53.21)	1,322 (58.71)	912 (59.05)	1,314 (63.46)	< 0.001
Past	984 (23.60)	515 (24.00)	333 (25.98)	403 (22.65)	
Current	855 (23.18)	309 (17.29)	187 (14.97)	218 (13.89)	
Physical activity					
Inactive	2,395 (57.01)	1,152 (54.80)	762 (53.93)	985 (51.79)	0.017
Active	1,582 (42.99)	856 (45.20)	604 (46.07)	877 (48.21)	
BMI (kg/m^2)					
< 18.5	189 (4.82)	83 (4.30)	47 (3.39)	69 (3.81)	0.088
18.5–23	1,559 (36.50)	790 (36.46)	558 (39.38)	777 (38.86)	
23–25	932 (21.62)	512 (24.03)	340 (23.12)	445 (23.68)	
≥ 25	1,590 (37.06)	742 (35.21)	484 (34.11)	631 (33.65)	
Clinical health conditions[c]					
Self perception of health status					
Good	1161 (31.29)	622 (32.67)	414 (31.14)	541 (30.62)	0.870

(Continues)

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TABLE 1 | (Continued)

Characteristics	Non-users ($N = 4329$)	1 product users ($N = 2167$)	2 products users ($N = 1450$)	≥ 3 products users ($N = 1943$)	p value[b]
Normal	2069 (51.36)	1004 (50.33)	712 (52.58)	990 (52.56)	
Bad	777 (17.35)	396 (17.00)	245 (16.28)	334 (16.82)	
The number of chronic diseases[c]					
0	2400 (63.02)	1164 (60.72)	807 (59.72)	1256 (69.45)	< 0.001
1	1305 (26.28)	705 (28.23)	450 (29.85)	517 (23.49)	
2	520 (9.01)	255 (9.58)	168 (9.21)	146 (6.28)	
≥ 3	96 (1.70)	42 (1.48)	23 (1.21)	21 (0.79)	

Abbreviations: BMI, body mass index; DS, dietary supplements; KNHANES, Korea National Health and Nutrition Examination Survey.
[a]Values are expressed as number (percentages).
[b]P-value was calculated using a chi-squared test.
[c]The chronic disease include hypertension, diabetes, cancer, dyslipidemia, cardiovascular disease, and liver disease.

products, including MV and MM, and single vitamins or mineral products.

3.3 | Total Nutrient Intake According to Daily DS Tablet Consumption

Greater consumption of DS tablets was significantly associated with higher total intake of all nutrients, with the contribution of DS to total intake also increasing as the number of tablets consumed rose, although the degree of increase varied widely across the nutrients evaluated (all P-trend ≤ 0.004) (Table 4, Figure S1). The proportion of intake attributed to DS increased, ranging from a 1.71-fold increase for vitamin B12, from 21% for those consuming 0 < ~ ≤ 1 tablet per day to 36% for those consuming > 5 tablets per day, to a 3.72-fold increase for calcium, from 7% to 26% over the same range of tablet consumption.

3.4 | Nutritional Adequacy According to Daily DS Tablet Consumption

Increasing DS tablet consumption, up to > 5 tablets per day, was associated with a significant decrease in the prevalence of nutrient deficiencies across most of nutrients (P-trend < 0.001) (Table 5, Figure S2). Among the nutrients, vitamin C showed the greatest improvement, with the proportion of intake below the EAR dropping sharply by 57.29%, from 80.59% among non-users to 51.45% with > 0 ~ ≤ 1 tablet per day, and further to 23.30% with > 5 tablets per day. In contrast, iodine showed the smallest reduction, decreasing modestly by 19.42%, from 79% among non-users to 72.13% with > 0 ~ ≤ 1 tablet per day, and 59.58% with more than > 5 tablets per day.

However, greater DS tablet consumption was also associated with a significant increase in the prevalence of intake exceeding the UL for certain nutrients (all P-trend ≤ 0.022) (Table 5, Supplementary Figure 3). Specifically, the proportion exceeding the UL for vitamin C rose sharply from 0.03% in non-users to 0.36% in those consuming > 0 ~ ≤ 1 tablet per day, and further to 16.17% in those consuming > 5 tablets per day. Notably, these excessive intakes of vitamin C were found to be largely attributable to DS use, with the PAF for exceeding the UL due to consuming > 2 tablets per day estimated at 93.3%. Similarly, excessive intakes of iodine, iron, and magnesium also increased with higher tablet consumption per day, although the prevalence remained below 5% even in the highest category.

Moreover, overall nutritional adequacy showed limited improvement with increasing DS tablet consumption (Figure 2; Supplementary Table 2). The MAR increased progressively, starting at 0.60 among no DS users, rising to 0.69 for users of > 0 ~ ≤ 1 tablet per day, 0.72 for > 1 ~ ≤ 2 tablets per day, 0.76 for > 2 ~ ≤ 3 tablets per day, and stabilizing around 0.77 for those consuming > 3 tablets per day.

In sensitivity analyses, stratifying all analyses by age and sex yielded results that did not materially differ from the main findings (Tables S3–1 to S5-5).

