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Original Research

# The Nutritional Benefit of UV-Exposed Mushrooms for the Dutch Population: Modeling the Addition of UV-Exposed Mushrooms to the Diet

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ABSTRACT

**Background:** Mushrooms are rich in fiber and vitamins B and vitamin D when exposed to UV light and are sometimes used as a meat substitute. A modeling study showed that adding a mushroom portion (84 g/d) to the diet of an American population caused a significant improvement in the intake of several nutrients.

**Objective:** To study the association between habitual intake of mushrooms and nutrient intake and to assess the change in micronutrient intake with the modeled addition of 60 or 84 grams of UV-exposed mushrooms to the diet of the Dutch population, with a subanalysis on subjects with a low animal: plant protein ratio.

**Methods:** A modeling study was conducted in 3121 Dutch persons aged 9-80 y, using cross-sectional data from the Dutch National Food Consumption Survey 2012-2016. Linear regression was used to explore the association between habitual intake of mushrooms and nutrients. Habitual intake and nutritional adequacy were calculated before and after the modeled addition of mushrooms.

**Results:** A small association was observed between the habitual intake of mushrooms and the intake of copper, niacin, and vitamin B2 (beta ranging from 0.002 to 0.039). The modeled addition of UV-exposed mushrooms increased the intakes of plant protein (by 5–7%), fiber (4–6%), niacin (10–20%), vitamin D (176–388%), folate (11–17%), potassium (6–10%), and copper (29–48%). Nutritional adequacy also improved significantly. For subjects with a low animal:plant protein ratio, the added mushrooms increased the intakes of niacin (11–22%), potassium (6–11%), and vitamin D (190–445%).

**Conclusions:** Consumption of mushrooms contributes to higher intakes of copper, niacin, and vitamin B2. Addition of UV-exposed mushrooms to the diet of the Dutch further improves nutrient intakes and, most notably, vitamin D, especially for people with low animal food consumption.

*Keywords*: mushrooms, UV light, Dutch, vitamin D, nutritional intake, nutritional adequacy

## Introduction

The role of mushrooms in diets has started to gain more attention in recent years due to their nutritional benefits [1]. Although mushrooms are characterized as vegetables in terms of nutrition [2], they contain more plant-based protein than most other vegetables as they belong to the category of fungi [3]. At the same time, they are low in calories due to the small amounts of digestible carbohydrates and fat, making them suitable for a wide variety of diets [3]. Mushrooms are fiber-rich, with several vitamins B, vitamin D when exposed to UV light and other micronutrients such as potassium and copper [1, 4]. UV light–exposed edible mushrooms provide an alternative source of vitamin D that does not require fortification and can also be accessible for those who follow vegan or vegetarian diets. Although much of the vitamin D in the diet is in the form of D3 and comes from animal products, mushrooms contain mostly vitamin D2 [5]. Vitamin D3 leads to a greater increase of serum 25(OH)D than vitamin D2 [5, 6], but vitamin D2

*Abbreviations:* AI, adequate intake; EAR, estimated average requirement; EFSA, European Food Safety Authority; SPADE, Statistical Program to Assess Dietary Exposure.

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and D3 have similar positive impacts on their corresponding 25(OH)D hydroxylated forms [6]. When baseline levels of 25(OH) D form are low, such as during winter, a similar efficacy of daily dosed vitamin D2 and D3 was found in a recent systematic review and meta-analysis [6].

Fulgoni & Agarwal [7] found that the modeled addition of a serving of raw mushrooms (84 g) had a significant effect on the habitual intakes of Americans, as determined by the National Health and Nutrition Examination Survey (NHANES) 2011-2016. Specifically, there was an increase in dietary fiber, several vitamins B, copper, phosphorus, potassium, selenium, and iron. When the same types of mushrooms had been exposed to UV light, containing 5 μg of vitamin D per serving, there was also a significant increase in vitamin D intake [7]. The results suggested that increased mushroom consumption would benefit the American population, as it would help them reach dietary goals through food intake rather than through supplements and without significantly increasing the total energy intake [7]. These findings may be especially relevant for people following a plant-based diet, which has been growing recently due to health and environmental concerns [8]. Plant-based diets can be challenging in some cases since they must be balanced carefully to include appropriate amounts of nutrients [9]. Mushrooms have been used extensively as a meat substitute and an alternative source of protein in their original form, remaining one of the more widespread options for those seeking to reduce animal product consumption [10, 11]. In addition to the high protein content, mushrooms contain all 9 essential amino acids [12, 13]. After in vitro digestion, amino acids per gram of protein of mushrooms meet the amino acid requirements [14]. Therefore, in case of plant-based diets, the nutritional content of mushrooms is even more important.

The findings of Fulgoni & Agarwal [7] are likely to also be relevant for the Dutch population, especially regarding vitamin D. The recommended intake of vitamin D for the general population is 15 μg according to the European Food Safety Authority (EFSA) [15], and 10 μg according to the Health Council of the Netherlands, except for people aged >71 who are recommended 15 μg [16]. However, the usual vitamin D intake of the Dutch population between the years 2012 and 2016 was far below these recommendations, with a mean of 4.9 μg per d [17]. This highlights the need to increase vitamin D intake, especially because sunlight exposure is often insufficient in most European countries during the winter and even more so in northern countries such as the Netherlands [18, 19]. The Novel Food UV-exposed increased vitamin D *Agaricus bisporus* may be a useful tool to address the issue since 100 g of raw mushrooms contain 15 μg of vitamin D [20]. This would be 12.6 μg per serving of 84 g of raw mushrooms, as opposed to 5 μg in the research by Fulgoni & Agarwal [7].

This study aimed to investigate *1*) the association between habitual mushroom consumption and the intake of several nutrients in the Dutch population, *2*) the effect of the modeled addition of UV-exposed mushrooms to the diet on nutrient intakes and nutrient adequacies in the Dutch population and persons with a low animal:plant protein ratio.

# Methods

## Intake data

Data from the Dutch National Food Consumption Survey 2012–2016 was used as a basis for the habitual intake of the Dutch population [7]. Information about nutritional intake was collected through 2 nonconsecutive 24-h dietary recalls. The nutritional components of each food were determined based on the Dutch food composition database (NEVO version 2016). For the purposes of this study, participants between 9 and 80 y of age were included, similar to the research of Fulgoni & Agarwal [7]. Therefore, the sample size was $N = 3121$, with 1043 adolescents and 2078 adults analyzed separately (Supplemental Figure 1). Additionally, a subanalysis was performed on subjects in the lowest quartile of the animal:plant protein ratio ($N = 781$) to target the persons with the closest approximation to a plant-based diet.

For the evaluation of the nutritional adequacy of the population based on adequate intake (AI) or estimated average requirement (EAR), the guidelines by EFSA were used [21]. The Health Council of the Netherlands adopted most of these recommendations [22]. In the assessment of vitamin D adequacy, sunlight exposure was not taken into account.

## Mushroom portions

Two portion sizes were used for the statistical modeling: 60 g (portion 1) and 84 g (portion 2) of raw mushrooms per d. The larger portion size is comparable to Fulgoni & Agarwal [7], while the smaller portion size was chosen to simulate the consumption of a portion of mushrooms (84 g) on 5 out of 7 d, resulting in an average of 60 g/d. The mushrooms used for modeling were *Agaricus bisporus*, known as brown or white button mushrooms, and listed as 'mushroom raw' in the NEVO database (code 19) [2]. Their nutritional profile can be found in Supplemental Table 1. *Agaricus bisporus* mushrooms were chosen as the most relevant to the Dutch population as they accounted for 96% of mushroom consumption in this dataset, with the remaining 4% comprising several other mushroom types. Specifically for the Novel Food UV-exposed *Agaricus bisporus* [20], the only difference from the NEVO data is the increased vitamin D content of 15 μg per 100 g.

## Statistical analysis

Statistical analyses were done using IBM SPSS Statistics, version 28.0.0.0. The association between mushroom consumption and nutrient intake was examined through regression in the group of mushroom consumers, defined as the subjects with any intake of mushrooms. Vitamin D was not included since it is not present in the types of mushrooms consumed. For each nutrient, model 1 was adjusted for sex, age, and energy intake, and model 2 was further adjusted for the intake of relevant food groups. First, relevant food groups were determined based on literature about the sources of each nutrient. Secondly, it was determined if the addition of each food group changed the regression model significantly ($P<0.05$ and $\geq 10\%$ change in the beta of mushroom consumption). The food group with the biggest change was added to model 1, and if there were several, the process was repeated with the new model until all food groups were either added or discarded.

To evaluate the effect of adding 2 different portion sizes of UV-exposed mushrooms to the diet through statistical modeling, the baseline habitual intakes and 95% confidence intervals (CI) of the population were determined using the Statistical Program to Assess Dietary Exposure (SPADE, version 4.1.00). All SPADE analyses were performed in R