4 | Discussion

In this nationwide study of Korean adults, 56% reported DS use. Among DS users, 61% used multiple DS products and MVM was most commonly used, often combined with single-vitamin and mineral products. Most DS products contained high nutrient levels relative to daily requirements. Greater consumption of daily DS tablets significantly reduced nutrient deficiencies, but it also increased the risk of exceeding ULs, particularly for vitamin C, iodine, iron, and magnesium, yielding only diminishing the marginal gains in overall nutritional adequacy.

DS use has risen globally with growing health awareness and accessibility [1–6]. In Korea, where rapid population aging has led to increasing interest in preventive health, this trend has been particularly pronounced, where DS use surged from 34.2% in 2007–2009 [14] to 70% in 2020 [3]. In our analysis characterizing DS usage patterns, majority of DS users consumed two or more products. This may reflect a popular belief that combining multiple supplements with diverse functionalities may offer greater synergistic or complementary health benefits. Similar trends have been reported in prior studies, with such

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TABLE 2 | Commonly used DS product patterns according to the number of DS products in KNHANES 2019–2020.

	1 product users ($N = 2167$)		2 products users ($N = 1450$)		≥ 3 products users ($N = 1943$)	
Rank	**Type**	**Frequency (%)**	**Type**	**Frequency (%)**	**Type**	**Frequency (%)**
1	Other	702 (32.4)	MVM, Other	303 (28.88)	MVM, Single vitamin or mineral, Other	904 (57.73)
2	Single vitamin or mineral	649 (29.95)	Single vitamin or mineral, Other	297 (28.31)	MV, Single vitamin or mineral, Other	239 (15.26)
3	MVM	648 (29.9)	MVM, Single vitamin or mineral	238 (22.69)	MVM, MV, Other	155 (9.9)
4	MV	148 (6.83)	MV, Other	76 (7.25)	MVM, MV, Single vitamin or mineral	94 (6)
5	MM	20 (0.92)	MVM, MV	53 (5.05)	MVM, MM, Other	52 (3.32)
6	—	—	MV, Single vitamin or mineral	53 (5.05)	MM, Single vitamin or mineral, Other	51 (3.26)
7	—	—	MM, Other	16 (1.53)	MVM, MM, Single vitamin or mineral	33 (2.11)
8	—	—	MM, Single vitamin or mineral	6 (0.57)	MV, MM, Other	16 (1.02)
9	—	—	MVM, MM	5 (0.48)	MV, MM, Single vitamin or mineral	12 (0.77)
10	—	—	MV, MM	2 (0.19)	MVM, MV, MM	10 (0.64)

Note: 1 Products that are not MVM, MV, MM, single vitamin or mineral.
Abbreviations: DS, dietary supplements; KNHANES, Korea National Health and Nutrition Examination Survey; MVM, multi vitamin and mineral; MV, multi vitamin; MM, multi mineral.

prevalence rates of 35.1%–61% in US [35, 36] and 55% in Korea [10].

In particular, among multiple DS users, MVMs were the most frequently consumed DS in our analyses, often combined with single-vitamin and mineral supplements. This prevalent use of multiple DSs, primarily involving MVMs, may reflect a preference in seeking convenient, comprehensive solutions addressing broader nutritional needs for general health maintenance. Similar high MVM consumption has been observed in many regions, including the US (63%) [2], Australia (17.5%) [9], Greece (42%) [37], and prior other Korean studies (15%–39%) [3, 14]. These findings indicate diverse DS use behaviors and significant reliance on DS as a major contributor to nutrient intake among Korean adults.

Additionally, manufacturers often formulate DS products with high nutrient levels [38, 39]. A US study analyzing 1,246 DS products found that median nutrient levels in the product ranged from 1.25 to 5 times the daily reference values for 11 out of 13 nutrients, with the 90th percentile reaching up to 10 times the median [39]. Similarly, 12%–15% of vitamin and mineral DS products in the UK exceeded 100% of RNI [38]. This Korean nationwide study also found that DS products contain nutrients near or above the RNI levels, mirroring a global high-dose formulation trend. Taken together, such widespread use of multiple high-dose DS raises concerns about exceeding safe intake despite benefits in reducing deficiencies questioning for optimal usage strategies.

However, the risks and benefits of DS usage remain unclear. To date, only a US NHANES study of 10,698 adults conducted nutrient assessment according to MVM frequencies [23]. It found that frequent MVM use up to ≥ 21 days/month significantly increases intake, from a 1.31-fold for calcium to 7.35-fold for vitamin B6, while substantially reducing nutrient inadequacy. The proportion below the EAR dropped from 95.6% among non-users to 3.86% among the most frequent users for vitamin D, 86.9% to 0.50% for vitamin E, 54.6% to 19.3% for magnesium, and 40.5% to 18.8% for calcium. However, it also led to more individuals exceeding Uls—calcium rising from 0.47% to 4.13%, iron from 0.01% to 2.90%, zinc from 0% to 3.59%, and folate from 0% to 4.05%. Similarly, we also found a dual-edged nature of frequent DS use. DS use up to five tablets per day nearly doubled its contribution to total intake, significantly reducing deficiency risk, but increasing the excessive intake risk, particularly for vitamin C.

Moreover, when MAR was examined to understand overall nutritional balance of multiple nutrients, we found that MAR improvement gradually declined and plateaued at three or more tablets per day, which suggests limited additional benefits and reinforces U-shape dose-related evidence questioning the clinical efficacy of such frequent practices [20, 21, 40]. Our earlier KNHANES study similarly showed that the significant inverse association between vitamins and mineral supplements and non-alcoholic fatty liver disease becoming non-significant beyond two or more supplements per day [40]. Likewise, Nurses' Health Study and the Health Professionals Follow-up Study found reduced all-cause or colorectal cancer-specific mortality at 3–5 MVM tablets per week, but no benefits at 6–9 tablets

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TABLE 3 | Distribution of nutrients contained in the DS product by supplement type and comparison with KDRI in KNHANES 2019–2020.

Nutrients	KDRI[1] RNI or AI	MVM[2] (*N* = 861) Median (25th–75th)	MVM[2] (*N* = 861) %/RNI or AI[6]	MV[3] (*N* = 347) Median (25th–75th)	MV[3] (*N* = 347) %/RNI or AI[6]	MM[4] (*N* = 87) Median (25th–75th)	MM[4] (*N* = 87) %/RNI or AI[6]	Single vitamin or mineral[5] (*N* = 1181) Median (25th–75th)	Single vitamin or mineral[5] (*N* = 1181) %/RNI or AI[6]
Vitamins									
Fat-soluble vitamin									
Vitamin A (μgRAE/d)[7]	650	600 (334.1–753.8)	92	600 (300–700)	92	—	—	471.2 (210–800)	72
Vitamin D (μg/d)[8]	10	10 (4.4–12.5)	100	10 (5–25)	100	—	—	25 (25–50)	250
Vitamin E (mg/d)[8]	12	11 (5.5–25)	92	9.8 (3.8–11)	82	—	—	4.4 (3.3–11)	36
Vitamin K (μg/d)[8]	65	50 (27.5–70)	77	25 (25–36)	38	—	—	—	—
Water-soluble vitamin									
Thiamin (mg/d)[7]	1.1	2.2 (1.1–16.6)	200	3.9 (1.2–33.3)	358	—	—	4.1 (4.1–4.1)	368
Riboflavin (mg/d)[7]	1.2	2 (1.2–13)	167	2 (1.2–10)	167	—	—	5 (1.4–5)	417
Niacin (mg/d)[7]	14	18 (10–35)	129	20 (13–50)	143	—	—	2.3 (2.3–2.3)	16
Vitamin B^6 (mg/d)[7]	1.4	3 (1.5–12)	214	2.5 (1.5–15)	179	—	—	5 (2.9–52.5)	357
Vitamin B_{12} (μg/d)[7]	2.4	11 (2.8–50)	458	16 (3–100)	667	—	—	1000 (6–1500)	41667
Vitamin C (mg/d)[7]	100	93.1 (50–150)	93	100 (50–250)	100	—	—	925 (100–1000)	925
Folate (μg/d)[7]	400	300 (200–400)	75	400 (200–400.1)	100	—	—	620 (400–800)	155
Biotin (μg/d)[8]	30	50 (30–125)	167	54 (30–100)	180	—	—	3000 (300–5000)	10000
Pantothenic acid (mg/d)[8]	5	10 (5–18)	200	6.9 (5–46)	138	—	—	500 (500–500)	10000
Minerals									
Macromineral									
Calcium (mg/d)[7]	700	162.3 (50–237)	23	—	—	158.4 (46–300)	23	157 (60–210)	22
Magnesium (mg/d)[7]	280	94.3 (50–105.5)	34	—	—	50 (48–125)	18	300 (150–400)	107
Micromineral									
Copper (mg/d)[7]	0.65	0.8 (0.5–1)	123	—	—	0.5 (0.5–0.5)	77	1 (1–1)	154
Iron (mg/d)[7]	14	9 (4.7–15)	64	—	—	3 (1.4–6.2)	21	25 (18–40)	179
Iodine (μg/d)[7]	150	150 (75–150)	100	—	—	65 (50–12500)	43	—	—
Manganese (mg/d)[8]	3.5	2 (1–3)	57	—	—	1.5 (1–2)	43	1 (0.3–10)	29
Molybdenum (μg/d)[7]	25	45 (25–60)	180	—	—	23 (23–23)	92	—	—

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TABLE 3 | (Continued)

Nutrients	KDRI[1] RNI or AI	MVM[2] (*N* = 861) Median (25th–75th)	MVM[2] (*N* = 861) %/RNI or AI[6]	MV[3] (*N* = 347) Median (25th–75th)	MV[3] (*N* = 347) %/RNI or AI[6]	MM[4] (*N* = 87) Median (25th–75th)	MM[4] (*N* = 87) %/RNI or AI[6]	Single vitamin or mineral[5] (*N* = 1181) Median (25th–75th)	Single vitamin or mineral[5] (*N* = 1181) %/RNI or AI[6]
Selenium (μg/d)[7]	60	45 (20.3–55)	75	—	—	33.3 (16.5–55)	56	25 (16.5–100)	42
Zinc (mg/d)[7]	8	8.5 (4.3–13)	106	—	—	5 (2.6–8.5)	63	5 (2.8–8.5)	63

Abbreviations: –, not applicable or no reference value; AI, adequate intake; KDRI, Korean Dietary Reference Intake; KNHANES, Korea National Health and Nutrition Examination Survey; MM, multi mineral; MV, multi vitamin; MVM, multi vitamin and mineral; RNI, recommended nutrient intake.