**TABLE 1**
Associations between mushroom consumption and various nutrients in Dutch mushroom consumers (*N* = 519).

| Nutrient | Model | B (SE) | 95% CI | P value | $R^2$ | $R^2$ adj |
|---|---|---|---|---|---|---|
| Plant protein, g[1] | 1 | 0.042 (0.020) | 0.002, 0.081 | 0.038 | 0.572 | 0.569 |
| | 2 | 0.021 (0.018) | -0.014, 0.056 | 0.25 | 0.663 | 0.659 |
| Fiber, g[1] | 1 | 0.032 (0.015) | 0.003, 0.061 | 0.030 | 0.611 | 0.608 |
| | 2 | 0.0001 (0.011) | -0.022, 0.022 | 0.99 | 0.641 | 0.645 |
| Potassium, mg[2] | 1 | 4.406 (1.620) | 1.223, 7.589 | 0.007 | 0.179 | 0.174 |
| | 2 | 2.256 (1.172) | -0.046, 4.559 | 0.06 | 0.805 | 0.802 |
| Copper, mg[3] | 1 | 0.005 (0.001) | 0.003, 0.006 | <0.001 | 0.450 | 0.446 |
| | 2 | 0.004 (0.001) | 0.002, 0.005 | <0.001 | 0.500 | 0.495 |
| Vitamin B1, mg[4] | 1 | 0.0001 (0.0010) | -0.002, 0.002 | 0.89 | 0.320 | 0.315 |
| | 2 | -0.0004 (0.001) | -0.002, 0.001 | 0.68 | 0.440 | 0.432 |
| Vitamin B2, mg[5] | 1 | 0.001 (0.001) | -0.001, 0.003 | 0.46 | 0.405 | 0.401 |
| | 2 | 0.002 (0.001) | 0.0003, 0.004 | 0.016 | 0.739 | 0.735 |
| Niacin, mg[6] | 1 | 0.055 (0.018) | 0.018, 0.091 | 0.003 | 0.426 | 0.421 |
| | 2 | 0.039 (0.016) | 0.008, 0.070 | 0.013 | 0.586 | 0.582 |
| Vitamin B6, mg[7] | 1 | 0.001 (0.001) | -0.002, 0.003 | 0.55 | 0.387 | 0.383 |
| | 2 | -0.001 (0.001) | -0.004, 0.001 | 0.21 | 0.572 | 0.567 |
| Folate, µg[3] | 1 | 0.084 (0.118) | -0.456, 0.397 | 0.66 | 0.373 | 0.368 |
| | 2 | -0.334 (0.197) | -0.722, 0.053 | 0.09 | 0.446 | 0.441 |

SE, standard error, $R^2$ adj., adjusted $R^2$. Model 1 is adjusted for age, sex, and energy intake.
[1] Model 2 additionally adjusted for fruit/vegetable, and nut consumption per d.
[2] Model 2 additionally adjusted for fruit/vegetable, meat, and dairy (liquid) consumption per d.
[3] Model 2 additionally adjusted for fruit/vegetable consumption per d.
[4] Model 2 additionally adjusted for fruit/vegetable, meat, dairy (liquid), and rice/pasta/potatoes consumption per d.
[5] Model 2 additionally adjusted for meat, dairy (liquid), and dairy (solid) consumption per d.
[6] Model 2 additionally adjusted for meat consumption per d.
[7] Model 2 additionally adjusted for fruit/vegetable, and meat consumption per d.

(version 4.0.2). Energy intake, macronutrients, and fiber were analyzed with a 1-part model, which is used for nutrients that are consumed daily through food products by almost everyone [23]. Fiber could also be taken in the form of supplements; however, there was not enough information in the data about their intake frequency, and only 17 participants (0.5%) had an intake of fiber from supplements. Therefore, the use of fiber supplements was not taken into account for the habitual intake. The micronutrients were analyzed with a 3-part model, which is used when there are intakes both from food sources and dietary supplements [23]. In all analyses, bootstrapping was used to determine CI. Subsequently, 60 g and 84 g raw, UV-exposed *Agaricus bisporus* mushrooms were added to the daily intake data, and the habitual intakes with CI were calculated anew in the same way.

For the subanalysis based on animal:plant protein ratio, the ratio of animal:plant protein was calculated and divided into quartiles. Next, mean nutrient intakes were calculated for each quartile and differences between the quartiles were determined with t-tests. For the nutrient intakes that were significantly lower in subjects in the lowest quartile of the animal:plant protein ratio, the same process as described above was used to calculate the habitual intakes in that group, before and after the addition of UV-exposed mushrooms.

The evaluation of nutritional adequacy was also done directly through SPADE. For nutrients with an EAR, the percentage of the population below the given, age-dependent cut-off values were calculated. When an EAR was not available, AI values were used. Significant differences were determined based on nonoverlapping CI, both for habitual intakes and nutritional adequacy percentages.

## Results

### Study population

The sample population consisted of 1043 adolescents aged 9 to 18 y and 2078 adults aged 19 to 80 y. The distribution of males and females was the same between adolescents compared with adults and between mushroom consumers compared with nonconsumers. Out of the total sample, 519 subjects (135 adolescents and 384 adults) consumed any amount of mushrooms on at least one recorded day. The consumed quantities per d ranged from 0.22 to 114 g with a mean of 12 g in adolescents, and from 0.30 to 115 g with a mean of 17 g in adults.

### Association between mushroom consumption and nutrient intake

In mushroom consumers, daily mushrooms consumption was significantly associated with several nutrients. Specifically, every 100 g of mushroom consumption is associated with an increase of 3.2 g of fiber, 441 mg of potassium, 0.5 mg of copper, 5.5 mg of niacin, and 4.2 g of plant protein (Table 1, model 1). However, most of these associations disappeared after further correcting for relevant food groups for each nutrient (Table 1, model 2). The ones that were still significant were the associations between mushroom consumption and copper (0.4 mg per 100 g of mushrooms), vitamin B2 (1.4 µg per 100 g of mushrooms), and niacin (3.9 mg per 100 g of mushrooms).

### Habitual intake changes

The modeled addition of 2 different portions of UV-exposed mushrooms to the diet changed the intake of several nutrients

**TABLE 2**
Habitual intake of Dutch adolescents (ages 9–18, $N = 1043$) and percentage of the population below the EAR or above the AI in the original data, and after addition of raw, UV-exposed mushrooms

| $N = 1043$ | No mushroom addition | | Mushroom portion 1 (60 g) | | Mushroom portion 2 (84 g) | |
|---|---|---|---|---|---|---|
| Nutrient | Mean (95% CI) | Adequacy | Mean (95% CI) | Adequacy | Mean (95% CI) | Adequacy |
| | | % < EAR (95% CI) | | % < EAR (95% CI) | | % < EAR (95% CI) |
| Energy, kcal | 2140 (2104, 2165) | - | 2150 (2115, 2176) | - | 2155 (2120, 2180) | - |
| Carbohydrates, g | 267 (262, 271) | - | 267 (262, 271) | - | 267 (262, 271) | - |
| Fats, g | 81.6 (80.2, 83.0) | - | 81.9 (80.5, 83.3) | - | 82.0 (80.6, 83.4) | - |
| Protein, g | 70.4 (69.1, 71.4) | - | 71.8 (70.5, 72.8) | - | 72.3 (71.0, 73.4) | - |
| Plant protein, g | 29.0 (28.4, 29.5) | - | 30.3 (29.7, 30.9)* | - | 30.9 (30.2, 31.5)* | - |
| Vitamin B1, mg[1] | 1.39 (1.13, 1.71) | 0.6 (0.1, 1.4) | 1.43 (1.17, 1.76) | 0.2 (0.0, 0.6) | 1.45 (1.19, 1.77) | 0.2 (0.0, 0.4) |
| Vitamin B2, mg | 1.81 (1.50, 1.99) | 36 (34, 39) | 1.96 (1.68, 2.17) | 23 (20, 25)* | 1.99 (1.71, 2.26) | 18 (16, 20)*¥ |
| Niacin, mg[1] | 17.2 (16.8, 17.9) | 8.1 (5.9, 10.2) | 19.6 (19.2, 20.3)* | 1.2 (0.6, 1.7)* | 20.6 (20.2, 21.3)* | 0.5 (0.2, 0.7)* |
| Vitamin B6, mg | 1.70 (1.66, 1.89) | 22 (18, 24) | 1.77 (1.73, 1.96) | 16 (13, 18) | 1.81 (1.76, 1.99) | 14 (11, 16) |
| Folate, µg | 236 (231, 248) | 52 (49, 54) | 262 (257, 274)* | 37 (34, 39)* | 277 (267, 286)* | 30 (27, 33)*¥ |
| | | **% > AI (95% CI)** | | **% > AI (95% CI)** | | **% > AI (95% CI)** |
| Fiber, g | 18.0 (17.5, 18.3) | 39 (36, 41) | 18.9 (18.4, 19.2)* | 45 (43, 48)* | 19.2 (18.8, 19.6)* | 48 (45, 50)* |
| Potassium, mg | 2588 (2550, 2631) | 9 (8, 11) | 2779 (2742, 2822)* | 14 (12, 16)* | 2856 (2818, 2899)* | 17 (15, 18)* |
| Copper, mg | 1.24 (1.21, 1.27) | 46 (44, 49) | 1.67 (1.64, 1.70)* | 94 (93, 96)* | 1.84 (1.81, 1.87)*¥ | 99 (99, 99)*¥ |
| Vitamin D, µg | 3.2 (3.1, 3.3) | 0.4 (0.3, 0.9) | 12.2 (12.0, 12.4)* | 7 (6, 9)* | 15.8 (15.6, 16.0)*¥ | 63 (58, 65)*¥ |

AI, adequate intake, CI, confidence interval, EAR, estimated average requirement. * Significant difference from intake without mushroom addition and ¥ significant difference of portion 2 to portion 1, based on nonoverlapping CI.
[1] For vitamin B1 and niacin, the percentage below the EAR is calculated using values of mg/MJ/d according to EFSA guidelines.

significantly. For adolescents (Table 2), the addition of portion 1 and portion 2 increased the intake of plant protein (by 5% and 7%, respectively), fiber (5% and 7%), potassium (7% and 10%), copper (35% and 48%), niacin (14% and 20%), folate (11% and 17%), and vitamin D (277% and 388%). In all these cases, the nutritional adequacy of the population also improved significantly, with the percentage below the EAR decreasing for niacin from 8% to 1% with portion 1 and portion 2, and for folate, it decreased from 52% to 37% with portion 1 and to 30% with portion 2. For the nutrients with an AI, the percentage above that threshold increased, for fiber from 39% to 45% and 48%, for potassium from 9% to 14% and 17%, for copper from 46% to 94% and 99%, and for vitamin D from 0.4% to 7% and 63% with portion 1 and portion 2, respectively. In addition, whereas the mean of vitamin B2 did not increase significantly, the percentage below the EAR did have a significant decrease from 36% to 23% with portion 1 and to 18% with portion 2.