[1]RNI or AI values for women aged 30–49.

[2]Products contain at least three vitamins and at least one mineral.

[3]Products contain two or more vitamins.

[4]Products contain two or more minerals.

[5]Products contain only a single vitamin or only a single mineral.

[6]"%/RNI or AI" represents the percentage of median intake values, compared to RNI (or AI).

[7]Nutrient with RNI reference value.

[8]Nutrient with AI reference value.

per week, and a 1.58 fold increase in colorectal cancer-specific mortality at > 10 tablets per week [21]. A meta-analysis of 53 randomized controlled trials also found that vitamin E and beta-carotene supplementation above, but not below, the recommended dietary allowance level may increase all-cause mortality risk [20].

Overall, our findings and prior evidence caution against over-reliance of DS beyond addressing nutrient gaps. DS effects can vary by nutrient status, with supplementation in well-nourished populations potentially negating benefits or even increasing disease risk. For instance, folate's role in preventing neural tube defects was evident during the pre-fortification era in the US, but less so in post-fortification [41]. Similarly, while vitamin D's benefit on mortality risk [42] was not observed among non-deficient individuals [43]. Diabetes risk increased from 1.04 (0.60–1.80) in individuals with plasma selenium ≤ 113.4 ng/mL to 2.50 (1.32–4.77) in those with > 113.4 ng/mL [44]. Furthermore, nutrients from food sources often reported to provide greater benefit than supplements [43, 45]. Accordingly, the US Preventive Task Force concluded insufficient evidence to support DS use for primary prevention of major chronic diseases such as cardiovascular disease or cancer [22].

Several biological mechanisms may explain the observed plateau in MAR improvement. While vitamins and minerals support immune, metabolic, and antioxidant functions, nutrient absorption and utilization often plateau once dietary requirements are met due to homeostatic regulation, with excess excreted or redirected from their primary function [11]. Excessive intake can disrupt physiological balance and impair nutrient absorption and metabolism. High antioxidants may induce oxidative stress, disrupt redox signaling, and impair immune surveillance. High-dose supplementation of vitamin C [46], vitamin E [20], beta-carotene [20], and selenium levels [47, 48], alone or combined, was associated with increased risk of diabetes [48], cancers [47], age-related cataract [46] and mortality [20]. High magnesium may cause neuromuscular dysfunction, cardiovascular irregularities, and impaired calcium metabolism [49], while excessive calcium intake can promote vascular calcification and kidney stones, increasing cardiovascular [18] and renal complications [50].

This study has several strengths. It is the first nationally representative Korean analysis to quantify DS use patterns and their dose-response effects on nutrient adequacy and excess intake. Assessing both individual nutrient adequacy and overall balance leverages the strengths of both metrics, offering a comprehensive view of nutritional status. These nationally generalizable findings provide the most up-to-date dose-response evaluation of DS impact on nutritional status across 19 micronutrients and new insights into optimal DS use.

However, several limitations should be noted. The use of a single 24-h recall to estimate food intake may not accurately reflect usual diet and introduce random error, potentially arising from day-to-day variability intake or seasonal fluctuation. Nonetheless, a year-round rolling survey design of KNHANES 2019–2020 may help mitigate, at least, seasonal bias at the population level. Self-reported DS use is subject to recall bias, including omission and dose misreporting, particularly for non-prescription products.

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TABLE 4 | Absolute total nutrient intake and contribution of DS to total intake according to DS tablets in KNHANES 2019-2020[1,2].

Nutrients	Non-user (only food) (N = 4,329)	0< tablet/d ≤ 1 (food + DS) (N = 1,928)		1 < tablets/d ≤ 2 (food + DS) (N = 1,305)		2 < tablets/d ≤ 3 (food + DS) (N = 889)		3 < tablets/d ≤ 4 (food + DS) (N = 700)		4 < tablets/d ≤ 5 (food + DS) (N = 235)		5 < tablets/d (food + DS) (N = 408)		P-trend[4]	P-trend[5]
	Total intake, Mean (S.E.)	Total intake, Mean (S.E.)	% of DS[3]	Total intake, Mean (S.E.)	% of DS[3]	Total intake, Mean (S.E.)	% of DS[3]	Total intake, Mean (S.E.)	% of DS[3]	Total intake, Mean (S.E.)	% of DS[3]	Total intake, Mean (S.E.)	% of DS[3]		
Vitamins															
Fat-soluble vitamin															
Vitamin A (μgRAE/d)	225.65 (12.83)	303.63 (17.30)	13	357.86 (23.06)	20	417.78 (27.04)	25	424.44 (28.28)	26	437.99 (38.17)	26	456.79 (37.51)	28	< 0.001	< 0.001
Vitamin D (μg/d)	0.91 (0.09)	2.81 (0.19)	28	4.43 (0.33)	43	6.89 (0.55)	56	8.94 (0.74)	60	8.90 (1.06)	59	9.45 (1.02)	62	< 0.001	< 0.001
Vitamin E (mg/d)	4.63 (0.19)	7.48 (0.33)	23	9.49 (0.44)	34	11.36 (0.58)	39	12.65 (0.74)	43	14.49 (1.26)	46	15.35 (1.27)	48	< 0.001	< 0.001
Vitamin K (μg/d)	109.74 (6.95)	113.29 (7.28)	3	119.49 (8.27)	5	126.72 (9.00)	6	126.60 (8.89)	7	118.59 (10.33)	8	125.31 (12.14)	10	< 0.001	< 0.001
Water-soluble vitamin															
Thiamin (mg/d)	0.86 (0.07)	2.19 (0.16)	24	2.67 (0.18)	31	3.36 (0.27)	37	3.74 (0.32)	41	4.21 (0.54)	44	3.72 (0.43)	42	< 0.001	< 0.001
Riboflavin (mg/d)	1.01 (0.05)	2.34 (0.11)	22	2.66 (0.14)	29	3.46 (0.23)	35	3.61 (0.28)	37	3.77 (0.41)	40	3.42 (0.33)	38	< 0.001	< 0.001
Niacin (mg/d)	6.65 (0.23)	10.21 (0.40)	22	11.07 (0.45)	27	13.12 (0.62)	34	13.87 (0.77)	35	14.83 (1.23)	40	16.21 (1.12)	44	< 0.001	< 0.001
Vitamin B_6 (mg/d)	0.16 (0.04)	1.27 (0.10)	31	1.66 (0.13)	40	2.36 (0.21)	47	2.69 (0.26)	51	2.92 (0.43)	54	2.68 (0.33)	54	< 0.001	< 0.001
Vitamin B_{12} (μg/d)	2.05 (0.16)	4.33 (0.32)	21	5.11 (0.40)	26	6.87 (0.59)	32	7.97 (0.80)	35	8.63 (1.28)	37	8.43 (1.02)	36	< 0.001	< 0.001
Vitamin C (mg/d)	33.39 (2.13)	71.25 (4.82)	29	103.38 (7.61)	40	140.61 (10.80)	49	189.20 (16.78)	55	189.14 (20.49)	58	213.40 (24.05)	59	< 0.001	< 0.001
Folate (μg/d)	222.29 (8.14)	300.51 (11.53)	31	345.94 (14.73)	37	416.71 (18.06)	47	443.25 (22.90)	49	454.16 (31.58)	52	493.58 (33.11)	54	< 0.001	< 0.001
Biotin (μg/d)	12.83 (0.67)	20.51 (1.15)	16	23.79 (1.41)	21	28.63 (1.89)	28	30.79 (2.16)	28	34.69 (3.48)	31	38.84 (4.31)	37	< 0.001	< 0.001
Pantothenic acid (mg/d)	3.54 (0.12)	5.58 (0.22)	19	6.17 (0.24)	23	7.56 (0.36)	30	7.99 (0.44)	32	8.51 (0.69)	33	9.41 (0.85)	37	< 0.001	< 0.001

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TABLE 4 | (Continued)

Nutrients	Non-user (only food) (N = 4,329) Total intake, Mean (S.E.)	0< tablet/d ≤ 1 (food + DS) (N = 1,928) Total intake, Mean (S.E.)	% of DS[3]	1 < tablets/d ≤ 2 (food + DS) (N = 1,305) Total intake, Mean (S.E.)	% of DS[3]	2 < tablets/d ≤ 3 (food + DS) (N = 889) Total intake, Mean (S.E.)	% of DS[3]	3 < tablets/d ≤ 4 (food + DS) (N = 700) Total intake, Mean (S.E.)	% of DS[3]	4 < tablets/d ≤ 5 (food + DS) (N = 235) Total intake, Mean (S.E.)	% of DS[3]	5 < tablets/d (food + DS) (N = 408) Total intake, Mean (S.E.)	% of DS[3]	P-trend[4]	P-trend[5]
Minerals Macro-mineral															
Calcium (mg/d)	358.79 (11.02)	403.32 (12.66)	7	429.27 (14.02)	10	475.97 (17.17)	13	491.32 (18.60)	17	486.99 (24.54)	18	579.42 (26.96)	26	< 0.001	< 0.001
Magnesium (mg/d)	216.87 (4.13)	234.65 (4.73)	24	247.02 (5.43)	34	268.22 (6.17)	43	280.13 (7.35)	47	283.04 (10.09)	51	319.43 (11.39)	54	< 0.001	< 0.001
Micromineral															
Copper (mg/d)	0.75 (0.02)	0.86 (0.02)	8	0.91 (0.02)	12	0.96 (0.03)	13	1.05 (0.04)	15	1.07 (0.06)	17	1.12 (0.05)	18	< 0.001	< 0.001
Iron (mg/d)	7.49 (0.27)	8.63 (0.33)	9	9.46 (0.35)	13	9.97 (0.41)	14	10.16 (0.44)	16	9.96 (0.55)	15	10.92 (0.53)	18	< 0.001	< 0.001
Iodine (μg/d)	42.30 (3.42)	53.97 (4.38)	9	59.18 (5.33)	14	66.92 (6.30)	14	71.76 (7.53)	16	69.79 (8.66)	17	68.28 (8.36)	21	< 0.001	< 0.001
Manganese (mg/d)	3.29 (0.07)	3.67 (0.09)	7	3.86 (0.10)	11	4.05 (0.11)	13	4.18 (0.14)	15	4.12 (0.17)	16	4.29 (0.18)	18	< 0.001	< 0.001
Molybdenum (μg/d)	129.50 (2.60)	135.25 (2.95)	3	134.07 (3.49)	4	140.04 (3.69)	5	137.39 (4.41)	6	139.20 (5.50)	6	134.65 (5.65)	7	0.004	< 0.001
Selenium (μg/d)	52.43 (1.82)	62.90 (2.24)	9	65.14 (2.48)	12	71.5 (2.76)	16	75.72 (3.40)	17	77.79 (4.06)	19	74.94 (3.90)	21	< 0.001	< 0.001
Zinc (mg/d)	7.63 (0.15)	10.46 (0.22)	19	11.56 (0.30)	26	13.31 (0.38)	33	14.18 (0.47)	36	14.63 (0.69)	37	15.02 (0.62)	37	< 0.001	< 0.001