For adults (Table 3), nutrient intakes that increased significantly with both portions (portion 1 and portion 2, respectively) were plant protein (5% and 6%), fiber (4 and 6%), potassium (6% and 8%), copper (29% and 40%), niacin (10% and 14%), and vitamin D (176% and 247%), with corresponding increases

**TABLE 3**
Habitual intake of Dutch adults (ages 19–80, $N = 2078$) and percentage of the population below the EAR or above the AI in the original data, and after addition of raw, UV-exposed mushrooms

| $N = 2078$ | No mushroom addition | | Mushroom portion 1 (60 g) | | Mushroom portion 2 (84 g) | |
|---|---|---|---|---|---|---|
| Nutrient | Mean (95% CI) | Adequacy | Mean (95% CI) | Adequacy | Mean (95% CI) | Adequacy |
| | | % < EAR (95% CI) | | % < EAR (95% CI) | | % < EAR (95% CI) |
| Energy, kcal | 2158 (2135, 2183) | - | 2169 (2146, 2193) | - | 2174 (2150, 2198) | - |
| Carbohydrates, g | 232 (229, 235) | - | 232 (229, 235) | - | 232 (229, 235) | - |
| Fats, g | 86.2 (85.0, 87.5) | - | 86.5 (85.3, 87.8) | - | 86.6 (85.4, 87.9) | - |
| Protein, g | 82.1 (81.2, 83.1) | - | 83.5 (82.6, 84.5) | - | 84.0 (83.1, 85.1) | - |
| Plant protein, g | 31.3 (30.9, 31.8) | - | 32.7 (32.3, 33.2)* | - | 33.3 (32.8, 33.7)* | - |
| Vitamin B1, mg[1] | 2.53 (2.11, 2.86) | 0.1 (0.0, 0.3) | 2.57 (2.15, 2.90) | 0.0 (0.0, 0.1) | 2.58 (2.17, 2.92) | 0.0 (0.0, 0.1) |
| Vitamin B2, mg | 2.92 (2.56, 3.20) | 30 (29, 32) | 3.10 (2.74, 3.38) | 18 (17, 20)* | 3.16 (2.77, 3.49) | 14 (13, 15)*¥ |
| Niacin, mg[1] | 23.6 (23.1, 24.3) | 1.0 (0.5, 1.5) | 25.9 (25.4, 26.7)* | 0.1 (0.0, 0.2)* | 26.8 (26.4, 27.6)* | 0.0 (0.0, 0.1)* |
| Vitamin B6, mg | 2.77 (2.51, 3.03) | 22 (20, 25) | 2.84 (2.58, 3.10) | 17 (15, 19) | 2.87 (2.61, 3.13) | 15 (13, 17) |
| Folate, µg | 363 (346, 383) | 37 (35, 40) | 390 (372, 409) | 25 (23, 27)* | 400 (382, 418) | 21 (19, 22)*¥ |
| | | **% > AI (95% CI)** | | **% > AI (95% CI)** | | **% > AI (95% CI)** |
| Fiber, g | 20.7 (20.4, 21.0) | 20 (18, 22) | 21.6 (21.3, 21.9)* | 24 (22, 26)* | 22.0 (21.7, 22.3)* | 26 (24, 28)* |
| Potassium, mg | 3297 (3263, 3336) | 37 (35, 39) | 3489 (3456, 3528)* | 47 (45, 49)* | 3566 (3532, 3605)*¥ | 51 (49, 53)*¥ |
| Copper, mg | 1.49 (1.46, 1.51) | 44 (41, 46) | 1.92 (1.89, 1.94)* | 88 (86, 89)* | 2.09 (2.06, 2.11)*¥ | 96 (95, 97)*¥ |
| Vitamin D, µg | 5.1 (4.9, 5.4) | 4 (4, 5) | 14.0 (13.8, 14.4)* | 20 (18, 22)* | 17.6 (17.4, 18.0)*¥ | 82 (80, 85)*¥ |

CI, confidence interval; AI, adequate intake; EAR, estimated average requirement; *Significant difference from intake without mushroom addition, and ¥ significant difference from portion 2 to portion 1, based on nonoverlapping confidence intervals.
[1] For vitamin B1 and niacin, the percentage below the EAR is calculated using values of mg/MJ/d according to the EFSA guidelines.

in population adequacy. Specifically, the percentage below the EAR decreased for niacin from 1% to 0% with both portions, and the percentage above the AI increased for fiber from 20% to 24% and 26%, for potassium from 37% to 47% and 51%, for copper from 44% to 88% and 96%, and for vitamin D from 4% to 20% and 82% with portion 1 and portion 2, respectively. Without a change in the intake mean, the percentage below the EAR also significantly decreased for vitamin B2 (30% to 18% and 14%) and folate (37% to 25% and 21%) with portion 1 and portion 2, respectively.

## Low animal:plant protein ratio

The lowest quartile of the animal:plant protein ratio (value range 0:100 - 48:52) consisted of 336 adolescents and 445 adults with an equal proportion of males and females. The average intake of fiber, copper, and folate tended to decrease as the animal:plant protein ratio increased, whereas the mean intake of potassium, niacin, and vitamins B1, B2, B6, and D increased (Supplemental Table 2).