Abbreviations: DS, dietary supplements; KNHANES, Korea National Health and Nutrition Examination Survey; S.E., standard error of mean.

[1]The absolute total intake and the contribution of DS to the total intake were adjusted for age (continuous, years), sex (men, women), energy intake (continuous, kcal/day), education level (less than elementary school, middle school, high school, college or higher), household income (low, middle-low, middle-high, high), body mass index (< 18.5, 18.5-23, 23-25, ≥ 25 kg/m^2), physical activity (inactive, active).

[2]Participants who consumed products other than tablets, capsules, bags or bottles form were excluded.

[3]"% of DS" represents the percentage of contribution of intake from DS to total intake.

[4]P-trend for total intake across the daily tablet consumption groups was calculated including the ordinal categorical variable of the daily tablet consumption groups as a continuous term.

[5]P-trend for contribution of DS to total intake across the daily tablet consumption groups was calculated including the ordinal categorical variable of the daily tablet consumption groups as a continuous term.

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TABLE 5 | Prevalence of total nutrient intake below EAR and above UL according to the DS tablets in KNHANES 2019-2020[1,2].

	Non-user (only food) (N = 4,329)		0< tablet/d ≤ 1 (food + DS) (N = 1,928)		1 < tablets/d ≤ 2 (food + DS) (N = 1,305)		2 < tablets/d ≤ 3 (food + DS) (N = 889)		3 < tablets/d ≤ 4 (food + DS) (N = 700)		4 < tablets/d ≤ 5 (food + DS) (N = 235)		5 < tablets/d (food + DS) (N = 408)				
Nutrients	**% < EAR**	**% > UL**	**% < EAR**	**% > UL**	**% < EAR**	**% > UL**	**% < EAR**	**% > UL**	**% < EAR**	**% > UL**	**% < EAR**	**% > UL**	**% < EAR**	**% > UL**	**P-trend[3]**	**P-trend[4]**	**PAF (%)**
Vitamins																	
Fat-soluble vitamin																	
Vitamin A[5,6]	84.72	0	73.22	0	65.08	0	56.08	0	53.53	0	54.47	0.01	53.87	0.01	< 0.001	< 0.001	44.44
Vitamin D[6]	—	0	—	0	—	0.01	—	0.02	—	0.02	—	0.02	—	0.02	—	< 0.001	89.93
Vitamin E[6]	—	0	—	0	—	0	—	0	—	0	—	0	—	0	—	< 0.001	85.25
Water-soluble vitamin																	
Thiamin[5]	44.36	—	25.07	—	21.05	—	15.95	n/a	13.68	—	12.57	—	15.97	—	< 0.001	—	—
Riboflavin[5]	41.93	—	24.17	—	18.70	—	13.57	n/a	14.34	—	12.82	—	13.73	—	< 0.001	—	—
Niacin[5,6,7]	81.62	—	58.54	—	55.95	—	45.48	—	43.40	—	43.34	—	34.24	—	< 0.001	—	—
Vitamin B6[5,6]	99.32	0	70.61	0	61.73	0.01	54.57	0.01	49.15	0.01	48.32	0.01	47.18	0.02	< 0.001	< 0.001	78.25
Vitamin B_{12}[5]	50.34	—	35.45	—	31.72	—	29.27	n/a	23.11	—	22.58	—	23.13	—	< 0.001	—	—
Vitamin C[5,6]	80.59	0.03	51.45	0.36	39.88	2.15	29	4.06	25.14	6.54	23.09	9.53	23.30	16.17	< 0.001	< 0.001	93.33
Folate[5,6,7]	76.55	0	56.93	0	49.72	0	37.05	0	33.73	0.01	34.46	0.05	33.22	0.03	< 0.001	< 0.001	—
Minerals																	
Macro-mineral																	
Calcium[5,6]	82.08	0	75.97	0	70.27	0	61.92	0	60.97	0	61.02	0	45.32	0	< 0.001	< 0.001	29.45
Magnesium[5,6,7]	67.95	0	57.98	0	52.35	0.02	44.53	0.09	37.34	0.25	38.02	0.34	27.80	1.23	< 0.001	< 0.001	98.93
Micromineral																	
Copper[5,6]	25.38	—	21.36	—	17.02	—	15.65	—	15.11	—	11.12	—	11.91	—	< 0.001	—	—
Iron[5,6]	50.35	0.39	40.66	0.59	32.40	1.23	29.12	2.12	26.68	1.35	30.51	1.70	20.76	2.97	< 0.001	< 0.001	52.65
Iodine[5,6]	79	1.43	72.13	1.98	67.07	1.75	62.55	2.51	60.14	2.12	56.30	1.05	59.58	3.31	< 0.001	0.022	9.41
Manganese[6]	—	0.01	n/a	0.01	—	0.01	—	0.02	—	0.02	—	0.02	—	0.03	—	< 0.001	29.37
Molybdenum[5,6]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.510	0.270	11.43
Selenium[5,6]	32.92	0	22.08	0	21.45	0	17.51	0	14.23	0.01	14.97	0	16.09	0	< 0.001	< 0.001	46.56
Zinc[5,6]	36.57	0.01	17.61	0.11	14.94	0.22	10.36	0.29	8.17	0.41	8.22	0.41	8.72	0.54	< 0.001	< 0.001	69.54