The micronutrients that were significantly lower in quartile 1 were examined further within that population ($N = 781$). The habitual intake before and after modeled mushroom additions is displayed in Table 4, separately for adolescents and adults. In adolescents, there were significant increases in the habitual intake of niacin (by 15% with portion 1 and by 22% with portion 2), potassium (by 8% and 11%), and vitamin D (by 318% and 445%). The percentage below the EAR decreased significantly for niacin from 22% to 4% and 2%, but also for vitamin B2 from 54% to 38% and 31% despite no change in habitual intake. For the other nutrients, the percentage above the AI increased significantly, for potassium from 6% to 10% and 11%, and for vitamin D from 1% to 5% and 50%. The same nutrients showed significant changes in adults. The habitual intake of niacin increased by 11% with portion 1 and 15% with portion 2, potassium increased by 6% and 9%, and vitamin D by 190% and 266%, respectively. Regarding nutritional adequacy, the percentage below the EAR decreased for vitamin B2 from 45% to 31% and 26%, and for niacin from 5% to 1% and 0.3%. The percentage above the AI increased significantly for potassium from 32% to 40% and 44%, and for vitamin D from 4% to 18% and 71%.

# Discussion

In mushroom consumers, mushroom consumption was significantly associated with the intakes of copper, niacin, and vitamin B2. The modeled addition of UV-exposed mushrooms to the Dutch diet significantly increased the intake of plant protein, fiber, niacin, vitamin D, folate, potassium, and copper. This benefit was also evident in the nutritional adequacy of the population for these nutrients, as well as for vitamin B2. For people with a low animal:plant protein ratio, i.e., a diet in which more protein comes from plant-based foods than animal sources, the addition of mushrooms resulted in increased intakes and nutritional adequacy of niacin, vitamin D and potassium, as well as an increase in the nutritional adequacy of vitamin B2.

An association was observed between mushroom consumption and copper, vitamin B2 and niacin after adjusting for relevant food groups, although most regression coefficients were small (ranging from 0.002 to 0.039). It is possible that some

**Table 4**
Habitual intake of adolescents and adults in the lowest quartile of animal:plant protein ratio and percentage of the population below the EAR or above the AI in the original data and after the addition of raw, UV-exposed mushrooms.

| Adolescents ($N = 336$) | No mushroom addition | | Mushroom portion 1 (60 g) | | Mushroom portion 2 (84 g) | |
|---|---|---|---|---|---|---|
| Nutrient | Mean (95% CI) | Adequacy % < EAR (95% CI) | Mean (95% CI) | Adequacy % < EAR (95% CI) | Mean (95% CI) | Adequacy % < EAR (95% CI) |
| Vitamin B1, mg[1] | 1.45 (0.92, 1.98) | 5 (2, 8) | 1.49 (0.96, 2.02) | 2 (0, 4) | 1.50 (0.98, 2.04) | 1 (0, 3) |
| Vitamin B2, mg | 1.78 (1.12, 2.28) | 54 (50, 60) | 1.96 (1.30, 2.46) | 38 (34, 43)* | 2.03 (1.37, 2.53) | 31 (28, 36)* |
| Niacin, mg[1] | 15.1 (14.0, 15.9) | 22 (17, 27) | 17.4 (16.4, 18.2)* | 4 (2, 7)* | 18.4 (17.3, 19.2)* | 2 (1, 3)* |
| Vitamin B6, mg | 1.75 (1.37, 1.90) | 40 (34, 45) | 1.83 (1.46, 1.98) | 33 (27, 37) | 1.85 (1.47, 2.00) | 30 (24, 34) |
| | | **% > AI (95% CI)** | | **% > AI (95% CI)** | | **% > AI (95% CI)** |
| Potassium, mg | 2379 (2314, 2463) | 6 (5, 8) | 2570 (2505, 2654)* | 10 (7, 12)* | 2646 (2582, 2731)* | 11 (9, 14)* |
| Vitamin D, μg | 2.8 (2.5, 3.1) | 0.5 (0.0, 1.2) | 11.8 (11.5, 12.1)* | 5 (3, 8)* | 15.3 (15.1, 15.7)*¥ | 50 (45, 55)*¥ |
| **Adults ($N = 445$)** | **No mushroom addition** | | **Mushroom portion 1 (60 g)** | | **Mushroom portion 2 (84 g)** | |
| Nutrient | Mean (95% CI) | Adequacy % < EAR (95% CI) | Mean (95% CI) | Adequacy % < EAR (95% CI) | Mean (95% CI) | Adequacy % < EAR (95% CI) |
| Vitamin B1, mg[1] | 2.92 (2.17, 3.93) | 1.1 (0.0, 2.5) | 2.96 (2.21, 3.97) | 0.7 (0.0, 1.3) | 2.98 (2.23, 3.98) | 0.5 (0.0, 1.0) |
| Vitamin B2, mg | 3.08 (2.39, 3.97) | 45 (41, 48) | 3.26 (2.57, 4.15) | 31 (28, 35)* | 3.33 (2.64, 4.22) | 26 (22, 29)* |
| Niacin, mg[1] | 21.9 (20.7, 22.9) | 5 (3, 8) | 24.2 (23.0, 25.2)* | 0.7 (0.1, 1.4)* | 25.1 (23.9, 26.2)* | 0.3 (0.0, 0.7)* |
| Vitamin B6, mg | 2.82 (2.47, 3.37) | 33 (29, 38) | 2.90 (2.53, 3.43) | 27 (23, 33) | 2.92 (2.57, 3.47) | 25 (21, 30) |
| | | **% > AI (95% CI)** | | **% > AI (95% CI)** | | **% > AI (95% CI)** |
| Potassium, mg | 3176 (3105, 3237) | 32 (29, 35) | 3369 (3297, 3429)* | 40 (37, 43)* | 3445 (3374, 3506)* | 44 (41, 47)* |
| Vitamin D, μg | 4.8 (4.2, 5.2) | 4 (2, 5) | 13.8 (13.2, 14.2)* | 18 (15, 21)* | 17.4 (16.8, 17.8)*¥ | 71 (67, 75)*¥ |

AI = adequate intake, CI = confidence interval, EAR = estimated average requirement. * = Significant difference from intake without mushroom addition and ¥ = significant difference of portion 2 to portion 1, based on nonoverlapping CIs.

[1] For vitamin B1 and niacin, the percentage below the EAR is calculated using values of mg/MJ/d according to EFSA guidelines.

associations are significant due to the large sample, but not very strong since the mushroom quantities consumed were quite small, on average 12 g/d for adolescents and 17 g/d for adults. However, these results align with a study by O'Neil et al. (24) using NHANES 2001–2010 data, which showed that mushroom consumption is associated with a higher intake of several nutrients, including vitamins B1 and B2, niacin, folate, copper, and potassium [24]. This indicates that the associations found in the present study are accurate. As a point of difference, O'Neil et al. [24], as well as other studies reporting associations between mushroom consumption and intake of fiber [25], potassium [26], and folate [27], did not correct for other food groups. This could explain the fewer significant associations found in the current study.

As expected, the modeled addition of UV-exposed mushrooms to the diet caused no significant change in the energy, carbohydrate, fat, and total protein intake of the population because mushrooms are not calorie-dense and have a high water content [1]. To the contrary, there were significant increases with the addition of each portion of UV-exposed mushrooms to the intake of plant protein, niacin, vitamin D, fiber, potassium, and copper in both age groups, as well as folate in adolescents only. This is mostly in line with the results of Fulgoni & Agarwal [7], although they reported that folate intake only increased in adults. Fulgoni & Agarwal [7] also observed differences in vitamins B1, B2, and B6, which were not significant in the current analysis. This could be due to the nutritional profiles of the mushrooms used for dietary modeling, which were different between the 2 studies. Fulgoni & Agarwal [7] used 2 mushroom compounds, one including 3 different types of commonly consumed mushrooms (white, crimini, and portabella at a 1:1:1 ratio) and one other only oyster mushrooms. Both compounds had different nutritional profiles to *Agaricus bisporus* mushrooms, including higher amounts of vitamins B1 and B2 per portion. Additionally, the sample size from NHANES (4810 adolescents of ages 9–18 and 14,990 adults of ages $\geq$19) was much larger than that of the Dutch National Food Consumption Survey (1043 adolescents and 2078 adults), leading to more significant results.

The increased intake of the various nutrients led to several improvements to the nutritional adequacy of the population with the modeled addition of either 60 g or 84 g of UV-exposed mushrooms per day. Specifically, the percentage below the EAR decreased significantly for vitamin B2, niacin, and folate, whereas the percentage above the AI increased for fiber, potassium, copper, and vitamin D for all ages. These results partly align with the results of Fulgoni & Agarwal [7], although they did not observe significant changes in adequacy of niacin, folate, and fiber in adolescents. In adults, they found additional significant differences in vitamins B1 and B6 but not in fiber and vitamin D. These discrepancies could be explained by the fact that recommendations for nutrient intakes are often higher for Americans than Europeans, making the results on population adequacy more difficult to compare.

Vitamin D showed the largest difference in intake with the modeled addition of UV-exposed mushrooms to the diet. With the 84 g added portion of mushrooms, the habitual intake quintupled for adolescents and tripled for adults. The percentage that met the AI had an even larger change, increasing 16 times with the 60 g portion and over 150 times with the 84 g portion for adolescents. For adults, the percentage that met the AI increased almost 5 times with the 60 g portion and almost 20 times with the 84 g portion. This is a more significant increase than what was presented by Fulgoni & Agarwal [7], who reported an increase of 10 times for adolescents and about 7 times for adults. This can be explained by the higher concentration of vitamin D in UV-exposed mushrooms used in the modeling of the current study (12.6 μg compared with 5 μg per portion of 84 g). Both studies demonstrate the potential use of UV-exposed mushrooms to increase vitamin D intake in a similar way to food fortification, which is considered the most effective strategy for combating vitamin D deficiency on a large scale [28].