Abbreviations: –, not applicable or no reference value; DS, dietary supplements; EAR, estimated average requirement; KNHANES, Korea National Health and Nutrition Examination Survey; PAF, population attributable fraction; UL, tolerable upper intake level.

[1]The percentage of nutrient intake below the EAR and above the UL was adjusted for age (continuous, years), sex (men, women), energy intake (continuous, kcal/day), education level (less than elementary school, middle school, high school, college or higher), household income (low, middle-low, middle-high, high), body mass index (< 18.5, 18.5–23, 23–25, ≥ 25 kg/m^2), and physical activity (inactive, active).

[2]Participants who consumed products other than tablets, capsules, bags or bottles form were excluded.

[3]P-trend for the percentages of nutrient intake below the EAR across the daily tablet consumption groups was calculated including the ordinal categorical variable of the daily tablet consumption groups as a continuous term.

[4]P-trend for the percentages of nutrient intake above the UL across the daily tablet consumption groups was calculated including the ordinal categorical variable of the daily tablet consumption groups as a continuous term.

[5]Nutrient with EAR reference value.

[6]Nutrient with UL reference value.

[7]The UL excess estimates for niacin, folate, and magnesium were based on intakes from non-food sources, such as DS, according to Korean Dietary Reference Intake.

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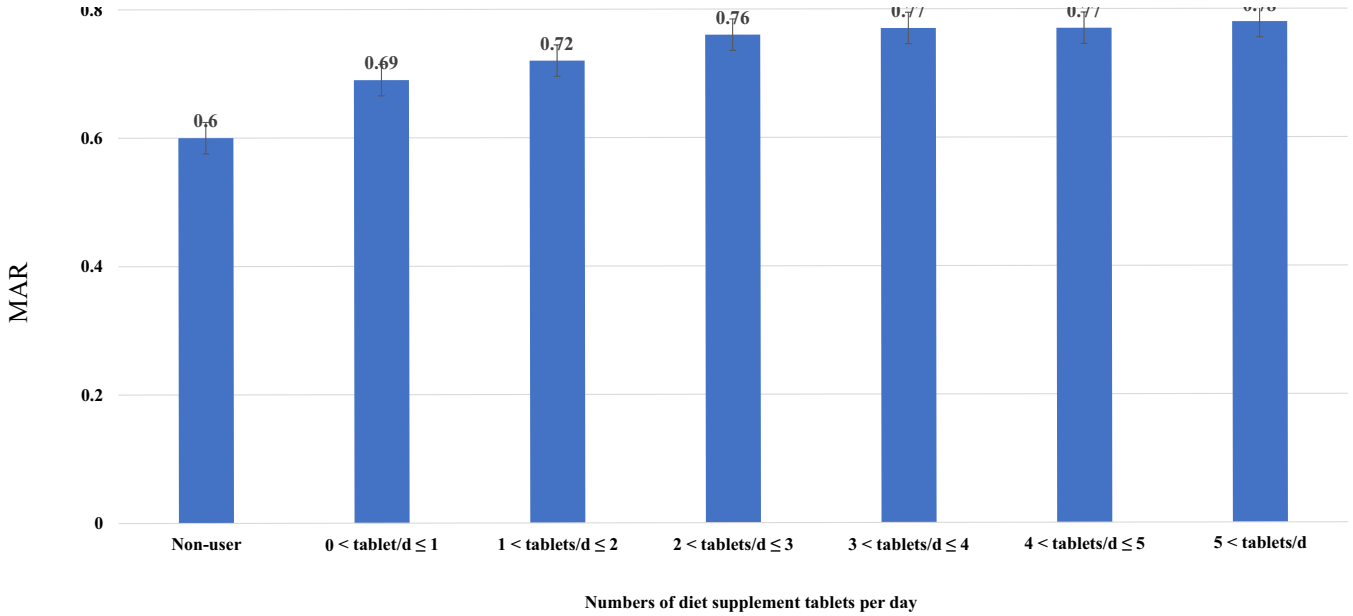


FIGURE 2 | The MAR according to the number of diet supplement tablets per day. MAR, mean adequacy ratio.