Regarding the amount of UV-exposed mushrooms, the 84 g portion showed a significant additional benefit compared with the 60 g portion in the modeled habitual intake and population adequacy of copper and vitamin D for all ages, as well as potassium for adults. The population adequacy of vitamin B2 and folate was also improved significantly with the 84 g portion compared with the 60 g portion, without a significant difference in means. Whereas the 60 g portion was sufficient to show a significant benefit for most nutrients, in the case of vitamin D, the nutritional adequacy of the population was still only 7% for adolescents and 47% for adults. The 84 g portion further increased the values to 63% and 82%, respectively, meaning more than half of the population of all ages met the AI. Therefore, when the goal is to reach the AI for vitamin D using UV-exposed mushrooms, the larger portion of 84 g may be favorable. However, note that such an addition may not be feasible for everyone in practice but may be used by specific groups.

People with a low animal:plant protein ratio (range 0:100 – 48:52) had lower intakes of vitamins B1, B2, B6, D, niacin, and potassium but higher intakes of fiber, folate, and copper compared with those with higher ratios. The nutritional adequacy of this group was also lower compared with the general population for all nutrients. For instance, for niacin, the percentages below the EAR were 3 times higher than the general population for adolescents and 5 times higher for adults. The modeled addition of UV-exposed mushrooms increased not only the habitual intakes of niacin, vitamin D, and potassium but also the nutritional adequacy of these nutrients and of vitamin B2 as well. Most notably, with portion 2, the nutritional adequacy percentages in adolescents increased by 20% for niacin, by 23% for vitamin B2, and by 49% for vitamin D. In adults, the most significant increases in adequacy percentages with portion 2 were vitamin B2 by 19%, potassium by 12%, and vitamin D by 67%. Considering that mushrooms are a good source of plant protein and can be used as partial meat replacement, they could be especially useful to this population group to increase the intake of some nutrients often found in animal products.

The strengths of this study include the use of a large dataset provided by a reputable source, the Dutch National Institute for Public Health and the Environment. This resulted in a representative sample of the Dutch population. Furthermore, the design of this study is based on previously conducted studies using statistical modeling to see the effect of diet modifications on nutrient intakes [7, 29–31]. To the contrary, a limitation is that recently, after the current analyses were performed, data from the Dutch National Food Consumption Survey 2019–2021 were presented [32]. Therefore, these results do not reflect the latest intake data, which indicated that the Dutch population consumes more vegetables and less meat compared with 2012–2016. This could lead to different results, such as a higher mean mushroom consumption. Additionally, nutrient intake and adequacy could be higher for some nutrients due to a higher vegetable intake and lower for others due to lower meat intake. Another limitation is that there were no separate analyses by sex because of group size consideration, despite a significant difference in intakes between males and females. Additionally, it was not possible to analyze certain important micronutrients found in mushrooms, such as vitamin B5 and ergothioneine, because the Dutch National Food Consumption Survey does not offer such information. Another limitation is that the effect of sunlight exposure on vitamin D adequacy was not taken into account. According to the Health Council of the Netherlands [16], the Dutch population gets, on average, 7 μg of vitamin D per day with sufficient sun exposure, but values can be higher in the summer and lower in the winter. Since sun exposure is often insufficient (18), its contribution was not considered, but that might not be accurate for the whole population. Finally, it is important to note that the results reported are based on statistical modeling using raw mushrooms, which could be quite different if mushrooms are cooked before consumption. To the contrary, the cross-sectional association showed that increasing prepared mushrooms increases the intake of copper, vitamin B2, and niacin, indicating the intake of these nutrients actually increases even after preparation. Still, many nutrients, such as vitamins, are partially lost during the cooking process due to being water-soluble or heat-sensitive [33, 34]. The vitamin D and flavonoid content of mushrooms, for instance, was shown to be lower after cooking and heavily dependent on time and method (retention range for flavonoids: 21–71% and for vitamin D: 62–88%) [35, 36]. Therefore, larger portions of cooked mushrooms might be necessary to achieve similar benefits on nutrient intake. Further research is needed to formulate more realistic recommendations, possibly using modeling with boiled, grilled, or baked mushrooms instead.

## Conclusion

In conclusion, this study showed an association between mushroom intake and intake of copper, vitamin B2, and niacin. The modeled addition of UV-exposed mushrooms to the habitual diet of the Dutch population led to significant benefits in the intake and nutritional adequacy of most examined nutrients, especially vitamin D. The addition of 60 g of UV-exposed mushrooms per day was sufficient to observe significant improvements in all nutrients for all ages, but especially the nutritional adequacy for vitamin D increased exponentially with the 84 g portion. Finally, for the part of the population with a low animal:plant protein ratio, the addition of UV-exposed mushrooms could bring the intakes of vitamin B2, vitamin D, niacin, and potassium closer to the recommended values. As diets low in animal products become more widespread, these findings could become even more relevant to a large segment of the population.

## Author contributions

Authors responsibilities were as follows—LB, EvdH, and IG designed research. The database was kindly provided by the National Institute for Public Health and the Environment. LB conducted research, performed statistical analysis, and wrote the paper. IG and LdG had primary responsibility for final content. All authors have read and approved the final manuscript.

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## Data availability

Data described in the manuscript, code book, and analytic code will be made available upon request.

## Conflict of interest

EvdH is employed by Scelta Mushrooms B.V. for 2 d/w that sells mushroom products, not including fresh mushrooms, to other companies. LB, LdG, and IG declare no conflicts of interest.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cdnut.2023.102039.

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