Furthermore, limiting records to four DS products and missing data from discontinued or uninformative products overestimate nutrient inadequacy or underestimate nutrient excess. Using RNI or AI cut-off values in MAR, which are designed to meet the requirements of 97%–98% individuals, might also underestimate population-level nutrient adequacy. Nonetheless, concurrently analyzing the prevalence of intakes below the EAR and above the UL complements the MAR results, balancing evidence on risks of both nutrient inadequacy and excess. Finally, generalizing these results beyond Korean adults with varied dietary and supplement use patterns needs caution.

In conclusion, our study reveals frequent, high-dose, multiple DS use among Korean adults, which effectively reduced nutrient deficiencies. But it increased the risk of excessive intake, yielding only diminished gains for overall nutritional adequacy. These findings support conservative dietary guidelines advocating moderate DS use to complement a diet [12]. Further studies are warranted to develop evidence-based strategies for safe and moderate DS use and to investigate clinical outcomes associated with DS usage patterns.

Author Contributions

The study concept and design of the study was conducted by Seungyoun Jung. Data curation was conducted by Seongha Kim, Jihee Shin, Yoonmi Park, Kwang Suk Ko, Hye Mi Kim, Chaewon Lee, and Soohan Jung. Formal analyses were conducted by Seongha Kim. Manuscript was drafted by Seongha Kim and Seungyoun Jung. Manuscript was edited by Seungyoun Jung. Kwang Suk Ko, Seok-Hee Lee, Yooheon Park, Huiwon Seo, Ga-Hee Shin, Sangmin Lee, Byeongchul Kang critically reviewed the manuscript and contributed to the interpretation of data; Study supervision was conducted by Seungyoun Jung. Seungyoun Jung had primary responsibility for final content. All authors read and approved the final manuscript.

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Ethics Statement

All KNHANES protocols were approved by the institutional review boards of the KCDC, and participants provided written informed consent. This study adheres to the principles of the Helsinki Declaration and was approved by the institutional Review Board of Ewha Womans University (IRB no. ewha-202309-0032-03).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data described in the manuscript, code book, and analytic code will be made publicly and freely available without restriction at https://knhanes.kdca.go.kr/knhanes/main.do.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Table S1: Comparison of average daily intake from food and DS between our study and KNHANES dataset.

Table S2: The NAR and MAR according to the number of DS tablets per day.

Table S3-1: Absolute total nutrient intake and contribution of DS to total intake according to DS tablets among men in KNHANES 2019-2020.

Table S3-2: Absolute total nutrient intake and contribution of DS to total intake according to DS tablets among women in KNHANES 2019-2020.

Table S3-3: Absolute total nutrient intake and contribution of DS to total intake according to DS tablets among adults aged 19-39 years in KNHANES 2019-2020.

Table S3-4: Absolute total nutrient intake and contribution of DS to total intake according to DS tablets among adults aged 40-64 years in KNHANES 2019-2020.

Table S3-5: Absolute total nutrient intake and contribution of DS to total intake according to DS tablets among adults aged ≥65 years in KNHANES 2019-2020.

Table S4-1: Prevalence of total nutrient intake below EAR and above UL according to the DS tablets among men in KNHANES 2019-2020.

Table S4-2: Prevalence of total nutrient intake below EAR and above UL according to the DS tablets among women in KNHANES 2019-2020.

Table S4-3: Prevalence of total nutrient intake below EAR and above UL according to the DS tablets among adults aged 19-39 years in KNHANES 2019-2020.

Table S4-4: Prevalence of total nutrient intake below EAR and above UL according to the DS tablets among adults aged 40-64 years in KNHANES 2019-2020.

Table S4-5: Prevalence of total nutrient intake below EAR and above UL according to the DS tablets among adults aged ≥65 in KNHANES 2019-2020.

Table S5-1: The NAR and MAR according to the number of DS tablets per day among men.

Table S5-2: The NAR and MAR according to the number of DS tablets per day among women.

Table S5-3: The NAR and MAR according to the number of DS tablets per day among adults aged 19-39 years.

Table S5-4: The NAR and MAR according to the number of DS tablets per day among adults aged 40-64 years.

Table s5-5: The NAR and MAR according to the number of DS tablets per day among adults aged ≥65 years.

Figure S1: Contribution of DS to total intake according to DS tablets in KNHANES 2019-2020.

Figure S2: Prevalence of total nutrient intake below EAR according to the DS tablets in KNHANES 2019-2020.

Figure S3: Prevalence of total nutrient intake above UL according to the DS tablets in KNHANES 2019-2020

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